ATTACHMENT 41

Browns Ferry Replacement Steam Dryer
Stress Analysis
(Non-Proprietary)

GE Hitachi Nuclear Energy

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Engineering Report

Browns Ferry Replacement Steam Dryer Stress Analysis

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REVISION HISTORY

Revision	Date	Changes
0	August 2015	Initial issue.

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ACRONYMS AND ABBREVIATIONS

Term	Description
1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
$\mu\varepsilon$	Micro Strain (10^{-6} length/length)
ASR	Alternating Stress Ratio
APDL	ANSYS Parametric Design Language
ASME	American Society of Mechanical Engineers
AVS	Acoustic Vibration Suppressor
B&U	Bias and Uncertainty
Browns Ferry	Browns Ferry Nuclear Plant
BFN	Browns Ferry Nuclear Plant
BWR	Boiling Water Reactor
CLTP	Current Licensed Thermal Power
CP	Current Power
DAS	Data Acquisition System
DoE	Design of Experiments
DoF	Degree of Freedom
EPU	Extended Power Uprate
FSRF	Fatigue Strength Reduction Factor
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Model
FIV	Flow-Induced Vibration
FFT	Fast Fourier Transform
FRF	Frequency Response Function
FF	Full Frequency, or Full Frequency Spectrum
GEH	GE Hitachi Nuclear Energy
HCF	High Cycle Fatigue

Term	Description
[[	]]
HPCI	High Presure Coolant Injection
Hz	Hertz
[[	]]
MASR	Minimum Alternating Stress Ratio
Mlbs/hr	Millions pounds per hour
MPC	Multi Point Constraint
MSIV	Main Steam Isolation Valve
MSL	Main Steam Line
MSLB	Main Steam Line Break Outside Containment
MW_{th}	Megawatt Thermal
NP	Next Power Level
NRC	Nuclear Regulatory Commission
OBE	Operating Basis Earthquake
OE	Operating Experience
OLTP	Original Licensed Thermal Power
Pa	Pascal
PATP	Power Ascension Test Plan
PBLE	Plant Based Load Evaluation
PBLE01	PBLE Input [[ ]]
PBLE02	PBLE Input [[ ]]
PSD	Power Spectral Density
psi	Pounds per square inch
psia	Pounds per square inch absolute
psid	Pounds per square inch differential
PT	Penetrant Test
PTF	Plate Thickness Factor
RCIC	Reactor Core Isolation Cooling
RFO	Refueling Outage
RMS	Root-Mean-Squared

Term	Description
RPV	Reactor Pressure Vessel
RSD	Replacement Steam Dryer
SDAR	Steam Dryer Analysis Report
SCF	Stress Concentration Factor
SF	Singularity Factor
SG	Strain Gauge
SRV	Safety Relief Valve
SSE	Safe Shutdown Earthquake
TC	Test Condition
TSV	Turbine Stop Valve
TVA	Tennessee Valley Authority
VFD	Variable Frequency Drive
VPF	Vane Passing Frequency
ZPA	Zero Period Acceleration

1.0 EXECUTIVE SUMMARY

This report documents the stress analyses for the replacement steam dryer (RSDs) for each of the three Browns Ferry Nuclear Plant (BFN) units. The focus of these analyses is to demonstrate that the RSD will maintain structural integrity during normal plant operation and under transient and accident conditions. Fatigue analyses were performed for flow-induced vibration (FIV) and hydrodynamic loads during normal operation at extended power uprate (EPU) power levels. Primary stress evaluations were performed for normal, upset, emergency and faulted loading conditions at EPU power levels. [[

]].

The BFN RSD design incorporates the replacement steam dryer design features that were developed to accommodate the high FIV acoustic loads that led to the failure of the original BWR/3 dryers at EPU operating conditions. The prototype for the BFN RSDs is the curved hood RSD installed in a BWR/4 plant with operating conditions that are similar to those for BFN. A later version of the prototype dryer was installed in a BWR/6. The prototype RSD dryer design has operated successfully in both of these plants. As part of the BFN RSD design, additional iterative design analyses were performed to redistribute the loads throughout the structure and reduce the peak dryer stresses. Successful operation of the prototype RSD design at full EPU power levels in the previous plants, along with the additional design refinement, provide assurance that the BFN RSDs will maintain structural integrity during normal operation.

For the fatigue analyses, the GE Hitachi Nuclear Energy (GEH) Plant Based Load Evaluation (PBLE) methodology was [[

]]. To account for uncertainties in the steam dryer structural frequency response between the idealized FEM and the as-built dryer, [[

]] The stresses from these analyses form the basis of the fatigue assessment.

The overall uncertainties associated with the load definition and structural response methodology [[

]] Additional adjustment factors were developed to address load effects that may not be accounted for in the [[ ]] acoustic pressure measurements (e.g., loading generated by the recirculation pump vane passing pulsations). [[ ]] data taken during the power ascension were used to develop [[ ]] EPU scaling factors to project the FEM stress results to EPU conditions.

The [[ ]] B&U values and the other adjustment factors were applied to the stress results of the FEM analyses, and then projected to the EPU power level conditions to determine the peak dryer stresses at EPU. When compared to the fatigue acceptance criteria, the stress margins for all dryer components exceed the Nuclear Regulatory Commission (NRC) recommended minimum alternating stress ratio (MASR) greater than 2.0. The results of these fatigue evaluations confirm that each BFN RSD is structurally adequate to accommodate the expected FIV loads at EPU conditions.

Primary stress analyses were performed for the design load combinations for normal, upset, emergency and faulted conditions. The methodologies used for the primary stress analyses are the same as those used for the original steam dryer design analyses. The results of these analyses demonstrate that at EPU conditions, the steam dryer will maintain structural integrity during normal operation as well as for transient and accident conditions.

A Power Ascension Test Plan (PATP) for the initial cycle of EPU operation at all three BFN units is presented. The BFN RSD design is [[ ]] however, the RSD for the [[ ]] The plan includes [[ ]] The test program describes the [[ ]] locations and methodology for developing fatigue stress acceptance limit criteria used to assure that the dryer stresses remain acceptable during the power ascension. Upon reaching full EPU power, fatigue stress evaluations will be performed based on plant measurements at EPU to confirm that the RSD stresses are acceptable for long-term operation of the RSD dryers.

The structural analyses and power ascension monitoring program assure that the BFN RSDs will maintain structural integrity during normal operation and under transient and accident conditions for the design life of each RSD.

2.0 BROWNS FERRY REPLACEMENT STEAM DRYER ANALYSIS OVERVIEW

2.1 Analysis Process Overview

The BFN RSD design is based on the BWR/4 prototype RSD design that has been used in two BWR/4 units and one BWR/6 unit operating at EPU conditions. The prototype design has been improved to incorporate lessons learned from the BWR/4 RSD Operating Experience (OE), design refinements incorporated during the BWR/6 RSD project, and further refinements from BFN RSD stress studies to ensure that the BFN RSD would meet the NRC recommended 2.0 MASR margin to the fatigue acceptance criterion (Reference 1).

The BFN units are very similar to the BWR/4 prototype plant, in particular with respect to the plant geometry and operating conditions that determine the acoustic pressure loading acting on the steam dryer. These plants are the GEH BWR/4 design with 251-inch diameter reactor pressure vessels (RPVs) and operate at virtually the same power level and steam flow velocity conditions (see data provided in Table 4.1-23). The BFN units and the BWR/4 prototype plant have stagnant branch lines (dead-legs) on the MSLs. The FIV loading on the BFN RSDs is [[ ]] as the loads measured on the BWR/4 prototype.

The three BFN units are virtually identical, with only minor geometrical differences that may slightly impact the characteristics of the acoustic resonances that are expected to develop in the standpipes for the SRVs. The main difference between the original steam dryers for the three units is the hold-down rod location. [[ ]] This is further discussed in Section 3.2.1, Functional Modifications. [[ ]]

Figure 2.1-1 provides a high level overview of the analysis process. The steam dryer acoustic pressure loads for the BFN FIV analysis were developed from BFN [[ ]] using the PBLE02 methodology (Appendix C of this report). [[ ]] Based on an evaluation of the SRV standpipe geometry, MSL flow velocities, and the [[ ]] acoustic pressure measurements from the three units, [[ ]] Because there are no BFN MSL measurements at EPU flow conditions, [[ ]] The resonance frequencies were determined from [[

]] which is the most appropriate SRV acoustic resonance load to use in synthesizing the BFN SRV resonance loads. In the fatigue stress evaluation of the BFN RSD, the stresses for steam dryer components were first calculated by FEA at BFN CLTP conditions, and then extrapolated to full EPU conditions based on BFN specific scaling factors developed from trending of the power ascension data.

The steam dryer component stresses accounted for stress intensification due to welds and [[ ]] These stresses were adjusted with a set of bias and uncertainty (B&U) terms, including [[ ]] B&U from the BWR/4 prototype RSD benchmarking predictions compared to on-dryer strain measurements; the bias factor for [[ ]] The adjusted stress results at EPU condition meets the NRC-recommended MASR criteria of 2.0 to the American Society of Mechanical Engineers (ASME) Code endurance limit of 13,600 pounds per square inch (psi).

Primary stress analyses for specified load combinations compared to ASME stress limits demonstrated that the RSD will maintain structural integrity (i.e., no generation of loose parts) during normal operation as well as for transient and accident conditions.

For the [[ ]] steam dryer, [[ ]] will be instrumented. Power ascension limit curves were developed for the [[ ]] Measurements will be taken during power ascension and the steam dryer stresses will be projected to the current power level, the next power level, and to full EPU condition in order to assure that the stresses will not exceed the fatigue limit during power ascension and will remain below the fatigue acceptance criterion at full EPU. Once [[ ]] reaches the full EPU power level, a confirmatory stress analysis will be performed to demonstrate that the fatigue stresses are acceptable for long term steam dryer operation.

For the [[ ]] Once at full EPU power, confirmatory evaluations will be performed for each [[ ]] to demonstrate that the fatigue stresses are acceptable for long term steam dryer operation.

[[ ]]

Figure 2.1-1: Steam Dryer Analysis Methodology Overview

3.0 BROWNS FERRY REPLACEMENT STEAM DRYER DESIGN

3.1 BWR/4 Replacement Steam Dryer Design

In accordance with NRC Regulatory Guide 1.20 (Reference 2), the BFN RSD for the lead unit is classified as [[ ]] The BFN RSD is based on a field tested design of a curved hood six-bank RSD used in a BWR/4 reactor that has completed its comprehensive vibration assessment program at EPU conditions. This BWR/4 RSD serves as the "valid prototype" for the BFN RSD.

In order to maintain the structural integrity at the EPU loading conditions, the BWR/4 RSD design uses [[ ]]. In addition, the use of [[ ]] as discussed in Section 3.2.2. This steam dryer also uses [[ ]] to improve the stress distribution and move the welds away from the stress concentration at these panel junctions. The RSD also uses an improved [[ ]]. As a result, the baseline BWR/4 prototype RSD design is significantly more robust than the original steam dryer it replaced. The same holds true for the RSD design for BFN Units 1, 2, and 3. Both the BFN reactor vessel and the BWR/4 reactor vessel where the BWR/4 prototype RSD was installed have the same internal diameter; thus, in essence, the BFN RSD design envelope remains essentially unchanged from the BWR/4 prototype RSD.

In order to validate that the BFN RSD is similar to the prototype BWR/4 RSD, a study was conducted by placing the prototype BWR/4 design load onto the BFN RSD design. The results indicate that dynamic response remained relatively unchanged between the BWR/4 prototype and the BFN design. This study provides additional assurance that the changes implemented to improve the prototype baseline design do not invalidate the classification of the baseline BWR/4 design as a "valid prototype" in accordance with US NRC Regulatory Guide 1.20 (Reference 2), [[ ]]

Figure 3.1-1, with nomenclature provided in Table 3.1-1, provides an overview of the BFN RSD and the steam dryer component nomenclature. Differences between the prototype BWR/4 steam dryer and the BFN RSD are discussed in Section 3.2 below.

Table 3.1-1: Replacement Steam Dryer Component Nomenclature

[[		[[	
			]]
	]]		

*Items noted are not shown in Figure 3.1-1.

[[ ]]

Figure 3.1-1: Browns Ferry Nuclear Plant Replacement Steam Dryer Design (See Table 3.1-1 for number definitions)

3.2 Modifications Made for Browns Ferry Nuclear Plant

The BFN Units 1, 2, and 3 RSDs are very similar to the BWR/4 prototype steam dryer design. In general, some design modifications were incorporated to accommodate the RPV design differences (functional modifications) and others to improve the performance of the steam dryer because of lessons learned or to increase the fatigue margin (design improvements). One additional difference to note is the [[

]]. GEH has conducted testing on the [[ ]] and has concluded that there is no change in steam dryer performance. The [[ ]] was updated based on the new design.

3.2.1 Functional Modifications Facilitating RPV Interface

The functional modifications encompass design changes required to effectively install and maintain the steam dryer given that the BFN RPV design differs slightly from the RPV where the prototype was installed. In addition, the design changes facilitate the need for only one RSD design to fit all three BFN reactor units because there are minor differences where the steam dryer hold down brackets are located in the vessel head and in the locations and sizes of the steam dryer brackets.

The BFN original steam dryers used lifting rods that protruded upward from the steam dryer to interface with the RPV hold-down brackets. The major design change to the prototype regarding functionality is [[

]]

For the prototype installation, [[

]] For the BFN RSD design, [[

]]

A steam dryer global interference study for BFN was conducted as part of the standard design practice. This study specifically evaluates all key RPV to steam dryer interfaces, orthogonally and radially. The purpose of this design study is to assure adequate clearance and design target overlaps are maintained. Specific consideration for thermal expansion during vessel heat up is also taken into account. This study concludes that the clearances are adequate at both operating temperature and cold shutdown.

3.2.2 Design Improvements to the BWR/4 Prototype Design

As previously mentioned, the design improvements to the prototype design were implemented in the [[ ]] and BFN RSD designs for two reasons: to address lessons learned due to manufacturing or operating experience, and to increase fatigue margin to meet recommended fatigue acceptance criteria with a MASR greater than 2.0.

3.2.2.1 Design Improvements Due to Lessons Learned

Based on operating experience for the prototype BWR/4 RSD, the BFN RSD incorporated [[ ]] design modifications as follows:

[[

]]

3.2.2.2 Design Improvements to Increase Fatigue Margin

Additional design changes were required to improve the fatigue life of the BFN RSD to resist the FIV pressure loading and postulated SRV resonance loading. These modifications provide a more robust steam dryer design and are listed as follows:

[[

]]

[[ ]]

Figure 3.2-1: [[ ]]

[[ ]]

Figure 3.2-2: [[ ]]

[[ ]]

Figure 3.2-3: [[ ]]

[[ ]]

Figure 3.2-4: [[ ]]

[[ ]]

Figure 3.2-5: [[ ]]

[[ ]]

Figure 3.2-6: [[ ]]

[[ ]]

Figure 3.2-7: [[ ]]

4.0 BROWNS FERRY REPLACEMENT STEAM DRYER FATIGUE EVALUATION

This section describes the FIV stress analysis for the BFN RSDs. The purpose of this analysis is to demonstrate that the alternating stresses during normal operation at EPU conditions remain within the design fatigue acceptance criterion with the factor of 2.0 margin recommended by the NRC in Reference 1. Section 4.1 documents the development of the design load definitions for the FIV analysis. Section 4.2 provides the details of the structural analyses.

4.1 Flow Induced Vibration (FIV) Design Load Definition

The following sections describe the design load definition for the FIV analysis. The acoustic load definition was developed from acoustic load measurements taken [[ ]] The [[ ]] measurements taken during power ascension were used to develop scaling factors for projecting the CLTP analysis results to full EPU conditions. Based on analyses of the SRV standpipe geometry and main steam line flow velocity conditions, an SRV acoustic resonance is anticipated to initiate and grow as the plant moves into the EPU operating range. Because the resonance does not exist at the current power operating conditions, [[ ]].

Reactor operating conditions and non-acoustic loads also affect the vibratory response of the steam dryer during normal operation. [[ ]]

4.1.1 [[ ]] Acoustic Loads Measurements

The acoustic load definition for the BFN RSDs was developed from acoustic load measurements taken [[ ]] This section provides a summary of the following topics:

- [[ ]]
- Data Acquisition System (DAS),
- Data Acquisition Summary, and
- Data Filtering and Scaling.

The methodology used to [[ ]] for the steam dryer load evaluation is described in more detail in Appendix C.

4.1.1.1 [[ ]]

[[ ]] where [[ ]] is used to define the fluctuating pressure loads on the steam dryer.

For [[

]]

[[

]]

[[ ]] The resulting signal from [[

]]

The process for determining [[ ]] The PBLE model was run [[ ]] This assessment uses [[ ]]. The figure shows [[ ]]. Unit 1 is presented here [[ ]]. This selection process is discussed later in Section 4.1.3.

[[ ]]

Figure 4.1-1: Browns Ferry Unit 1 [[ ]]

4.1.1.2 Data Acquisition System

The DAS equipment used to gather [[ ]] at BFN from 2007 through 2011 was a [[ ]] This system meets criteria for dynamic measurements as outlined in Appendix C. This DAS is a computer-based system capable of acquiring and [[ ]] This system is suitable for dynamic measurements for a frequency bandwidth of at least [[ ]]. It is sensitive enough to detect and measure [[ ]]

The DAS has an option to set the bridge excitation to zero volts. [[ ]] Figure 4.1-2 shows a comparison of [[

]] It is not possible to completely shield the cables and strain gauges from electrical noise in the plant. More discussion on Figure 4.1-2 is in Section 4.1.1.4 for data filtering.

[[ ]]
[[ ]]

Figure 4.1-2: [[ ]]

4.1.1.3 Data Acquisition Summary

[[ ]] acoustic measurements have been taken at each of the BFN units. Data was taken in 2007 and 2008 at Unit 1, in 2010 at Unit 3, and in 2011 at Unit 2. The installation at each unit consisted of [[ ]]. During each time period a data acquisition test program was conducted to collect power ascension data. The presented 10V data trace represents the Active SG signal with 10 volts of excitation applied to the SG when recording the strain data. The 0V trace is the recorded data when no excitation voltage is applied to the SG. This is done in order to identify electrical noise that may be present at the time when the data is recorded.

This acquired test data serves as input to RSD design basis acoustic load definition using the PBLE02 methodology described in Appendix C.

A more detailed summary of these test campaigns can be found in Appendix D. The collection of [[ ]] data to support steam dryer limit curve monitoring during the EPU power ascension test program is described in Section 6.0.

4.1.1.4 Data Filtering and Scaling

The first step in the filtering process for BFN was to [[

]]

Figure 4.1-2 is an example of a PSD used for [[

]]

Table 4.1-1 lists the frequencies that were judged [[
]]

Table 4.1-1: [[ ]]

[[		
		]]

The electrical noise was filtered using [[

]]

The result is [[

]]

Figure 4.1-3 shows an example of the filtering [[

]] Figure 4.1-4 shows the same filtered data for [[

]]

The filtered [[

]] is discussed in more detail in Appendix C.

[[

]] The PBLE02 load definition development is described in Section 4.1.2.

[[ ]]
[[ ]]

Figure 4.1-3: [[ ]]

[[ ]]
[[ ]]

Figure 4.1-4: [[ ]]

4.1.2 PBLE02 Acoustic Load Definition

The acoustic pressure load definition used for the BFN RSD design and structural analyses was developed with the PBLE02 acoustic load methodology using the [[
]] taken at each of the three units.

4.1.2.1 Steam Dryer Fluctuating Load Definition

The RSD FIV response analysis uses the [[ ]] to develop the pressure load. The PBLE02 methodology used in the present work is described in Appendix C [[

]]

A 3D acoustic FEM of the Browns Ferry RSD and RPV was constructed [[

]]

[[ ]] regions with different steam properties are defined in the RPV/steam dryer acoustic model as shown in Figure 4.1-5:

- [[

]]

The following acoustic boundary conditions are applied to the acoustic model as shown in Figure 4.1-6:

[[

]]

Additional input [[
]]. Table 4.1-21 and Table 4.2-24

show these parameters for the Browns Ferry acoustic FEM. [[
]] (Figure 4.1-5).

The acoustic FRFs are calculated by [[
]]

For the Browns Ferry acoustic model, the [[
]].

[[ ]]

Figure 4.1-5: Browns Ferry PBLE Acoustic Model (3D Mesh Cross Section)

[[ ]]

[[ ]]

[[ ]]

Figure 4.1-6: Browns Ferry PBLE Acoustic Model with Applied Bottom Boundary Conditions

[[ ]]

Figure 4.1-7: Browns Ferry PBLE Acoustic Model

[[ ]]

[[

]] Only the steam dryer is shown in the figures.

[[ ]]

Figure 4.1-8: Browns Ferry Acoustic Steam Dryer [[ ]] **Locations**

[[ ]]

Figure 4.1-9: Browns Ferry Acoustic Differential FRFs
[[ ]] **Points**

[[ ]]

Figure 4.1-10: Browns Ferry PBLE Acoustic FRFs Pressure Distribution
([[ ]])

[[

]]

The [[ ]] are used to reconstruct the wave field in the [[

]] It should be noted that the CLTP [[

]] (see Table 4.1-2).

[[ ]]

Figure 4.1-11: Browns Ferry [[ ]]

The nozzle acoustic velocities are then used to excite the RPV/steam dryer acoustic FEM. The relationship between [[ ]] The TransMatrix also includes internal [[ ]]. The [[ ]] represent the acoustic effects of the [[ ]].

[[ ]] pressure loads are then calculated and recorded at all nodes on the acoustic model that are adjacent, or coincident with, nodes on the surface of the structural FEM. [[ ]]

Browns Ferry [[ ]] PBLE02 on-dryer acoustic differential pressure loads are calculated on all steam dryer surface nodes. [[ ]] is presented here as it was the [[ ]]

Figure 4.1-12 presents an example of differential pressure PSD, which is based on the Sum PSD of the [[ ]] on the steam dryer [[ ]]

The [[ ]] pressure PSD plot points to several amplitude peaks, which represent the interaction of the [[ ]] input pressure and RPV acoustic FRFs. Figure 4.1-13 presents several [[ ]] pressure distribution plots (3D contour plots) at several peak frequencies [[ ]]. For clarity only the steam dryer is displayed in the figures.

[[ ]]

Figure 4.1-12: [[ ]]

[[ ]]

Figure 4.1-13: Browns Ferry [[

]]

A [[ ]] pressure loads (i.e., [[ ]]) from the adjacent acoustic model nodes are mapped to the surface of the structural FEM. These mapped [[ ]] pressure loads were used to perform the FIV structural analyses. This process is performed [[ ]]

4.1.2.2 [[ ]]

The [[ ]] data acquisition for each Browns Ferry power ascension TC consisted of data sets [[ ]]

Dividing [[ ]] acoustic loads. A [[ ]] acoustic loads.

The length [[ ]] to capture the peak structural response. The [[ ]] from the PBLE02 calculated on-dryer [[ ]] pressure loads at [[ ]] (Figure 4.1-8). [[ ]] provide inputs to the FIV analyses that are representative of the highest expected loads with good frequency content in each frequency band, [[ ]] PBLE loads definitions used in the Browns Ferry steam dryer FIV stress analyses.

The steps in [[ ]] process are:

[[

]]

The above process for [[ ]] FIV analyses is illustrated below using the Browns Ferry [[ ]] data.

Figure 4.1-14 and Figure 4.1-15 show respectively [[ ]] PBLE02 [[ ]] The pressure load for [[ ]]

[[ ]]

Figure 4.1-14: Browns Ferry [[ ]]

[[ ]]

Figure 4.1-15: Browns Ferry [[

]]

An additional [[

]]

Acoustic pressure load distributions are generated and mapped onto the structural model for a total of [[ ]]. Figure 4.1-16 and Figure 4.1-17 present examples of PBLE02 calculated [[ ]] pressure load distributions (3D contour plots) at [[ ]] used in the FIV analyses.

It should be noted that the respective [[ ]] FIV stresses [[ ]]

In summary, [[ ]] for use the in Browns Ferry steam dryer FIV stress analyses. [[ ]] good frequency content to ensure that all the structural modes are well excited. Also, [[ ]] are included in the final Browns Ferry stress adjustment [[ ]].

[[ ]]

Figure 4.1-16: Browns Ferry [[
]]

[[ ]]

Figure 4.1-17: Browns Ferry [[ ]]

4.1.3 [[ ]]

[[

]]

4.1.3.1 Browns Ferry [[ ]] Pressure PSD Comparison

Each unit's CLTP MSL data was pre-processed (filtered, [[ ]] and converted to internal pressure) and then processed using PBLE02 methodology (Appendix C) to develop acoustic pressure load sets.

Table 4.1-2 presents the CLTP test condition characteristics for the three units, [[ ]] A discussion on the recirculation pump VPF is covered later [[ ]]

Table 4.1-2: Browns Ferry Inputs

Unit	Power Level Test Condition	Data Recording Date	[[				
Unit 1	CLTP (99.0%)	Dec. 2008					
Unit 2	CLTP (100.0%)	April 2011					
Unit 3	CLTP (99.9%)	April 2010					]]

Table 4.1-3: Browns Ferry [[ ]]

Unit / MSL	[[							
Unit 1								
Unit 2								
Unit 3								]]

[[ ]]

[[ ]]

Figure 4.1-18: [[ ]]

Table 4.1-4: Browns Ferry [[ ]]

Unit	[[			
Unit 1				
Unit 2				
Unit 3				
				]]

[[ ]]

Appendix D presents the Browns Ferry CLTP measured [[ ]] To summarize the comparisons, Figure 4.1-19 shows [[ ]]). The PSD represents [[ ]]

Because the purpose of this project is the structural evaluation of the RSDs, a better and more illustrative comparison between the three units is made using [[ ]] (this comparison is presented in Section 4.1.3.2). However, Figure 4.1-19 provides a direct comparison of the measured [[ ]]

As seen in Figure 4.1-19, the three units have overall similar frequency content. The highest [[ ]] pressure amplitude is at [[ ]]

The three units are virtually identical with respect to the plant geometry relevant to the pressure loading on the steam dryer and with respect to the reactor operating conditions. [[ ]] Given that the geometry and operating conditions are essentially the same for the three units, [[ ]]

]]

Because it is not possible [[

]].

[[ ]]

Figure 4.1-19: Browns Ferry CLTP All Units -
[[ ]]

4.1.3.2 Browns Ferry [[ ]] Pressure Loads Comparison

Using each unit's CLTP measured [[ ]] data and the PBLE02 methodology described in Appendix C; the [[ ]] pressure acoustic loads are developed for the three Browns Ferry units. For comparison purposes, the loads are calculated for [[ ]] (Figure 4.1-8). The [[ ]]

The comparisons [[ ]] for the three units are presented in several ways in the following sections:

[[ ]]

4.1.3.2.1 [[ ]] PSD Comparison

Figure 4.1-20 presents the three Browns Ferry Units, PBLE02 [[ ]] The comparisons are based on the [[ ]]

As seen in this figure, the three units have similar frequency content. [[ ]]

Overall, [[ ]]

[[

]]

[[ ]]

Figure 4.1-20: Browns Ferry [[
]]

4.1.3.2.2 [[ ]] Pressure Load Comparison

Figure 4.1-21 presents, for each of the three Browns Ferry units, the PBLE02 [[

]]. The comparison is based on the [[ ]] pressure loads of the [[
]]. The pressure load represents the [[
]].

[[

]]

The three units' [[

]]

[[ ]]

Figure 4.1-21: Browns Ferry [[

]]

4.1.3.2.3 [[ ]] Pressure Load Comparison

Figure 4.1-22 presents, for each of the three Browns Ferry units, PBLE02 [[

]] The comparison is based on the [[ ]] pressure loads of the [[ ]]. The pressure load represents [[

]].

[[

]]

As seen in these [[

]]

[[ ]]

Figure 4.1-22: Browns Ferry [[

]]

[[ ]]

Figure 4.1-23: Browns Ferry [[ ]]

4.1.3.2.4 [[ ]] Pressure Load Comparison

Figure 4.1-24 presents, for each of the three Browns Ferry units, PBLE02 [[ ]] The comparison is based on the Sum of the [[ ]]. The pressure load represents the [[ ]]

After [[ ]]

[[ ]]

Figure 4.1-24: Browns Ferry [[ ]]

4.1.3.3 Browns Ferry Unit Selection and Units Bounding Scaling Factors

Following the three units' pressure load comparison in the previous section, [[

]] Given that the geometry and operating conditions are practically the same for the three units, [[

]]

From equations [[

]]

[[ ]]

Figure 4.1-25: Browns Ferry [[ ]]

4.1.4 SRV Acoustic Load Definition

Regulatory Guide 1.20, Revision 3 (Reference 2), Section C 2.0 indicates studies of past failures have determined that flow-excited acoustic resonances within the valves, stand-off pipes and branch lines in the MSLs of BWRs can play a significant role in producing mid- to high-frequency pressure fluctuations and vibration that can damage MSL valves, the steam dryer and other RPV internals and steam system components. The SRV standpipe acoustic resonances are the main contributor to the mid- to high-frequency pressure fluctuations. Therefore, the potential for these SRV resonance loads is reviewed and, if needed, the SRV resonance loads are modeled in the load definition and analysis.

4.1.4.1 SRV Acoustic Load Synthesis

To analyze the SRV resonance loads, the Browns Ferry [[ ]] gauge data from all three units were first screened to identify existing acoustic sources up to CLTP conditions. [[ ]] Strouhal calculations for the potential resonance frequencies are used to confirm existing sources and to determine potential acoustic sources between CLTP and EPU conditions. [[

]] Details of the above processes are described in this section.

The SRV load process includes the development of SRV resonance load adders that are used in the base load for performing the structural analysis. For a plant with multiple SRV valves in each MSL with similar geometry, a band of potential frequency responses can be predicted for each line. The exact frequency response, location of prevailing acoustic source, and phase relationship between the acoustic source and the MSL mode at increased steam flow [[

]]

The methodology and approach used for Browns Ferry was to [[

]]

- The method used to create simulated SRV resonance loads at potential SRV frequencies [[ ]],
- The evaluation of the acoustic load sensitivity [[ ]],
- The [[ ]] for the structural FEA.

4.1.4.1.1 Identification of Potential SRV Resonance Frequencies

[[

]]

4.1.4.1.2 SRV Resonance Load Generation

[[

]]

4.1.4.1.3 SRV Resonance Amplitudes for Structural Analyses

[[

]]

4.1.4.2 Identification of Potential SRV Resonance Frequencies

[[

]]

Browns Ferry has the typical four MSL configurations where the steam line nozzles are offset ± 18° from the 90-270° line. Browns Ferry uses a common SRV acoustic standpipe configuration for all of the SRV branches. There are three SRV layouts in the MSL configuration, with MSLs A and B being mirror images of MSLs C and D; however, MSL C has one less SRV than MSL B. Lines A and D have three SRVs, as shown in Figure 4.1-26 and Figure 4.1-28. Line B has four SRVs and line C has three SRVs, on opposite sides of the MSL piping from the vessel. There is a Reactor Core Isolation Cooling (RCIC) line below the SRV on MSL C and a High Pressure Coolant Injection (HPCI) steam supply line below a dead-leg SRV on MSL B. There is a Reactor Vent line on MSL C, 44 inches below the centerline of the nozzle, as shown in Figure 4.1-26. It should be noted that previous testing and analysis has indicated that HPCI, RCIC, and vent lines are not significant contributors to acoustic signal content.

MSLs B and C each have a dead-leg section to accommodate SRVs. Because there is no steam flow in the stagnant dead-leg branches, there is no flow mechanism for exciting the standpipes in the dead-leg section. Therefore, it is not necessary to address potential acoustic resonance frequencies associated with the standpipes in the dead-leg branches.

MSL acoustic data taken on Unit 2 in 2006 (and on Unit 1 in 2007) indicated the presence of a resonance frequency at approximately [[ ]] associated with the blind flange standpipes without SRVs in the main steam flow path for MSLs A and D. Modifications have been performed to install acoustic vibration suppressor (AVS) inserts in place of the blind flanges on these standpipes for all three BFN units. The AVS inserts were not used in the blind flange standpipes in the stagnant dead-legs on MSLs B and C. The locations of the AVS inserts are shown in Figure 4.1-26. The AVS inserts reduce the depth of the standpipe cavity, shifting the fundamental resonance frequency from approximately [[ ]] for the blind flange to approximately [[ ]] with the AVS.

Subsequent to the modifications to install the AVSs, additional MSL acoustic data has been taken on all three BFN units that show the AVS inserts eliminated the [[ ]] acoustic resonances that were occurring in the standpipes with blind flanges at CLTP power level. The MSL acoustic data for each BFN unit used in the stress analyses for the RSDs were taken with the AVSs installed.

The [[ ]] fundamental frequency for the standpipes with AVS inserts is well above the frequency range of interest for the steam dryer structural analyses. Also, at the higher fundamental frequency, the steam line flow velocity necessary to induce an acoustic resonance in the AVS-equipped standpipes is well above the EPU operating range. Therefore, it is not necessary to address potential acoustic resonance frequencies associated with the standpipes with AVS inserts in the acoustic load definition.

Acoustic [[ ]] analyses have been performed [[

]]

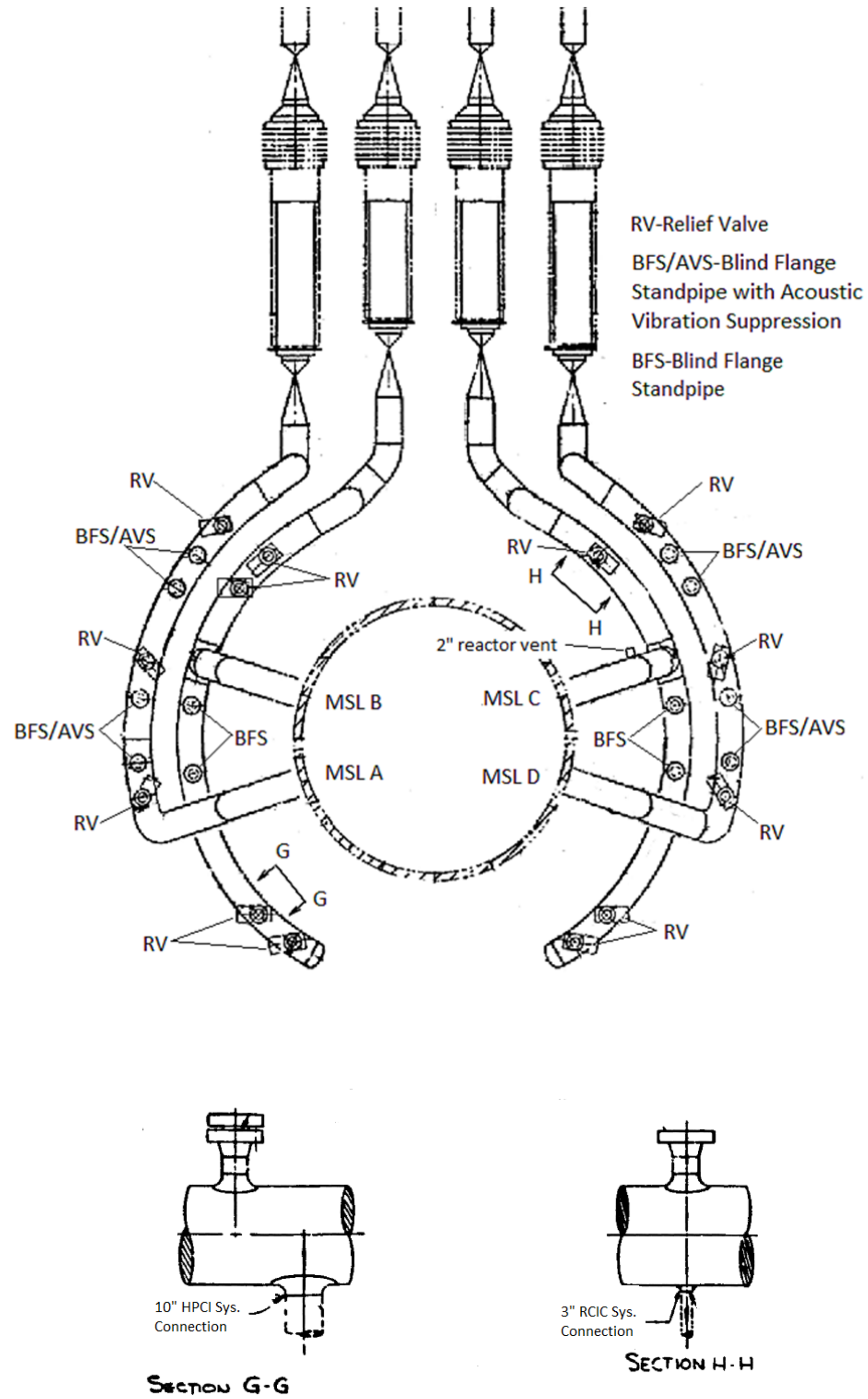

Figure 4.1-26: Browns Ferry SRV and Branch Line Layout

4.1.4.2.1 SRV Resonance Fundamental Frequency

A detailed [[ ]] of a single SRV standpipe and valve cavity was built and analyzed following the methodology described in Section 4.1.4.1.1. [[ ]] analysis of the single SRV indicates [[ ]] is approximately [[ ]]. Figure 4.1-27 shows the [[ ]]

[[ ]]

Figure 4.1-27: Single SRV [[ ]]

4.1.4.2.2 MSL Acoustic Mode Interactions

The SRV standpipe and MSL acoustics will interact and the combined system may resonate at frequencies different from that of the single valve standpipe fundamental frequency. The frequency of the combined system resonance has been observed in plant measurements to usually be within [[ ]] of the standpipe fundamental frequency. For that reason, [[

]] Typical SRV/MSL resonance mode shapes for MSL A and MSL B are shown in Figure 4.1-28 to Figure 4.1-31. Table 4.1-5 shows the results of the evaluation, with several prominent modes from [[ ]]. The predicted SRV resonance frequencies in Table 4.1-6 are candidates for modeling in the design acoustic load definition.

[[ ]]

Figure 4.1-28: Browns Ferry MSL [[ ]] **and SRV Resonance of MSL A at** [[ ]]

[[ ]]

Figure 4.1-29: Browns Ferry MSL [[ ]] **and SRV Resonance of MSL A at** [[ ]]

[[ ]]

Figure 4.1-30: Browns Ferry MSL [[ ]] **and SRV Resonance of MSL B at** [[ ]]

[[ ]]

Figure 4.1-31: Browns Ferry MSL [[ ]] **and SRV Resonance of MSL B at** [[ ]]**.**

4.1.4.2.3 Comparison with Browns Ferry MSL Measurements

The candidate SRV resonance frequencies in Table 4.1-6 were then compared against the MSL measurements taken during power ascension to CLTP in each of the three Browns Ferry units. These comparisons, supplemented with Strouhal calculations, are used to determine the final SRV resonance frequencies that will be synthesized in the design acoustic load definition. The Browns Ferry MSL strain gauge data from all three units were first screened to identify potential existing acoustic sources up to CLTP conditions. [[ ]]

Figure 4.1-32 shows the MSL acoustic pressure measurements taken in [[ ]] during the power ascension to CLTP. In Figure 4.1-33, an SRV acoustic resonance at approximately [[ ]] can be seen to initiate somewhere between the [[ ]]. The amplitude of the signal peaks at the [[ ]] power level and has decreased by the time the power level reaches [[ ]] CLTP. At [[ ]] power, the [[ ]] is also approximately [[ ]] and the [[ ]] signal may be [[ ]] As described in Section 4.1.5.4, it is not known if the apparent [[ ]] acoustic content in the MSL strain gauge measurements is a result [[ ]] For the purpose of the design acoustic load definition, the [[ ]] acoustic pressure measurements at the VPF are being [[ ]] Therefore, the peak amplitude of the [[ ]] signal at [[ ]] power will be conservatively assumed to be the peak of the SRV acoustic resonance.

No other SRV acoustic resonances are apparent in the MSL acoustic pressure measurements. Based on the Strouhal calculations discussed later in this section, there is the potential for SRV resonances at about [[ ]] (the SRV standpipe fundamental frequency) and in the [[ ]] range initiating near the [[ ]] CLTP power level. Close review of the individual MSL pressure measurements shows no sign of resonance onset in the [[ ]]. In the [[ ]], there may be some initial indications in the [[ ]] power level measurements; however, the acoustic signal at [[ ]] power is masked [[ ]], making the review inconclusive.

[[ ]]

Figure 4.1-32: Browns Ferry [[ ]]

Further insights into the potential SRV acoustic resonance frequencies can be obtained by comparing the predicted MSL/SRV acoustic frequencies from the [[ ]] with the frequency content measured in the MSL acoustic pressures. Figure 4.1-33 shows PSDs of the [[ ]] The main steam system is excited by broadband turbulent flow pressure fluctuations; the peaks in the PSD curves show where the acoustic modes in the steam system are being excited by the turbulent pressure fluctuations. The resonance in the SRV standpipe must acoustically couple through the acoustic modes in the steam system in order for the resonance to project an acoustic load on the steam dryer.

[[ ]]

Figure 4.1-33: Browns Ferry [[ ]]

In the [[ ]]. A comparison of the measured versus predicted modes is presented in Table 4.1-5. The predicted acoustic modes are close to the measured modes, given the uncertainties introduced by the tolerances in the as-built MSL and SRV geometry measurements and the simplifying assumptions necessary when modelling the MSL piping system.

Table 4.1-5: Predicted and Measured Resonant Frequencies

Predicted Frequencies (Hz)	Browns Ferry Measured Frequencies (Hz)
[[	
	]]

Strouhal calculations were performed to determine the expected amount of resonance growth for the postulated SRV resonance frequencies. The results are shown in Table 4.1-6. It should be noted that these Strouhal calculations are approximate in that they assume the average MSL flow velocity for the four steam lines and do not take into consideration the local flow velocity distributions within the pipe that are induced by upstream elbows and curves in the pipe. Therefore, the Strouhal numbers at the resonance onset will differ somewhat from the theoretical range. The onset for the observed [[ ]] is above [[ ]] Using the [[ ]] should initiate at about [[ ]] power and the [[ ]] should initiate at about [[ ]] CLTP. A flow velocity increase of about [[ ]] is typically needed to grow the resonance from onset to the peak resonance amplitude. [[ ]] the [[ ]] should be reaching peak amplitude just above [[ ]] CLTP power and should be significantly diminished at full EPU power. For the [[ ]], the peak resonance amplitudes are expected to occur at about full EPU power.

Table 4.1-6: Strouhal Numbers for Potential SRV Acoustic Resonances from BFN [[
]]

[[					
					]]

Based on the MSL measurements and the Strouhal calculations, there are three potential SRV resonance frequencies that may be expected to initiate at about the [[ ]] power level and increase in amplitude, peaking at or near the full EPU power level: [[ ]]. A review of the acoustic mode shapes shows that modeling the SRV resonance frequency at [[ ]] will tend to maximize the pressure loading on the steam dryer. When considering the uncertainties in predicting the exact frequency of the resonance, assuming the design resonance frequency at [[ ]] allows the [[ ]]

From the combined acoustic [[ ]] measurements, the selected frequencies for the steam dryer analysis are [[ ]]. The [[ ]] resonance is shown in the MSL measurements to be decreasing at [[ ]] power and is expected to be significantly diminished when the plant reaches full EPU power. To be conservative, the [[ ]] is included in the CLTP and EPU load definition with the peak amplitude measured at [[ ]] power, which will bound this resonance at all power levels.

4.1.4.3 SRV Adders for Design Acoustic Load Definition

In the previous section, two SRV resonance frequencies [[ ]] were selected to be included in the Browns Ferry structural analysis. [[ ]] The SRV Scale Factors described in the next section are then used to scale the stresses from the structural analysis to the final amplitudes for the EPU and CLTP load cases.

As discussed in section 4.1.4.1.2, the [[ ]] on the steam dryer. In order to accomplish this, the solution in section 4.1.4.1.2 was executed [[ ]].

The results demonstrated that [[ ]] Therefore a method was developed to define the simulated SRV loads [[ ]].

To evaluate the acoustic load sensitivity to the phasing, [[ ]] As can be seen, there is a [[ ]]

Table 4.1-7: SRV [[ ]]

[[					
					]]

[[ ]]

[[ ]]

Figure 4.1-34: Sensitivity Study for SRV Acoustic Loads [[ ]] **Hz**

[[

]]

[[ ]]

Figure 4.1-35: Browns Ferry [[
]]

[[

]] The resulting steam dryer pressure loads are shown in Figure 4.1-12. This figure shows that the [[

]].

4.1.4.4 Projecting Simulated SRV Loading to EPU

Section 4.1.4.1 of this document discusses the development of SRV resonance load adders that were used to develop the base load for performing the structural analysis. This section discusses the development of scaling factors that are designed to project potential SRV loading up to EPU conditions. [[

]] The Browns Ferry MSL piping is similar to the BWR/4 prototype plant used for the RSD design and the MSL strain gauge acoustic loads for the prototype plant show similar frequency content as Browns Ferry. However, the SRV standpipe dimensions and valves [[

]]

Table 4.1-8 presents a comparison of the Browns Ferry SRV characteristics with the SRV characteristics for which SRV resonance loads have been measured on instrumented RSDs. [[

]]

Table 4.1-8: Comparison with Available SRV Resonance Measurements

[[			
			]]

[[ ]]

[[

]] shown in Figure 4.1-8. [[ ]], as shown in Table 4.1-9 below:

Table 4.1-9: Browns Ferry Replacement Steam Dryer Region Definitions

[[				
				]]

[[

]].

4.1.4.4.1 Browns Ferry SRV Resonance Onset and EPU Loads Trending Range

First a parameter must be defined for the identification and definition of the SRV resonance onset that will significantly affect the SRV EPU loads trending. The mean of [[ ]] are used in the definition of SRV resonance onset for both Browns Ferry and the reference plants (the red dashed curve of Figure 4.1-36 below). The sharp turning point of the SRV resonance curve is defined as the SRV resonance onset shown in Figure 4.1-36. [[ ]] In reality, the steam dryer or main steam line pressures will be a smooth function of the main steam line flow velocity. To improve the accuracy in SRV resonance onset definition and extraction, [[

]]

Figure 4.1-38 below illustrates the relation of Browns Ferry SRV resonance onset and EPU loads trending range.

[[ ]]

Figure 4.1-36: Definition of Browns Ferry [[ ]] **SRV Resonance Onset**

[[ ]]

Figure 4.1-37: [[ ]] Browns Ferry [[ ]] SRV Resonance Onset Curve

[[ ]]

Figure 4.1-38: Browns Ferry SRV EPU Loads Trending Range

Calculation of BWR/3 SRV Resonance Onset and Trending Range

[[

]] shown in Figure 4.1-42. Table 4.1-10 provides the projected Browns Ferry SRV resonance loads at EPU. Figure 4.1-43 illustrates the trended Browns Ferry SRV resonance loads curves.

Table 4.1-10: [[ ]] **Browns Ferry SRV EPU Loads** [[ ]]

[[			
			]]

[[ ]]

Figure 4.1-39: [[ ]] Projected [[ ]] SRV Resonance Loads

[[ ]]

Figure 4.1-40: [[ ]] SRV Resonance Onset

[[ ]]

Figure 4.1-41: Comparison of Browns Ferry and [[ ]] **SRV Resonance Onset**

[[ ]]

Figure 4.1-42: [[ ]] **SRV EPU Loads Trending Range and Test Condition**

[[ ]]

Figure 4.1-43: Projected Browns Ferry SRV Loads at EPU

4.1.4.4.2 Browns Ferry SRV EPU Loads Adjustment

[[ ]] provided in Table 4.1-10 above. [[ ]]

BWR/3 PBLE Loads Bias

The projected [[ ]] PBLE loads, defined using [[ ]], are used in the SRV EPU loads trending as discussed above. [[

]]

Table 4.1-11: [[ ]]
[[ ]]

[[					
					]]

Table 4.1-12: [[ ]]

[[ ]]

[[			
			]]

Table 4.1-13: [[
]]

[[			
			]]

[[ ]]

Browns Ferry and BWR/3 Steam Dryer Acoustic Mode Shape Scaling

[[

]]

Table 4.1-14: Browns Ferry and [[ ]]

[[			
			]]

Table 4.1-15: Extracted and Corrected Browns Ferry Region RMS Pressures

[[			
			]]

[[

]]

4.1.4.4.3 Calculation of Browns Ferry [[ ]] Region RMS Pressure with SRV Adders at CLTP

[[

]]

The final adjusted Browns Ferry SRV EPU loads, [[ ]] given in Equation 4.1-14 above.

Table 4.1-16 gives the [[ ]] Browns Ferry [[ ]] of the [[ ]] with SRV adders at CLTP condition.

Table 4.1-16: Extracted Browns Ferry SRV EPU Loads from [[
]]

[[			
			]]

[[
]]

4.1.4.4.4 Combination and Calculation of BFN EPU Scaling Factors

<u>Calculation of BFN SRV EPU Loads Scaling Factors</u>

The SRV EPU scaling factors are [[
]] given in Equation 4.1-22 above. The steps used for the calculation of BFN SRV EPU loads scaling factors are given below:

[[

]]

Table 4.1-17 provides the Browns Ferry [[ ]] SRV EPU scaling factors calculated using the methodology discussed above.

Table 4.1-17: Browns Ferry [[ ]]**SRV EPU Scaling Factors**

[[			
			]]

[[
]]

Combination of BFN EPU Scaling Factors

[[

]]

4.1.4.4.5 Browns Ferry SRV EPU Loads Validation

[[

]]

[[ ]]

Figure 4.1-44: Comparison of Browns Ferry [[ ]] **SRV EPU loads defined and** [[ ]]

4.1.4.5 Projecting Simulated SRV Loading to CLTP

[[ ]]

The CLTP B&U is then expressed [[

]]

Table 4.1-18: [[ ]] SRV Resonance Load Adder Bias and Uncertainties

[[			
			]]

4.1.5 Reactor Operating Condition Effects

[[

]]

These reactor operating condition effects are discussed further in the following sections.

4.1.5.1 Reactor Dome Pressure

[[

]]

4.1.5.2 RPV Water Level

[[

]]

4.1.5.3 Core Flow Effect

Power ascension testing of an instrumented RSD showed a well-correlated relationship between the reactor core flow and the steam dryer structural response. [[

]]

Table 4.1-19: Core Flow Adjustment Factors

[[		
		]]

4.1.5.4 Recirculation Pump Vane Passing Frequency

The industry has observed containment noise and vibration driven by recirculation pump VPF pulsations. See Nuclear Regulatory Commission (NRC) Information Notice 95-16 (Reference 3) and GE SIL 600 (Reference 4). [[

]]

In preparation for the EPU project, the Browns Ferry [[ ]] recirculation piping was instrumented and testing was performed to confirm that the structural response of the recirculation piping would be acceptable at EPU conditions when excited by the VPF pulsations. [[

]]

The Browns Ferry [[
]] as are the recirculation pump design and plant operating conditions. [[

]] The recirculation discharge piping manifold and risers were replaced in [[ ]] The geometry of the replacement piping is different than the original piping in [[ ]] Based on the piping configurations and historical evidence (observations by plant personnel), the [[ ]] configurations [[
]]

An analysis of results for the maximum VPF response for the BWR/4 prototype benchmark steam dryer provides a means to estimate the increase in vibrational stress amplitude due to the VPF effect in the Browns Ferry RSD stress analysis. The following procedure was utilized to develop upper and lower steam dryer scale factors for the final stress adjustment to account for maximum VPF vibration:

[[

]]

This process was performed for both the BWR/4 prototype benchmark plant RSD [[
]] to find the largest impact; and as reported above, [[
]] The statistics for the

percentage contribution for [[ ]] of the BWR/4 prototype RSD are tabulated below in Table 4.1-20.

Table 4.1-20: Statistics of VPF Contribution to Strain Gauge Measurements in BWR/4 Benchmark Steam Dryer

[[		
		]]

In the final stress adjustment calculation, the mean over Strain Gauges (%) and the Standard Deviation over Strain Gauges (%) [[ ]] to develop a "VPF Scale Factor" [[

]] Thus, the final peak stresses for [[ ]] steam dryer [[ ]] to account for the potential VPF vibratory stresses at final EPU conditions for the Browns Ferry steam dryer; while the final peak stresses for [[ ]] steam dryer are [[ ]].

Several transmission paths for the VPF excitation have been postulated; however, [[

]]

4.1.6 Scaling Factors for EPU Conditions ([[ ]])

Trending is performed to characterize the increase in FIV load [[ ]] project the load to EPU conditions. The EPU scaling factor [[ ]] The [[ ]] loads grow in relation to [[ ]] The EPU scaling factor for the Browns Ferry SRV resonance at [[ ]] was discussed in Section 4.1.4.4.

Section 4.1.1 and Appendix C discuss [[ ]] for the RSD design analysis. [[ ]] The [[ ]] trending factor was calculated based on the [[ ]] The three units are virtually identical with respect to the plant geometry relative to pressure loading on the steam dryer and with respect to the other reactor operating conditions. Therefore the trending observed in [[ ]]

Projecting power ascension data as pressure loads on the steam dryer provides a direct assessment of the change in steam dryer load as a function of power [[ ]]

To derive the [[ ]] EPU scaling factors, the load was characterized [[ ]]. These loads were calculated in [[ ]].

For all frequency bands trend lines were fit through pressure load data [[

]]

Figure 4.1-45 depicts the CLTP PSD curve (green) and the EPU projection curve (pink) for [[ ]] steam dryer. [[ ]] as discussed in Section 4.1.4. Additional information on [[ ]] trending and projection is included in Appendix A, Section 6.3.4 and Appendix C. Additional regional steam dryer group plots related to trending are presented in Appendix D Section 5.0.

[[ ]]

Figure 4.1-45: CLTP Loads and EPU SRV Design Loads, [[ ]]

4.1.7 Browns Ferry Comparison to BWR/4 Prototype (Geometric, Acoustic Properties, and Load)

The Browns Ferry plants are quite similar to the BWR/4 prototype plant. Both BWR/4 plants have 251-inch RPVs and dead-legs on the MSLs; and operate at virtually the same power level, reactor pressure and steam flow conditions. The FIV loading on the Browns Ferry RSDs is expected to be approximately the same as that measured on the BWR/4 prototype, as discussed in this section and in Section 4.1.8. Therefore, the BWR/4 prototype [[ ]] are appropriate for validating the Browns Ferry FIV load definition for the RSD design. While the comparisons of primary interest are those with the BWR/4 prototype because of the similarities between the two plants, comparisons with the [[ ]] (Section 4.1.8.2) are also provided to document the operating experience of the [[ ]] being used in Browns Ferry.

The following sections provide comparisons between Browns Ferry and the BWR/4 prototype plant of the plant geometry, steam dryer geometry, reactor operating conditions, and acoustic loading on the steam dryer.

4.1.7.1 Plant Geometry Comparison

The BWR plant design evolution has resulted in similar reactor vessel, steam dryer, and MSL geometrical configurations, as well as similar plant operating conditions. As a result, the range of plant-to-plant variations that affect the steam dryer pressure loading is small. A consequence of this relatively small envelope of steam dryer conditions is that the prototype steam dryer experience can be applied to the Browns Ferry RSD. Table 4.1-22 provides a comparison of plant geometry between Browns Ferry and the BWR/4 prototype plant.

The geometric parameters may have an effect on the acoustic mode shapes within the vessel. The vessel and steam dome volumes are similar between the two plants. Therefore, differences in acoustic mode response are minimal as exhibited by the comparison of the acoustic properties and characteristics discussed in Section 4.1.7.3.

The RSD design load definition based on Browns Ferry specific [[ ]] and the plant-specific FIV fatigue analysis address the minor differences in plant geometry and operating conditions between Browns Ferry and the BWR/4 prototype plant.

The Browns Ferry and BWR/4 Prototype [[ ]] outlines are shown in Figure 4.1-46 and Figure 4.1-47, respectively.

Table 4.1-21: [[
]]

[[			
			]]

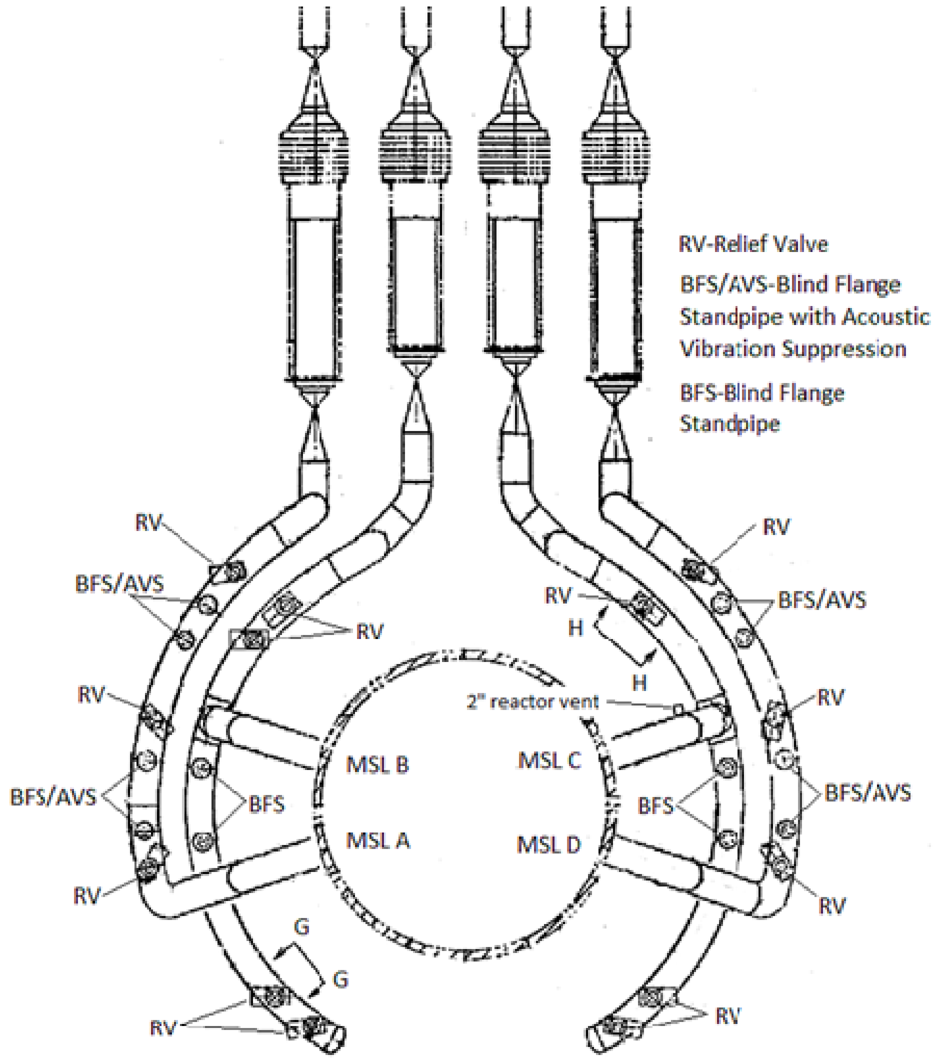

Figure 4.1-46: Browns Ferry U123 MSL Piping Outline

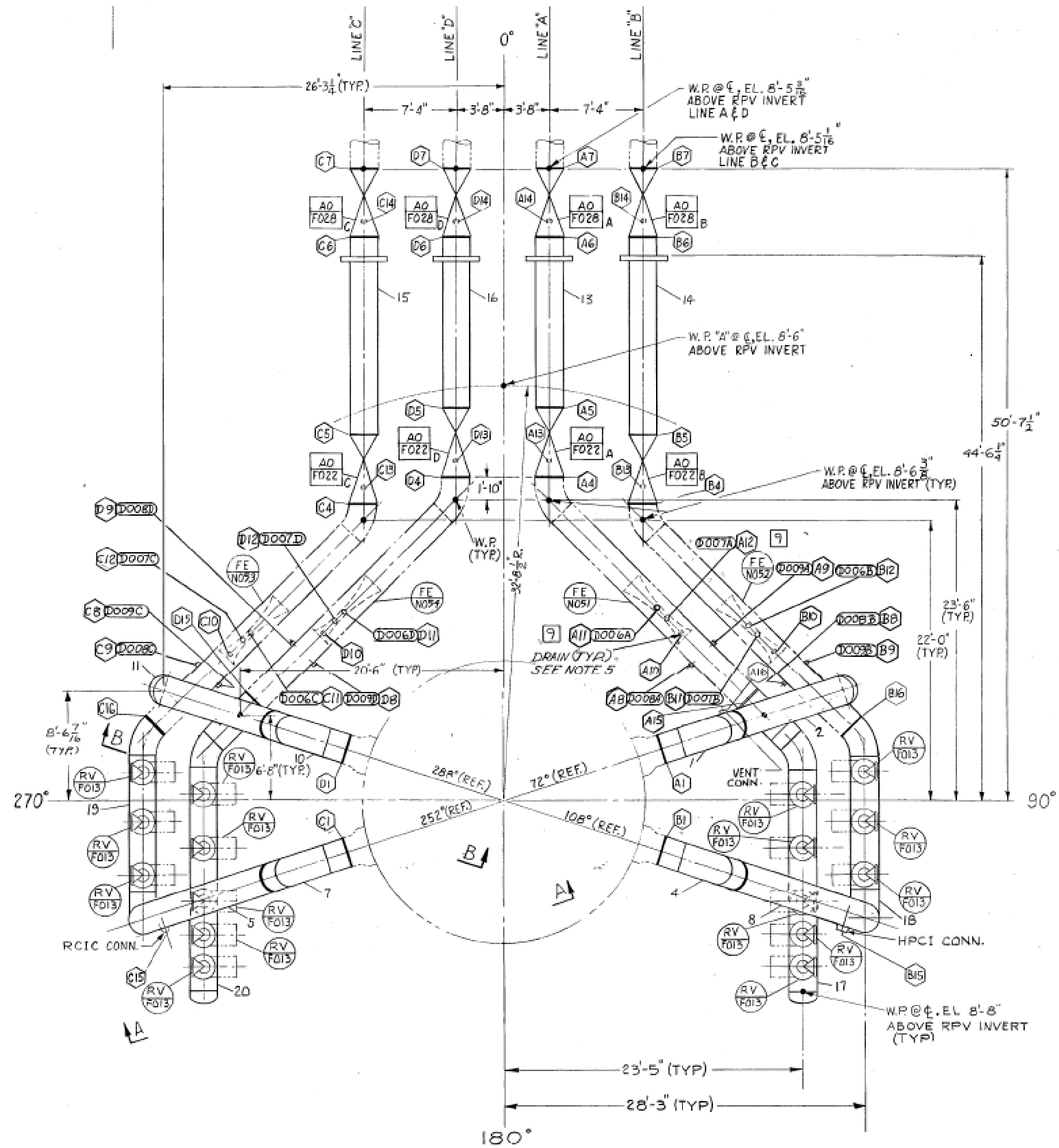

Figure 4.1-47: [[ ]]

4.1.7.2 Browns Ferry Steam Dryer Geometric Comparison to BWR/4 Prototype

Table 4.1-21 and Table 4.1-22 are comparisons of important dimensions for the steam dryer geometry. The comparison in Table 4.1-22 directly supports the design basis discussion by showing how similar the prototype steam dryer is compared to the design basis of the Browns Ferry RSD.

Table 4.1-22: [[ ]]

[[			

Table 4.1-22: [[ ]]

			]]

4.1.7.3 Operating Conditions and Acoustic Property Comparison

With respect to fluctuating pressure loads on the steam dryer, reactor power is significant only in that it determines the steam flow rate through the system. Because Browns Ferry and the prototype plant have identical power levels at EPU, the steam mass flows through the steam dryer are similar. The steam flow velocity in the [[ ]] The prototype plant and Browns Ferry also have identical nominal MSL inner diameters resulting in similar flow velocities. Therefore, the fluctuating pressure loads acting on the steam dryer are also similar. [[ ]]

Appendices B and C describe the important acoustic properties [[ ]] with respect to the PBLE acoustic modeling methodologies. The purpose of this section is to compare the plant operating conditions that determine these acoustic properties between the BWR/4 prototype plant used for the benchmark analyses and Browns Ferry.

Table 4.1-23 provides a comparison of the basic reactor operating conditions and Table 4.1-24 provides a comparison of the resulting acoustic properties that are used as inputs to the PBLE methodology. [[

]]

Table 4.1-23: [[

]]

[[			
			]]

Table 4.1-24: [[ ]]

[[			
			]]

4.1.7.4 Acoustic Loads Comparison

This section presents the acoustic pressure loads comparison between the plant analysis (Browns Ferry U1) and the BWR/4 prototype or benchmarking plant (BWR/4). As described in Sections 4.1.7.1 and 4.1.7.2, the Browns Ferry and BWR/4 prototype steam dome and steam dryer geometries are very similar. Also, the operating conditions described in Section 4.1.7.3 are comparable. Because the acoustic properties, geometries, and operating conditions are comparable, the vessel acoustic FRFs are similar between the two plants. [[

]]

The acoustic loads comparison consists of:

[[

]]

a) Browns Ferry [[ ]] vs. BWR/4 Prototype [[ ]] Comparison

Using the PBLE methodology as described in Appendix B, [[

]]. Details on the [[ ]] calculation are presented in Section 4.1.2.1 for Browns Ferry plant and in Appendix B for the BWR/4 prototype plant.

[[

]]

Figure 4.1-48 presents the [[

]] As seen in Figure 4.1-48, the two plants [[

]]

Some differences [[

]]

Figure 4.1-49 and Figure 4.1-50 present [[

]]. For clarity, only the steam dryer is displayed in the figures. Overall, large similarity is seen in these 3D plots.

The overall similarity [[

]]

[[ ]]

Figure 4.1-48: Browns Ferry vs. BWR/4 Prototype Acoustic [[
]]**)**

[[ ]]

Figure 4.1-49: Browns Ferry vs. BWR/4 Prototype Acoustic [[
]]

[[ ]]

Figure 4.1-50: Browns Ferry vs. BWR/4 Prototype Acoustic [[ ]]

b) Browns Ferry [[ ]] vs. BWR/4 Prototype [[ ]] Comparison

[[ ]]

Table 4.1-25 presents for Browns Ferry [[ ]] and BWR/4 prototype, [[ ]] The test conditions for the two plants yield approximately the same [[ ]] The vane passing frequencies for both recirculation pumps (A & B) are also presented. [[ ]]

Table 4.1-25: Browns Ferry [[ ]] vs. BWR/4 Prototype Inputs

[[							
							]]

Table 4.1-26: Browns Ferry [[ ]]

[[				
				]]

[[ ]]

Figure 4.1-51 shows the measured [[

]]

To summarize the comparisons for all [[ ]] Figure 4.1-52 presents the [[ ]] pressure PSD [[

]]

As seen in Figure 4.1-51 and Figure 4.1-52, the two plants have overall similar frequency content. The highest [[ ]] is at [[ ]] for the two plants.

Physically, the two plants are similar with respect to the plant geometry relevant to the pressure loading on the steam dryer and with respect to the reactor operating conditions. [[

]]

[[ ]]

(a) [[ ]]

[[ ]]

(b) [[ ]]

Figure 4.1-51: [[**]]**

[[ ]]

Figure 4.1-52: [[ ]]

c) Browns Ferry [[ ]] vs. BWR/4 Prototype PBLE02 On-Dryer Differential Pressure Comparison

Using Browns Ferry Unit 1 CLTP and the BWR/4 prototype Original Licensed Thermal Power (OLTP) [[ ]] The loads are calculated on [[ ]] on the steam dryer (Figure 4.1-8).

4.1.7.4.1 [[ ]]

Figure 4.1-53 presents Browns Ferry [[ ]] and the BWR/4 prototype PBLE02 [[ ]] PSD comparison. The comparison is based on the PSD [[ ]] on the steam dryer. The PSD represents [[ ]].

As seen in Figure 4.1-53, the two plants have similar frequency content. Overall, [[ ]] The highest peak in the frequency spectrum is at [[ ]] (dead-leg), [[ ]]

[[ ]]

Figure 4.1-53: [[ ]]

4.1.7.4.2 [[ ]]

Figure 4.1-54 presents Browns Ferry [[ ]] and the BWR/4 prototype PBLE02 [[ ]] comparison, which represent the [[ ]]. The comparison is based on [[ ]] points on the steam dryer. The pressure loads represent the means of [[ ]]

[[ ]]

[[ ]]

Figure 4.1-54: [[ ]]

4.1.7.4.3 [[ ]]

Figure 4.1-55 presents Browns Ferry [[ ]] and the BWR/4 prototype PBLE02 [[ ]] comparison. The comparison is based on the PSD [[ ]] The pressure load represents the mean of [[ ]].

[[ ]].

[[ ]]

Figure 4.1-55: [[

]]

d) Browns Ferry [[ ]] vs. BWR/4 Prototype Loads Comparison Conclusion

There are strong similarities between Browns Ferry and BWR/4 Prototype plants in their:

[[

]]

4.1.8 Comparison of Browns Ferry Projected Loads with Industry Data

This section presents a review of the limiting Browns Ferry loads with the available industry data. The key purpose of this section is to compare steam dryer loads from other plants and demonstrate the validity of the synthesized SRV loads in the loads definition. Industry data from the BWR/4 prototype plant, [[ ]] plant with similar steam dryer design and a [[ ]] steam dryer plant with strong SRV resonance content is used in the differential pressure PSD comparisons that follow. These comparisons demonstrate that the Browns Ferry SRV resonance load is reasonable design load for RSD EPU evaluation.

The previous sub-sections within this report have described the process to develop the limiting Browns Ferry steam dryer loads. This includes scaling acoustic data to EPU projected steam flow rates and adding synthesized signals for observed and potential SRV resonance at: [[ ]]. These SRV resonance frequencies are observed in Browns Ferry test data, and the signal amplitudes at these frequencies are expected to [[ ]].

The steam dryer loads from all the four plants are developed [[ ]] The comparison plots of the Browns Ferry projected loads with industry data from 3 plants are presented in Figure 4.1-56 and Figure 4.1-57 [[ ]] steam dryer [[ ]] respectively. [[ ]]

The Browns Ferry loads used in these comparisons are the projected loads at EPU condition used in the stress evaluation of the RSD. [[ ]] (Sections 4.1.4 and 4.1.6). The next sections briefly discuss each of the industry plants.

4.1.8.1 Comparison with BWR/4 Prototype Steam Dryer Plant Data:

The BWR/4 prototype plant has operated at EPU and has obtained [[ ]] at a steam velocity approximately [[ ]] of the Browns Ferry at EPU.

The BWR/4 prototype plant loads used in these comparisons are the projected loads at full EPU condition. The loads are developed using [[ ]]

In general, the BWR/4 prototype and Browns Ferry steam dryer loads have similar frequency content. The maximum peak load in the BWR/4 prototype is at [[ ]]

The BWR/4 prototype SRV resonance [[ ]] about [[ ]] at EPU condition. The Browns Ferry maximum acoustic load amplitude over the full spectrum is at the [[ ]]

The [[ ]] Thus, the potential effect of the VPF peak will be captured during FEA when [[ ]].

4.1.8.2 Comparison with [[ ]] Steam Dryer Plant Data:

The [[ ]] design was also installed in a [[ ]] plant. That plant with a similar RSD design has operated at EPU and has obtained [[ ]] at a steam velocity equivalent to Browns Ferry at EPU.

The [[ ]] plant loads are the projected loads at EPU condition. The loads are developed using [[ ]]

The Browns Ferry design load at SRV resonance is compared to the [[ ]] SRV resonance peaks at approximately [[ ]]. Although the Browns Ferry data does not specifically include a peak at these frequencies, the comparison of the synthesized Browns Ferry SRV load at [[ ]] vs. [[ ]] resonances shows that the synthesized load is roughly the same overall amplitude as the SRV resonance loads for [[ ]] with [[ ]]

The [[ ]] load content is dominated by the Browns Ferry [[ ]] The amplitude of the [[ ]] is much [[ ]]

4.1.8.3 Comparison with [[ ]] Steam Dryer Plant Data:

As discussed in Section 4.1.4, the [[ ]] resonance is the most appropriate SRV acoustic resonance load to use in synthesizing the Browns Ferry SRV resonance loads because both are first shear layer mode resonances. In addition, the [[ ]] plant experienced [[ ]] SRV resonance at about [[ ]]. The [[ ]] SRV resonance load measurements from the [[ ]] steam dryer are used for developing the design SRV resonance load amplitude at [[ ]] for the Browns Ferry acoustic load definition (Section 4.1.4).

The [[ ]] plant loads used in these comparisons are the projected loads at a MSL flow velocity equivalent to the Browns Ferry at EPU condition ([[ ]]). The equivalent [[ ]] is the one used in the development of Browns Ferry SRV amplitude at [[ ]]. The [[ ]] loads are adjusted [[ ]]

In general, the Browns Ferry loads have [[ ]]

[[

]]

The comparison plots demonstrate the reasonableness of the simulated SRV resonant load in comparison with the BWR/3 maximum response.

4.1.8.4 Summary of Browns Ferry Loads to Industry

In summary, the loads comparisons show that the projected Browns Ferry loading at EPU is consistent with the steam dryer loads for the BWR/4 prototype, [[ ]] plants at the similar MSL flow velocity. This provides an overall confirmation that the Browns Ferry design loads are reasonable. The comparisons also show that the Browns Ferry synthesized SRV resonance load at [[ ]] is a reasonable design load.

[[ ]]

Figure 4.1-56: Browns Ferry [[ ]] **PSD Loads to Industry Data Comparison** [[ ]]

[[ ]]

Figure 4.1-57: Browns Ferry [[ ]] **PSD Loads to Industry Data Comparison** [[ ]]

4.2 Steam Dryer High Cycle Fatigue Stress Analysis

A typical steam dryer has been described in Section 3.0 above. The various components of the steam dryer (e.g., hoods, plates, skirt) are included in the full steam dryer FEM and are described later in this section. The commercial finite element software ANSYS 14.0 is used for the dynamic analysis. A flow diagram showing the FIV High Cycle Fatigue (HCF) analysis algorithm is provided as Figure 4.2-1.

[[ ]]

Figure 4.2-1: FIV Fatigue Analysis Process

4.2.1 Steam Dryer Finite Element Model

The FEM for the Browns Ferry RSD is based on the BWR/4 prototype steam dryer model. The Browns Ferry RSD FE "global" model is shown in Figure 4.2-2. Nominal dimensions are used at all locations. The global FEM includes all the structurally significant components of the steam dryer. The Browns Ferry replacement dryer FEM incorporates all of the steam dryer design modifications and structural improvements from Sections 3.2.1 and 3.2.2.

[[ ]]

Figure 4.2-2: Browns Ferry Replacement Steam Dryer Finite Element Model

4.2.1.1 Steam Dryer FE Model Components

The entire steam dryer is broken into components for ease of navigation and to facilitate the stress scoping process. Table 4.2-1 provides a listing of all the stress scoping components. In essence, all of the like parts of the steam dryer assembly are grouped into a specific component to facilitate post processing.

Table 4.2-1: Steam Dryer Stress Scoping Groups

GRP #	Description	GRP #	Description
[[		[[	
			]]
	]]		

*Indicates component contained internal to the lower ring splice FE models.

4.2.1.2 Finite Element Model Properties

The RSD design is primarily comprised of stainless steel plates formed and welded together. Because in most regions the plate thicknesses are much smaller than the surface dimensions, the FEM of the RSD is well represented using shell elements.

4.2.1.2.1 Element Types

The element selection follows the element description in Section 5.1.1 of Appendix A. The FEM of the RSD contains [[ ]] element type is used. [[ ]] In the Browns Ferry RSD FEM, [[ ]] elements are used where the local base plate is connected to support ring area, where the local inner hood is connected to outlet end plate area, and where the drain channel support beams are connected to the skirt and drain channel. In these locations, [[ ]]. Additional element types include the [[ ]] element type used for trough spacers and the tie rods located inside the vane modules, the [[ ]] element type used to represent the steam dryer bracket interface locations and also used as a mechanism to establish vanes-to-top cap connections; and the [[ ]] element type used for the support ring, lifting rods and tie bar ends. In addition to the [[ ]] are used to model the details of the lower ring splices (discussed further in Section 4.2.1.3.2). [[ ]] are also used to provide a mass and stiffness representation of the vane bundles inside the steam dryer banks.

4.2.1.2.2 Material Properties

The RSD FEM consists of two main materials, [[ ]]. Additional material properties are defined for the perforated plate shell elements and imbedded moment transfer shell elements as discussed below.

Temperature dependent material properties are input for the stainless steel parts so that analyses other than operating temperature can be performed without modifying the FEM. Material Group G of Table TM-1 from the ASME BPVC Code, Section II, Part D (Reference 5) is used. [[ ]] This material is used for a vast majority of the structural FEM.

The water surrounding the skirt and drain channels contain a large number of [[ ]] rising from the reactor core and steam separators. The properties of the [[ ]] are calculated using equations defined in the process discussed in Section 5.1.3 of Appendix A. [[ ]]

Shell elements are used in some places to tie the structural shell moments to the solid support ring element's nodes (discussed further in Section 4.2.1.6.1). For these elements, [[ ]]

The vane bundles are enclosed by perforated plates on each side. The small holes in the perforated plates distribute the steam uniformly over the height of the vane bank. A typical perforated plate for the RSD design is shown for an inlet panel in Figure 4.2-3. A large perforated plate attached to one side of a steam dryer bank consists of multiple regions with different hole spacing and/or hole diameters resulting in a different volume fraction of the holes in these regions. [[

]]

[[ ]]

Figure 4.2-3: Typical Perforated Plate Design for Center Bank Inlet

[[ ]]

Figure 4.2-4: Typical Perforated Plate Design for Center Bank Inlet

4.2.1.3 Substructuring

Substructuring is a method to model a part of a larger model in more detail without adding a large number of degrees of freedom (DOFs) to the global FEM. In ANSYS, this is accomplished by generating so-called superelements ([[ ]]). For the Browns Ferry RSD structural FEM, [[ ]]

4.2.1.3.1 Vane Bundle Superelements

An overall description of the steam dryer vane bank is provided in Section 5.1.2 of Appendix A. The mass, stiffness and damping distributions of the numerous vanes are modeled to account for their inertia and stiffness effect on the steam dryer in the FIV analysis. The vane bundles represent components that need to be supported within the steam dryer structure, but they do not bear loads like the other steam dryer structural components. Furthermore, millions of elements would be required if the vane bundles were to be explicitly modeled in detail. The resulting FEM would be too large to be practical. Therefore, the modeling of the vane bundles is simplified in the global FEM. [[ ]]

A vane bundle is a collection of vanes, hooks, and tie rods between end plates and divider plates. There are a total of 22 vane bundles in the Browns Ferry RSD. Figure 4.2-5 shows the vane bundle positioning. The modeling of each of the vane bundles is described in more detail in Section 5.1.2 of Appendix A.

[[ ]] the same as the RSD. The density of the material was used to adjust the weight of the individual vane bundles to the known vane bundle design weight.

Master DOFs are defined at interface locations where, per the hardware design, certain vane bundle nodes in a superelement are interfacing with corresponding nodes of steam dryer components that are in the global model. These master DOFs are known as external master nodes.

In addition to the external master DOFs, internal nodes are also defined as master DOFs Internal master DOFs, are defined in the vane bundle models to properly capture the structure's dynamic behavior. The internal master DOFs are chosen to be consistent with the BWR/4 prototype steam dryer analysis benchmark FEM. Figure 4.2-6 shows the shell-dominant FEM of a vane bundle illustrating the interface points and master DOF setup.

A super-element generation pass creates the vane bundle super-element files from the detailed vane bundle models. The super-element files condense the ordinary DOFs from the regular ANSYS mesh into a stiffness, mass, and damping matrix relating the master DOFs to one another for each vane bundle. These [[
]].

[[ ]]

Figure 4.2-5: Top View of Steam Dryer FEM showing the Vane Bundle Designations

[[ ]]

Figure 4.2-6: Typical Vane Bundle FEM and Master DOF Setup

4.2.1.3.2 Lower Skirt Ring Splice Superelements

When designing [[ ]] The Browns Ferry RSD lower skirt ring design requires four splices, two at 0^O and 180^O azimuths and two at 94^O and 274^O azimuths. The 0^O and 180^O lower ring splices serve two purposes, [[ ]]

Stress predictions within the vane bundle superelements are not needed in the overall steam dryer structural evaluation; in contrast, the stress output within the lower ring splice superelements are required (these elements bear loads within the structure). Therefore, the lower ring splice meshes are well refined as is seen in Figure 4.2-7. The [[ ]] functions greatly enhancing the accuracy of the stress predictions from them.

The shell elements that interface with the global model are attached to the solid splice mesh using [[ ]] (discussed further in Section 4.2.1.6.3).

As with the vane bundle superelement FEMs, Master nodes are defined so that the lower support ring splice FEMs interface with the Global FEM correctly. Figure 4.2-8 provides an illustration of the master node selection for the lower ring splice superelements. Unlike the vane bundle models, the lower ring splice models have only external master nodes because the distribution of the external master nodes is adequate for resolution of the dynamic mode shapes as is evident in Figure 4.2-8.

Stress scoping is performed via an expansion pass. The expansion pass uses the reduced solution to calculate the results at all degrees of freedom within the superelement model. Once the results are expanded, the remainder of the stress scoping process is identical to the global model (see Section 4.2.3.4).

[[ ]]

Figure 4.2-7: Views of the Splices for the Lower Support Ring Superelement FEMs

[[ ]]

Figure 4.2-8: Lower Skirt Ring Splice Superelement Master Nodes (0^{O} and 180^{O} splices on top and 94^{O} and 274^{O} splices on Bottom)

4.2.1.4 Water Modeling

The skirt and drain channel of the steam dryer are partially submerged in the [[ ]] water. In order to treat this interface and for the fluid structure interaction in submerged regions, the fluid is modeled with [[ ]]. The water volume is contained on the outside diameter by the RPV wall and on the inside by the steam separators. The bottom is selected well below the steam dryer lower skirt ring. The fluid elements represent the thermodynamic properties of the steam water mixture.

As mentioned above, [[ ]] as described in section 5.1.3 of Appendix A. The inside and outside water levels are determined by a steam dryer hydraulic performance calculation. [[ ]] that is submerged. [[ ]] transmit the water resistance against the structural vibration [[ ]]

Figure 4.2-9 shows the instantaneous deflection of the water due to a lateral translation of the steam dryer FEM using a static analysis. The plot shows that the water behaves correctly as the various compartments (i.e., the water between the skirt and steam separators, the water within the drain channels, and the water outside the skirt and drain channels) interact with the steam dryer metal and deform as expected. (e.g., if the distance between the skirt and the RPV wall (modeled as displacement boundary conditions) is decreased, the water height increases due to an instantaneous deflection).

[[ ]]

Figure 4.2-9: An Illustration of the Water Modeling Due to Lateral Translation of the FEM

4.2.1.5 Element Mesh Density

The Browns Ferry RSD model element mesh density is consistent with the BWR/4 prototype FEM. This ensures that the benchmark analysis results are derived on the same basis as the current Browns Ferry RSD analysis. However, a separate mesh refinement study was performed on the RSD FEM to determine appropriate mesh bias factors as discussed in Section 4.2.2.

4.2.1.6 Connections between Shell Nodes-to-Solid Nodes

When 3D shell finite elements interface with 3D solid finite elements, a degree of freedom mismatch exists at the nodal interface. The shell element nodes possess six degrees of freedom (X, Y, and Z translations and rotations), and the solid element nodes possess only three (X, Y, and Z translations only). Without a method to account for this mismatch, a hinge would be produced. GEH recognizes three acceptable methods to tie the shell nodal rotations to the solid element nodes: [[

]] All methods are used in the Browns Ferry RSD FEM and are discussed further below.

4.2.1.6.1 [[ ]]

[[

]]

[[ ]]

Figure 4.2-10: [[

]]

4.2.1.6.2 [[ ]]

[[

]]

[[ ]]

Figure 4.2-11: [[ ]]

4.2.1.6.3 [[ ]]

[[

]]

[[ ]]

Figure 4.2-12: [[ ]]

4.2.1.7 Boundary Constraints

The steam dryer is held in place within the RPV by steam dryer support brackets that are steel blocks (lugs) that are welded to the RPV wall. These steam dryer support brackets are located nominally at 4^{O}, 94^{O}, 184^{O}, and 274^{O} azimuths. [[ ]] The 4^{O} and 184^{O} locations utilize seismic blocks that straddle the brackets constraining [[ ]] The lateral motion at the 94^{O} and 274^{O} [[ ]]

The steam dryer FEM is constructed such that four nodes are placed at the steam dryer interface location with the brackets. [[ ]]

The additional boundary constraints are applied to the water elements as described above in Section 4.2.1.4.

[[ ]]

Figure 4.2-13: Support Ring Boundary Constraints

4.2.2 Mesh Convergence Studies

The objective of the Browns Ferry convergence study was to evaluate the Browns Ferry FEM and determine an appropriate convergence factor for use in the final stress adjustment. The convergence factor adjusts global FIV analysis stresses for trends in stress as the FEM mesh size is decreased. The evaluation focused on high stress components from both the FEA primary stress evaluation and the final adjusted stress calculation. [[

]] An example submodel can be reviewed in Figure 4.2-14.

[[ ]]

Figure 4.2-14: Example sub model; ([[ ]])

Simulated FIV loading was applied through displacement boundary conditions or surface pressure as necessary to reproduce stress contours from the global FIV analysis. Stress values were extracted at locations of high stress. See Figure 4.2-15 for a comparison of stress contours from the hood tee submodel simulated FIV pressure loading and the global FIV analysis.

[[ ]]

Figure 4.2-15: Stress Contour Comparison of [[ ]]
(Left) Convergence Study Sub model –Stress Contour
(Right) Global FIV Analysis - Maximum Stress

The magnitude of stress in the submodel, shown in Figure 4.2-15, [[

]] See an example of trending stress values in Figure 4.2-16.

[[ ]]

Figure 4.2-16: Convergence Stress Trending

The maximum calculated convergence factor from the Browns Ferry FEM submodels was [[ ]] A summary of calculated convergence factors can be reviewed in Table 4.2-2.

Table 4.2-2: Calculated Mesh Convergence Factor by Component

[[		
		]]

An additional qualitative evaluation was performed [[

]]

4.2.3 Vibration Analysis Approach

This section describes the process used to perform the FIV structural analysis. The commercial finite element software ANSYS is used in the solution. For the flow-induced vibration of steam dryers, [[

]]

Displacement boundary conditions are applied to the steam dryer mount point locations in the steam dryer model at the steam dryer support brackets as discussed in Section 4.2.1.7. Displacement boundary conditions are also used to contain the fluid as discussed in Section 4.2.1.4. The support ring rests on four steam dryer support brackets that are welded attachments to the RPV wall. The motion of the steam dryer in the [[

]]

The acoustic loads and boundary conditions are mapped onto the steam dryer mesh for each time step of the acoustic load set generating [[ ]]. This process is known as load step mapping. Once the pressure loads are mapped onto the steam dryer, [[

]] The solution is processed [[ ]] After solution processing is completed, the FEA results are screened for the maximum stress intensity for each steam dryer component (see Table 4.2-1) by a peak-hold scoping process as discussed in Section 4.2.3.4. The stress maxima determine the steam dryer locations that are further processed with B&U to determine the final stress intensity for each steam dryer component. The further processing includes performing FFT calculations, applying appropriate Fatigue Strength Reduction Factors (FSRF) as discussed in Section 4.2.3.5, and applying [[ ]] trending and B&U multipliers to the stresses as discussed in Section 4.2.5.

4.2.3.1 Damping

[[ ]] damping is used in all of the analyses. [[ ]]. Then, using Equation 6.1-3 of Appendix A, [[ ]] are calculated for input into the structural analysis. Figure 4.2-17 represents [[ ]] analyses for the steam dryer FEA.

[[ ]]

Figure 4.2-17: [[ ]]

4.2.3.2 Uncertainty in Structural Modes

There is an uncertainty in the predicted structural mode frequencies and dynamic response of steam dryers because of the approximations in the structural model and variations in the as-built steam dryer as compared to the nominal design dimensions (Section 6.3 of Appendix A).

The modal uncertainty in the structural FEM is addressed [[ ]]. This is accomplished by [[

]] In addition to the nominal load case, [[ ]].

4.2.3.3 Acoustic Load Mapping

The load mapping process generates the load step files for solution processing. While the acoustic mesh is refined enough to adequately resolves the acoustic modes, it is much coarser then the structural FEM mesh. Using ANSYS internal matrix mapping functions and other ANSYS Parametric Design Language (APDL) algorithms, the differential pressure time history output from PBLE is converted to forces that are applied to the nodes that experience this pressure loading. The acoustic load surfaces encompass all of the structure above the water line [[ ]] Figure 4.2-18 shows pressure contour plots for the same load step for the acoustic FEM (left) and the structural FEM (right). These contour plots show that the loads are correctly mapped onto the structural FEM.

[[

]]

[[ ]]

Figure 4.2-18: Pressure Load Mapping for [[ ]] **Load Step**

4.2.3.4 Stress Scoping

After processing the transient solution, the results are screened for the [[ ]] This process is known as results scoping. In general, APDL algorithms are written with [[ ]] and other pertinent information at the [[ ]]

In ANSYS, multiple stress values are output at a given node. The stress scoping [[ ]]

4.2.3.4.1 Primary Scoping

The primary scoping process is straightforward. This process extracts the [[ ]] After looping through all of the time steps, [[ ]] The resulting data is output to text files [[ ]]

4.2.3.4.2 Weld Scoping

Unlike the primary scoping process, the weld scoping process [[ ]] as discussed in Section 4.2.3.5.

Like the primary scoping that was described in Section 4.2.3.4, [[ ]] All elements from the FEM that are bordering on the weld lines are identified. Each weld location may join together two or more different steam dryer components. The results are scoped for the [[ ]] in the initial fatigue assessment process discussed in Section 4.2.3.7.

4.2.3.5 Fatigue Strength Reduction Factors (FSRF)

The FSRF is a key component of the peak stress calculation at a specific location, namely the weld locations. In general, welds are relatively small compared to plates in the steam dryer and are not explicitly modeled in the global steam dryer FEM due to the plate construction. The welded connections are located where plates come together in the global FEM, [[ ]]. Stress concentrations due to welds are handled [[ ]]. The weld types of relevance for the steam dryer stress analysis [[ ]] Figure 4.2-1 of Appendix A shows the flow diagram for the calculation of fatigue stress with appropriate FSRFs.

[[

]]

4.2.3.5.1 Weld Quality Factor

[[ ]], as well as the use of qualified weld processes [[ ]], are used [[ ]] for new steam dryer analyses (Section 4.3 of Appendix A).

4.2.3.6 Plate Thickness Factors

The plate thickness factor (PTF) is applied to the stress at locations where the FEM lacks resolution to provide a detailed representation of the weld connection thickness. For instance, [[

]]

4.2.3.7 Initial Fatigue Assessment

In performing the fatigue evaluation for steam dryers under FIV loading, the maximum calculated stress intensity for each steam dryer component is determined as discussed in Section 4.2.3.4 for the primary and weld scoping. For the weld scoping stress intensities, the appropriate FSRF and/or PTF is applied as discussed in Sections 4.2.3.5 and 4.2.3.6. [[

]]

Table 4.2-3 and Table 4.2-4 [[

]] as discussed in Section 4.2.5 below.

Table 4.2-3: Raw Stress Table [[ ]]

[[																		
																		]]

[[																		
																		]]

[[

]]

Table 4.2-4: Raw Stress Table [[ ]]

[[																		
																		]]

[[																		
																		]]

[[

]]

4.2.4 Browns Ferry Replacement Steam Dryer Functional RPV Interface Attachments

The Browns Ferry RSD is attached to the RPV at four locations. As discussed in Section 4.2.1.7, [[ ]] Therefore, the analyses for these connections are performed separately, but in conjunction with the global model analyses.

Two distinct attachment designs are used in the Browns Ferry RSD design; seismic blocks and jack bolt/latch mechanisms. The following sections discuss these designs as well as associated qualification criteria for FIV fatigue and primary stress analyses.

4.2.4.1 Attachment Point Forces

The scoping components [[ ]] For the FIV fatigue analysis, [[ ]] Therefore, using the raw and adjusted stress information, the maximum fatigue forces are scaled to include the EPU factors as well as all applicable bias and uncertainties.

The reaction forces at the attachment locations for determining the seismic block and jack bolt/latch primary stresses are extracted in steam dryer design primary stress analyses discussed in Section 5.0. The primary membrane, bending, and shear stresses are calculated using these extracted reaction forces and then combined per Browns Ferry RSD load combinations described in Section 5.0. A summary of stress and fatigue values as compared to applicable limits is provided in Section 4.2.4.4.

4.2.4.2 Seismic Block Design and Analysis

Similar to the BWR/4 prototype RSD, the Browns Ferry RSD seismic blocks [[ ]] of the steam dryer at the 4 and 184 azimuth locations. Unlike the BWR/4 prototype design, [[ ]] Section 3.2.2.2. In addition, the weld length [[ ]] Figure 4.2-19 is an illustration of the seismic block design.

The seismic block is comprised of type 316 stainless steel. The modification of material in the design increases ultimate strength from 57,400 psi for 304L stainless steel to 71,800 psi for 316 stainless steel and results in proportional increases to certain faulted condition stress limit (i.e. average shear stress). A comparison of design stress intensity, Sm, yield strength, Sy, and ultimate strength, Su, for type 304L and type 316 stainless steel is shown in Table 5.1-1.

[[ ]]

Figure 4.2-19: Seismic Block Design

The capability of the seismic block design to withstand the FIV loads is evaluated by performing the stress analysis using closed form solution methods for the extracted reaction forces at the attachment locations from the global model. Calculations are performed at the top of the seismic block ear (i.e., smallest cross section) in addition to calculating the fatigue stress in the weld. The nominal stress in the weld [[ ]] as discussed in Section 4.2.3.5 to obtain the peak fatigue stress. The final peak alternating stress intensity for EPU is [[ ]] as shown in Table 4.2-6.

Primary membrane, bending, and shear stresses are calculated for the steam dryer service level load combinations (see Table 5.1-3) using a closed form solution (i.e., the applicable mechanics formula). As shown in Table 4.2-5 the most limiting normal or upset service level load combination is B-3 (operating basis earthquake load combination). The calculated primary membrane plus bending stress intensity is [[ ]]. The most limiting seismic block stress for the emergency service level [[ ]].

The most limiting stress for the faulted service level occurs in the D5 load case. The seismic block ear is loaded in shear for which the allowable stress is [[ ]]. The average shear on the seismic block ear for the D5 load case is [[ ]].

4.2.4.3 Jack Bolt and Latch Mechanism Design and Analysis

The jack bolt and latch mechanism is a functional modification to the prototype steam dryer design at the 94 and 274 azimuth locations. This assembly (illustration shown in Figure 4.2-20) performs three functions, balancing the steam dryer dead weight load, holding down the steam dryer from lifting off the brackets (a redundant feature considering the hold downs), and impeding lateral motion.

[[ ]]

Figure 4.2-20: Jack Bolt and Latch Mechanism Design

The jack bolt part of the assembly is used to balance the steam dryer dead weight load during installation. The jack bolt levelling procedure is also intended to prevent motion (i.e. rocking) during operation. The installation specification designates an installation torque such that each jack bolt carries [[
]] The steam dryer will therefore maintain contact with each steam dryer support bracket under normal operation and prevent steam dryer rocking. The latch mechanism serves as the function of steam dryer hold down during faulted events whereby the upward lifting pressure load overcomes the steam dryer dead weight load. This function was previously performed by lifting rods interfacing with hold down brackets in the reactor vessel head. [[

]]

The latch mechanism also serves the same function as the seismic blocks. The lateral motion at the 94 and 274 azimuth locations [[ ]]

The jack bolt and latch mechanism are comprised of [[ ]] The allowable stress differs from the 304L stainless steel. [[ ]]

As with the seismic blocks, the stress analysis is performed using closed form solution methods considering the reaction forces calculated in the global FEA. In the FEA the appropriate boundary condition due to uplift scenarios at the seismic blocks/latch/jack bolts are appropriately considered. The jack bolt and latch mechanism is purely mechanical (i.e., no welds); therefore, FSRFs do not apply. However, for the FIV fatigue analysis, [[ ]] is applied at the thread root in accordance with ASME BPVC Code, Section II, Part D (Reference 5). [[ ]] Therefore, the jack bolt/latch mechanism assembly exceeds the recommended FIV MASR of 2.0.

Primary stress calculations are performed on the jack bolt and latch mechanism for all primary stress load combinations (see Table 5.1-3) at multiple locations within the assembly using closed form solution and forces as discussed in Section 4.2.4.1. In addition to the primary stress intensities, thread shear and bearing stresses were also calculated. The most limiting normal or upset service level load combination is B-3 (operating based earthquake). [[ ]]

The calculated primary membrane plus bending stress intensity is [[ ]] which is less than the allowable [[ ]] For the support ring thread, the most limiting normal or upset service level load combination is B-3 with the shear stress of [[ ]]. Relative thermal expansion of the jack bolt with the stainless steel ring was considered in the evaluation. The limiting stress intensity due to combined mechanical and thermal loading is [[ ]] Relative thermal expansion of the jack bolt and support ring slip fit is in the range of the slip fit tolerance. Therefore, the jack bolt/latch mechanism is suitable for service based on the requirements of ASME BPVC Code, Section III (Reference 6).

4.2.4.4 Seismic Block, Jack Bolt and Latch Stress and Fatigue Summary

A summary of critical stress and fatigue values for the attachment point components are provided in Table 4.2-5 and Table 4.2-6. These values consider basic stress limits, special stress limits, and stress limits for threaded structural fasteners as applicable.

Table 4.2-5: Attachment Point Component Stress Summary

[[						

						]]

Table 4.2-6: Attachment Point Component Fatigue Summary

[[			
			]]

4.2.5 Bias and Uncertainty Adjustment to Stresses

The final stress adjustment is the process for converting the raw stresses as calculated based on [[ ]] Note that the [[ ]] For the initial calculations in this report before the power ascension, [[ ]] This same process is utilized for both the application Browns Ferry and the benchmark plant used to get the [[ ]] B&U (note that the benchmark stress adjustment only accounted for the EPU projection and did not attempt to correct for bias or uncertainty, as this is the process to determine those quantities).

As stated previously, the raw stress table has the peak vibratory [[ ]] stress for each component and weld based on FIV results and weld factor. The final stress adjustment starts with these raw stress values and then accounts for terms listed in Table 4.2-7. The more detailed overview of the process is shown in Figure 4.2-21, which is very similar to the process for the benchmark (see Figure 4.2-22), with obvious elimination of the later part of the process for comparing projections to measurements. In this portion of the process for final application stress adjustment, as previously stated, the B&U terms calculated in the benchmark are utilized to adjust the peak stress values using [[ ]] methodology as detailed in Appendix A Section 6.3.

Table 4.2-7: Final Stress Adjustment Terms

Term Name	How it is applied
[[	
	]]

[[ ]]

Figure 4.2-21: Overview of Final Stress Adjustment Process

As can be seen in Figure 4.2-21 and Table 4.2-7 a number of terms are applied to the final peak stress value for each component and weld in order to account for known B&U, as well as other items such as anticipated SRV resonances or other impacts anticipated for EPU from items such as higher steam velocities. The bias terms and stress factors are applied as [[

]]

ANSYS predicted sensor response can be developed in the same way as the stress [[ ]] The predicted sensor response can then be compared to measured sensor response per Figure 4.2-22 to develop [[ ]] B&U values. These results can then be used for the application case to project pre-EPU data to any number of other conditions.

The design calculation will be run at EPU with the [[ ]] SRV resonance at peak measured value and the [[ ]] SRV resonance at peak predicted value.

4.2.5.1 [[ ]] Benchmark Bias and Uncertainty

The [[ ]] B&U that is utilized to account for steam dryer analysis B&U for application to the Browns Ferry RSD was developed by performing a benchmark analysis on a similar plant (BWR/4 prototype) to the Browns Ferry design to capture the overall B&U of the analysis process. This includes using the same process for developing pre-EPU equivalent loads and projecting them to EPU conditions. This approach captures the combined impact of acoustic modeling and structural modeling accuracy, as well as addressing other measurement related bias and uncertainties, including instrument uncertainty. This comparison considers a plant very similar to the application plant in order to best capture the inherent modeling bias and uncertainties associated with modeling that plant type's basic geometry under comparable loading. This process compares strain predictions to on-dryer strain measurements at the highest projected power level available.

[[

]]

4.2.5.2 Benchmark Case

The benchmark plant that was utilized to develop [[ ]] B&U values to be applied to the Browns Ferry steam dryer analysis is very close in design to the Browns Ferry plant; both units are BWR/4 Designs with 251-inch vessel diameters. In addition, the benchmark plant was analyzed for similar operational conditions and projections were made over the same general percentage power increase (see Section 4.1.7.4 for a discussion of the full comparison).

Due to the similarities in the overall steam dryer geometry, acoustic FRFs, loads and plant operational parameters (See Section 4.1.7), the prediction for Browns Ferry is expected to be consistent with the benchmark utilized to develop the [[ ]] B&U. It follows that the biases and uncertainties based on the benchmarks are applicable to Browns Ferry.

As can be seen in Figure 4.1-53, the Browns Ferry and benchmark plant are very similar in most regards. In addition, Figure 4.1-52 shows, as would be expected due to similarities in the piping systems, that the signal content for the MSL strain gauge data is similar for CLTP conditions for both Browns Ferry and the benchmark plant.

4.2.5.3 Benchmark Process

Figure 4.2-22 below presents the process for calculating the [[ ]] B&U. The benchmark utilizes a high level process that is very similar to that outlined above in Figure 4.2-21. As previously stated, the intent is to follow exactly the same process for the benchmark case as the application. This will allow a full characterization of the process to predict stress/strain on a frequency basis.

[[ ]]

Figure 4.2-22: Basic Outline for Benchmark [[ ]] **Bias and Uncertainty Process**

As can be seen, the basic benchmark process involves processing pre-EPU [[ ]] (the goal is for benchmark power increase to match that of baseline application) exactly like the pre-EPU [[ ]] for the Browns Ferry application. [[

]]

4.2.5.4 Benchmark Results

The BWR/4 prototype benchmark results show that in general the [[ ]] projections for EPU conditions over-predict the strains when projections are compared to measured EPU on-dryer strains. Figure 4.2-23 and Figure 4.2-24 present the results for [[ ]] B&U over [[ ]]

[[ ]]

Figure 4.2-23: BWR/4 Prototype [[
]] **Bias and Uncertainty**

[[ ]]

Figure 4.2-24: BWR/4 Prototype [[ ]] **Bias and Uncertainty**

4.3 Acceptance Criteria

The steam dryer, including the steam dryer units, is a nonsafety-related item and is classified as an Internal Structure as defined in the ASME Boiler and Pressure Vessel Code, Section III (Reference 6), Subsection NG Paragraph NG-1122. The steam dryer is not a component governed by ASME Boiler and Pressure Vessel Code, Section III, however the design will comply with stress and fatigue criteria for core support structures defined in ASME Code Subsection NG-3000, [[ ]] as discussed in Subsection 4.2.3.5. The other exception to Subsection NG-3000 is that no temperature adjustment for the modulus of elasticity is performed when comparing the calculated alternating stress intensity against the fatigue acceptance criterion. This is discussed further in Section 4.1 of Appendix A.

Steam dryers are subjected to FIV caused by cyclic acoustic pressures during normal operation. They may experience on the order of 10^{11} stress cycles during a steam dryer's typical 40-60 year life span. Therefore, HCF contributes a majority of the steam dryer fatigue usage. The steam dryer FIV fatigue evaluation described in this section is consistent with the ASME BPVC Section III requirements. Other cyclic loads associated with normal and upset design events, including pressure, transient loads, and thermal cycling, have not been significant contributors to fatigue damage and with the heavier RSD are considered to add minimal fatigue usage. Therefore, the HCF life is the major design consideration.

The steam dryer structural analyses are performed assuming that the steam dryer will be operated for 40 to 60 years. The alternating stress intensity amplitudes caused by FIV are expected to be well within the elastic range during normal operation.

In performing the fatigue evaluation for steam dryers under FIV loading, the maximum stress intensity in each steam dryer component is found from the FIV stress analyses described in Section 4.2.3.7. The maximum stress intensities are then adjusted as necessary by the appropriate FSRFs defined in Section 4.2.3.5. In support of the Browns Ferry EPU project, the peak stress intensities are scaled to the projected power levels and flow rates using frequency dependent EPU trending factors. In addition, Section 4.2.5 discusses the biases and uncertainties and other factors incorporated into the results.

The design fatigue curves and curve selection criteria for Austenitic Ni-Cr stainless steel are given in the ASME BPVC Section III, Division 1, Appendix I, Figure I-9.2.2 and Figure I-9.2.3 (Reference 6). These figures provide curves that relate the allowable alternating stress amplitude to the number of fatigue cycles (a.k.a. S-N curves) for determining fatigue usage. The alternating stress limit is dependent on mean stress including primary, secondary, and residual stresses that are typically present near weld locations. Curve C is the most conservative of the three curves in Figure I-9.2.2 because it includes margin to accommodate the maximum allowable mean stress and may be used at or near the weld locations where higher residual stresses are typically present. In addition, Curve C is not dependent on the primary plus secondary stress range. [[
]]

The NRC recommendation for acceptance of a RSD component is that the maximum stress intensity amplitude be less than half of the allowable alternating stress intensity amplitude (Reference 7). Therefore, the acceptance criterion for the Browns Ferry RSD is half of the allowable alternating stress intensity amplitude, or 6,800 psi. GEH calculates the MASR as:

$$\boldsymbol{MASR = \frac{13{,}600\ psi}{Peak\ Stress\ Intensity\ Amplitude}} \qquad \textbf{Equation 4.3-1}$$

For each unique steam dryer component in Table 4.2-1, a final ASR is calculated. The RSD MASR is defined as the lowest ASR value of all the listed steam dryer components, refer to Table 4.4-1. The NRC recommendation guidance on acceptance criteria when evaluating all RSD components for power uprate is a MASR of 2.0 in accordance with Reference 1.

4.4 Flow Induced Vibration (FIV) Stress Intensity Results

Final FIV stress results at EPU, including B&U and non-acoustic loads (i.e., core flow and VPF) is provided as Table 4.4-1. The predicted ASR is greater than 2.0 for all components at EPU plant conditions [[

]]. Therefore, based on the acceptance criteria discussed in Section 4.3, the Browns Ferry RSD is acceptable for EPU operation.

Table 4.4-1: Browns Ferry Replacement Steam Dryer Final FIV Peak Stress Table for the Projected EPU Condition

STEAM DRYER COMPONENT	EPU	
	Peak Alternating Stress Intensity (psi)	Alternating Stress Ratio (ASR)
[[		

STEAM DRYER COMPONENT	EPU	
	Peak Alternating Stress Intensity (psi)	Alternating Stress Ratio (ASR)
		]]

5.0 BROWNS FERRY NUCLEAR PLANT RSD PRIMARY STRESS EVALUATION

The steam dryer is a nonsafety-related component and performs no active safety function; however, the steam dryer must maintain structural integrity during normal, transient and accident conditions and not generate loose parts that may interfere with the operation of safety systems. Section 4 of this report describes the fatigue evaluation and demonstrates that the steam dryer alternating stresses are sufficiently low to preclude the initiation of high cycle fatigue cracking during normal plant operation under EPU condition. This section provides the primary structural stress assessment under the design load combinations for all steam dryer components excluding seismic blocks and jack bolts/latches during Normal (Service Level A), Upset (Service Level B), Emergency (Service Level C), and Faulted (Service Level D) conditions at EPU power level. The analysis and results for seismic blocks and jack bolts/latches are discussed in Section 4.2.4. The primary structural stress assessment under the design load combinations and demonstrates that the steam dryer will maintain structural integrity during all modes of operation.

5.1 Design Criteria

The steam dryer, including the steam dryer units, is a nonsafety-related item and is classified as an Internal Structure as defined in the ASME Boiler and Pressure Vessel Code, Section III (Reference 6), Subsection NG Paragraph NG-1122. The steam dryer is not a component governed by ASME Boiler and Pressure Vessel Code, Section III, however the design will comply with stress and fatigue criteria for core support structures defined in ASME Code Subsection NG-3000, [[ ]] as discussed in Subsection 4.2.3.5. The other exception to Subsection NG-3000 is that no temperature adjustment for the modulus of elasticity is performed when comparing the calculated alternating stress intensity against the fatigue acceptance criterion. This is discussed further in Section 4.1 of Appendix A.

5.1.1 Material Properties

The steam dryer assembly is designed to be manufactured of ASME SA-240 Type 304L Stainless Steel, with the exception of the Seismic Blocks, which are Type 316 Stainless Steel, as well as the Jack Bolts and Latch Mechanism, which are both X-750, conforming to the requirements of the material and fabrication specifications. ASME material properties from ASME BPVC Code, Section II, Part D (Reference 5) are used for the steam dryer design evaluation. The applicable properties are summarized in Table 5.1-1.

Table 5.1-1: Material Properties

[[				
				]]

5.1.2 ASME Code Stress Limits for Load Combinations

The ASME Code, Subsection NG stress limits for the steam dryer primary structural stress assessment are listed in Table 5.1-2. Stress limits for Service Levels A, B and C are according to NG-3220; and for Service Level D are in accordance with ASME Code Section III Appendix F, Paragraph F 1331.

Table 5.1-2: ASME Code Stress Limits for SA-240 Type 304L

			[[	
Service Level	**Stress Category**	**Stress Limit**		
Design and Service Levels A & B	P_m	S_m		
	P_m+P_b	1.5S_m		
Service Level C	P_m	1.5 S_m		
	P_m+P_b	2.25 S_m		
Service Level D	P_m	Min(.7S_u or 2.4 S_m)		
	P_l + P_b	1.5(Pm Allowable)		]]

[[

]]

Legend:

P_m: General primary membrane stress intensity

P_l: Local primary membrane stress intensity

P_b: Primary bending stress intensity

S_m: ASME Code stress intensity limit

S_u: Tensile strength

5.1.3 Design Load Combinations

The recommended design load combinations for replacement stream dryer primary stress evaluations for Mark I Plants are provided in Reference 8 and listed in Table 5.1-3. The load term definitions in Table 5.1-4 define the terms used in Table 5.1-3. For faulted (Service Level D) load conditions, the MSLB outside containment acoustic load ($MSLB_{A\ hot\ standby}$) and differential pressure load ($MSLB_{DP\ hot\ standby}$) under the hot standby condition may result in more limiting load combination compared to using those loads under interlock condition (low core power/high core flow). Therefore, two additional load combinations under the hot standby condition, DW + $MSLB_{DP\ hot\ standby}$ (D-4) and DW + $MSLB_{A\ hot\ standby}$ (D-5), are added into Table 5.1-3. These combinations are addressed in the GEH steam dryer evaluation process in addition to those in BWRVIP-181A (Reference 8). The load combination of DW + $MSLB_{DP2}$ is bounded by DW + $MSLB_{DP}$ for hot standby; therefore, only DW + $MSLB_{DP\ hot\ standby}$ is analyzed in the Browns Ferry steam dryer design load combination primary stress evaluation.

Table 5.1-3: Browns Ferry Replacement Steam Dryer Design Load Combinations

[[			
			]]

[[

]]

Table 5.1-4: [[ ]]

[[	
	]]

5.2 Analysis Approach

5.2.1 Browns Ferry Replacement Steam Dryer FEM

The FEM described in Section 4.2.1 is used for the Browns Ferry RSD primary structural stress assessment. [[

]]

5.2.2 Loads for Design Primary Stress Evaluation

5.2.2.1.1 Steady State, Upset Transient, Emergency and Faulted Condition Pressure Loads

The pressure differentials across the steam dryer are calculated for four categories of events: normal, upset, emergency and faulted conditions. Normal conditions correspond to the plant steady-state operating conditions. Upset conditions address anticipated transient events. Emergency conditions are within the reactor internals design basis and are defined by the rapid vessel depressurization via operation of the automatic depressurization system relief valves. Faulted conditions correspond to the design basis accident events (e.g., MSL break).

5.2.2.1.2 Normal and Upset DP_N & DP_U

The normal and upset differential pressure loads are determined based on the methods defined in Appendix A, Section 8.1.3.1.3. The static pressure is divided into two general regions, which are an outer hood region that includes the higher pressure drop of the nozzle region and the rest of the steam dryer region. The static pressure drop across the steam dryer outer hood is determined by the pressure drop through the vane banks plus the static pressure drop along the steam dryer hoods at the analyzed hood elevation. The differential pressure loads for the components (other than the steam dryer outer hood) are conservatively estimated to be the same as the pressure drop through all the vane banks. For perforated plates, an equivalent pressure drop is applied and estimated as:

[[

]]

The fractions of closed area for Browns Ferry RSD are [[

]] The differential pressure loads are based on Browns Ferry EPU conditions. Figure 5.2-1 presents the pressure load applied on the steam dryer components.

As discussed in Section 8.1.3.1.3 of Appendix A, DP_U, the pressure differential load for the steam dryer for upset operation is determined based on DP_N and the upset multiplier. The upset multiplier used to define ΔP_U is [[ ]].

[[ ]]

Figure 5.2-1: Components and Pressure Loads Applied for DP_N

5.2.2.1.3 Differential Pressure Load during Emergency and Faulted Conditions

For emergency and faulted conditions, the pressure differentials across the steam dryer components are calculated using a nodalized blow-down LAMB model of the reactor vessel as discussed in Section 8.1.3.2.4 of Appendix A.

The limiting event for the emergency condition is the rapid RPV depressurization by actuation of the automatic depressurization system valves when the reactor is at high power. For EPU conditions, the differential pressure load during emergency operation (DP_E) is [[ ]] for the steam dryer vane bank. The differential pressure loads for the components other than steam dryer outer hood are conservatively estimated to be the same as the pressure drop through the steam dryer vane banks [[ ]] and for the perforated plates an equivalent pressure drop is applied.

For the faulted condition, the limiting event is the instantaneous circumferential break of one of the MSLs. Three reactor conditions are analyzed for this event as described in Section 8.1.3.2.4 of Appendix A, which are High Power, Interlock and Hot Standby. For EPU conditions, the differential pressure loads for the steam dryer outer hood and the steam dryer vane bank under these three conditions are listed in Table 5.2-1. The differential pressure loads for the components other than the steam dryer outer hood are conservatively estimated to be the same as the pressure drop through the steam dryer vane banks and for perforated plates an equivalent pressure drop is applied.

The differential pressure loads for components in the steam dryer FEM for emergency operation $DP_{E,}$ High Power $MSLB_{DP1}$, Interlock $MSLB_{DP2}$, and Hot Standby $MSLB_{DP}$ are the same as those shown in Figure 5.2-1 for DP_N.

Table 5.2-1: Faulted Condition DPs

[[			
			]]

5.2.2.2 Main Steam Line Break Event Acoustic Loads

The acoustic load on the face of the steam dryer hood during a MSLB event consists of two components, a load multiplier P_0 and normalized load distribution. The load multiplier determining the wave strength is based on the initial thermal hydraulic properties and transient characteristics (e.g., break time). The normalized load is the magnitude and distribution of the load based on the geometry and configuration of the dryer hood and steam lines. The methodology for determining the acoustic loads on the steam dryer hoods is described in Section 8.1.3.2.5 of Appendix A. Per this methodology the peak normalized acoustic load distribution on the face of the steam dryer hood for Browns Ferry steam dryer is determined, as well as the load multiplier P_0. The acoustic load is calculated at three reactor operating conditions defined by the load combination table.

The peak normalized acoustic load distribution for the three operating conditions is provided in Table 5.2-2. The multiplier P_0 is determined to be [[ ]]. The maximum acoustic loads ($MSLB_{A1}$, $MSLB_{A2}$ and $MSLB_{A\ hot\ standby}$) on the steam dryer hood due to the MSLB are obtained by applying the corresponding acoustic load multiplier, P_0, to the peak normalized distribution load. The components in the steam dryer FEM for these acoustic pressure loads ($MSLB_{A1}$, $MSLB_{A2}$ and $MSLB_{A\ hot\ standby}$) are shown in Figure 5.2-2.

Table 5.2-2: $MSLB_{A1}$ & $MSLB_{A2}$ and $MSLB_{A\ hot\ standby}$ Peak Normalized Acoustic Loads for MSLB

[[											

]]

[[ ]]

Figure 5.2-2: Components for MSLB Acoustic Pressure Loads

5.2.2.3 Turbine Stop Valve (TSV) Closure Event Loads (TSV_A/TSV_F)

The Turbine Stop Valve (TSV) closure event produces two loads on the steam dryer. The first (TSV_A) is due to the impact of the acoustic wave created by the valve closure. The second load (TSV_F) is caused by the inertial impact of the flow reversal in the steam lines. The methodology for determining these loads is similar to the methodology for determining the acoustic loads due to the MSLB and is described in Section 8.1.3.2.2 of Appendix A.

The peak normalized load distribution is shown in Table 5.2-3. For EPU conditions, the multiplier, P0, for the TSV_A condition, is [[ ]]. The maximum load on the steam dryer hood is obtained by applying the corresponding load multiplier P0 to the peak normalized load distribution. The TSV_F pressure differential is [[ ]]. This pressure differential load is applied on the steam dryer face that is directly opposite from steam line nozzle and is applied to the projected area of the steam line nozzle on to the steam dryer face. The components in the steam dryer FEM for TSV_A and TSV_F pressure loads are shown in Figure 5.2-3 and Figure 5.2-4.

Table 5.2-3: Peak Normalized Acoustic Loads for TSV_A

[[							

]]

[[ ]]

Figure 5.2-3: Components in Steam Dryer FEM for TSV_A Pressure Load

[[ ]]

Figure 5.2-4: Components in Steam Dryer FEM for TSV_F Pressure Load

5.2.2.4 Seismic Loads

Seismic events transmit loads to the steam dryer through the vessel support brackets. Horizontal loads due to a seismic event are [[ ]] as shown in Figure 5.2-5. The vertical response spectra were [[ ]]. Figure 5.2-6 shows the SSE acceleration response spectra for the Browns Ferry steam dryer in the horizontal North-South (N-S), East-West (E-W) and vertical directions used for steam dryer seismic spectral analysis. Figure 5.2-7 shows the Operating Basis Earthquake (OBE) acceleration response spectra, which are calculated as half of the SSE values. Structural damping of [[ ]] is applied to the response spectra.

[[ ]]

Figure 5.2-5: Horizontal Seismic Model

[[ ]]

Figure 5.2-6: SSE Seismic Acceleration Response Spectra

[[ ]]

Figure 5.2-7: OBE Seismic Acceleration Response Spectra

5.2.2.5 Zero Period Acceleration (ZPA)

The static structure analyses were performed using Zero Period Accelerations (2PAs) for seismic loads when frequency exceeds the ZPA frequency. The ZPAs applied in the design structural analysis are listed in Table 5.2-4.

Table 5.2-4: Zero Period Acceleration

[[			
			]]

5.2.2.6 Metal and Water Weight Load (DW)

The stresses caused by metal weight are obtained by applying G loading to the Browns Ferry replacement dryer FEM.

5.2.2.7 FIV Stresses

The FIV analysis for the Browns Ferry RSD during normal operation was documented in Section 4. The FIV final adjusted maximum stresses and maximum membrane stresses (including B&U) for each steam dryer component are conservatively taken [[ ]] Because the design load combination stress analysis is the primary structural assessment, [[ ]]. These stresses will be applied [[ ]].

5.2.3 Design Load Combination Analysis

The structural responses of the steam dryer to the design load combinations are evaluated using the ANSYS finite element code. The results of the individual load analyses are then combined for each load combination as specified in Table 5.1-3. The type of finite element structural analysis for each load type is identified in Section 8.1.4 of Appendix A. The analyses are performed assuming a normal reactor operating temperature.

5.3 Design Load Combination Primary Stress Evaluation Results

The Browns Ferry RSD was analyzed for the design load combinations (primary stresses) using the FEM as described in Section 4.2.1. The results of these analyses are used to assess steam dryer component primary stresses versus ASME design criteria for a total of eleven load combinations as described in Section 5.1.3 under normal, upset, emergency and faulted operation conditions at EPU power level. The summary of the primary structural stress assessment results for all steam dryer components excluding seismic blocks and jack bolts/latches is presented in

Table 5.3-1. The acceptance criteria used for these evaluations are the same as those used for safety-related components.

The results in Table 5.3-1 and Sections 4.2.4.2 and 4.2.4.3 indicate that the stresses for all structural components are below the ASME Code allowable limits at EPU operating conditions for Normal, Upset and Emergency service levels. All components meet the requirements for the Faulted service levels. The design load combination results provided in Table 5.3-1 in conjunction with the discussion in Sections 4.2.4.2 and 4.2.4.3 demonstrate the acceptability of the Browns Ferry RSD design at EPU operating conditions.

Table 5.3-1: BFN Replacement Steam Dryer EPU Design Load Combination Results for Normal, Upset, Emergency and Faulted Conditions

[[

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6.0 MONITORING DURING POWER ASCENSION AND FINAL ASSESSMENT AT EPU

The series of steps outlined in Section 2.0 describe the high level analysis and test related tasks that represent the GEH implementation of Regulatory Guide (RG) 1.20 requirements for the RSD. The focus of this report is the structural FIV analysis and test (i.e., measurement) requirements, which make up two of the three main elements of the comprehensive vibration assessment program described in the guide (the third element is inspection). This section describes the RG requirements as they relate to the RSD.

6.1 Regulatory Guide 1.20 Comprehensive Vibration Assessment Program

As discussed in Section 2.0, the RSD is subject to predictive analyses and verification through instrumentation during power ascension at initial startup. For the analysis, the fatigue stress amplitude acceptance limit is [[ ]]. For additional conservatism in the design basis predictive analysis, the analysis stress results will meet a recommended MASR of 2.0 between the analysis results and the fatigue acceptance limit. The power ascension monitoring then uses the fatigue limit stress amplitude of [[ ]] with a MASR of 1.0 as the basis for acceptance limits for the on-dryer instrument measurements during power ascension. A confirmatory stress analysis is performed based on the on-dryer measurements after reaching the full EPU power level.

This Steam Dryer Analysis Report (SDAR) and its appendices present the RSD analysis results and methodology, respectively. Appendix A (Table 10.1-1) provides a RG 1.20 compliance table which details how the methodology meets the recommendations specified in RG 1.20.

6.1.1 Classification

The [[ ]] RSD for Browns Ferry is classified [[ ]] The "valid prototype" for the Browns Ferry RSD design is the BWR/4 RSD described in Section 3.0. The [[ ]] classification is based on the comparisons to the "valid prototype" BWR/4 steam dryer provided in Section 3.1 and the changes that have been made in the Browns Ferry RSD design subsequent to the prototype design as described in Section 3.2. [[ ]] classification is also based on the similarities in the pressure loads acting on the steam dryers for the Browns Ferry and the BWR/4 prototype plants as shown in the comparisons between the two plants in Section 4.1.7.

The RSDs for the [[ ]] Browns Ferry units are classified as [[ ]] referencing the lead Browns Ferry unit design, testing and confirmatory analysis that will be performed as part of the EPU power ascension testing. The Browns Ferry RSD design is common to all three Browns Ferry units. The operating conditions and relevant plant geometry for the three Browns Ferry units are virtually identical. Therefore, the vibratory and stress response for the [[ ]] dryers are expected to be substantially the same as the lead unit.

6.1.2 Vibration and Stress Analysis Program

The design vibration and stress analysis for the Browns Ferry RSDs is common for all three units. The scope and detail of the analysis are the same as that used for a prototype steam dryer. The PBLE pressure load definition used in the analysis is based [[ ]] measurements taken at each of the three units [[ ]] This approach ensures that the nominal design differences between [[ ]]

Following power ascension to full EPU, a confirmatory analysis will be performed for the [[ ]] unit RSD. This analysis will include a final load definition and stress reanalysis of the steam dryer using the [[ ]] biases and uncertainties determined at EPU conditions and a comparison of predicted and measured pressures and strains on the RSD. The [[ ]] unit confirmatory analysis will provide the basis for the test acceptance criteria for the follow-on units. Power ascension monitoring for the [[ ]] units will be performed using [[ ]] the RSDs for the follow-on units will not be instrumented. Confirmatory evaluations will be performed for each of the follow-on units using the MSL measurements at EPU and the Browns Ferry specific biases and uncertainties developed from the [[ ]] confirmatory analysis. [[ ]]

6.1.3 Vibration and Stress Measurement Program

The power ascension for the Browns Ferry [[ ]] unit will be monitored using [[ ]] The instrumentation design ensures that there is sufficient and appropriate instrumentation to define the vibratory and stress response for those components in the Browns Ferry RSD that have been modified relative to the "valid prototype" BWR/4 steam dryer. In addition to the [[ ]] Test acceptance criteria for the [[ ]] unit will be provided through limit curves for [[ ]]

The [[ ]] unit confirmatory analysis will provide the basis for the test acceptance criteria for the [[ ]] Power ascension monitoring for the [[ ]] will be performed [[ ]] Test acceptance criteria for the [[ ]] will be provided through limit curves for [[ ]]

6.1.4 Inspection Program

During the first two scheduled Refueling Outages (RFO)s after reaching full EPU power conditions, a visual inspection of the RSD will be conducted for each unit. The inspection plan will be consistent with the industry guidance provided in References 9 and 10. The inspection plan will include an accessible exterior and interior critical locations identified in the vibration and stress analyses for the Browns Ferry RSDs.

6.2 Power Ascension Test Plan (PATP)

The primary objectives of the PATP are as follows:

- [[

  ]]
- Confirm the steam dryer analyses performed for the EPU conditions.

The Browns Ferry [[ ]] steam dryer to obtain data during power ascension. The [[ ]] are then compared with the [[ ]] limit curves. [[ ]] Note that the [[ ]] B&U analyses are accounted for in the development of the acceptance limits as described in Section 4.2.5.

The Browns Ferry [[ ]] will use [[ ]] The [[ ]] Demonstrating that the steam dryer pressure loads remain within the allowable pressure loads confirms that the steam dryer alternating stresses remain within the structural analysis basis in the [[ ]] unit confirmatory analysis.

[[

]]

Monitoring of various plant parameters potentially indicative of steam dryer/system failure will be continued after reaching EPU conditions. Moisture carryover, strain gauge monitoring and inspections results will be made available to the NRC Staff. Once EPU conditions are obtained and data collected at EPU conditions, a final stress analysis will be performed and submitted to the NRC.

6.3 Limit Curve Adjustment

[[

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[[ ]]

Figure 6.3-1: Generic Process for Updating Limit Curves

7.0 REFERENCES

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Appendix A

BWR Replacement Steam Dryer Structural Evaluation General Methodology

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ACRONYMS AND ABBREVIATIONS

Term	Description
ABWR	Advanced Boiling Water Reactor
ADS	Automatic Depressurization System
AOO	Anticipated Operation Occurances
ASME	American Society of Mechanical Engineers
BWR	Boiling Water Reactor
CFD	Computational Fluid Dynamics
CLTP	Current Licensed Thermal Power
DOF	Degrees of Freedom
DP	Delta (or differential) Pressure
DW	Dead Weight
ECCS	Emergency Core Cooling System
EPU	Extended Power Uprate
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Model
FIV	Flow Induced Vibration
FRF	Frequency Response Function
FSAR	Final Safety Analysis Report
FSRF	Fatigue Strength Reduction Factor
GEH	GE Hitachi Nuclear Energy
[[	]]
ISCOR	Program used for developing ASME loads
LAMB	Program used in ECCS-LOCA applications
LBL	Large Break LOCA
LOCA	Loss-of-Coolant Accident
[[	]]
MASR	Minimum Alternating Stress Ratio
MPC	Multi-Point Constraint

Term	Description
MSL	Main Steam Line
MSLB	Main Steam Line Break
NRC	Nuclear Regulatory Commission
OEM	Original Equipment Manufacturer
OLTP	Original Licensed Thermal Power
PATP	Power Ascension Test Plan
PBLE	Plant Based Load Evaluation
PBLE01	PBLE solution with [[ ]]
PBLE02	PBLE solution with [[ ]]
PS	Power Spectrum
PSD	Power Spectral Density
PTF	Plate Thickness Factor
RG	Regulatory Guide
RIPD	Reactor Internal Pressure Differences
RMS	Root Mean Square
RPV	Reactor Pressure Vessel
RSD	Replacement Steam Dryer
SDAR	Steam Dryer Analysis Report
SER	Safety Evaluation Report
SRSS	Square Root Sum of the Squares
SRF	Stress Ratio Factor
SRV	Safety Relief Valve
SSE	Safe Shutdown Earthquake
TSV	Turbine Stop Valve

1.0 INTRODUCTION

As a result of steam dryer fatigue issues at operating Boiling Water Reactors (BWRs) following the implementation of Extended Power Uprate (EPU), the United States (US) Nuclear Regulatory Commission (NRC) has issued revised guidance concerning the evaluation of steam dryers (References A.1 and A.2) for flow-induced vibrations. It must be demonstrated that the dryer will maintain its structural integrity when subjected to acoustic and hydrodynamic fluctuating pressure loads during normal plant operation. This demonstration of steam dryer structural integrity comes in three steps:

1. Predict the fluctuating pressure loads acting on the dryer and perform a structural analysis to qualify the steam dryer design,
2. Implement a startup test program for confirming the steam dryer design analysis results as part of the plant power ascension.
3. Implement an inspection program to inspect the critical high stress locations.

The approach used for the BWR Replacement Steam Dryer (RSD) structural evaluation includes the following:

I. Design
   a. Analyze the steam dryer design with design loads developed from [[ ]] using the Plant Based Load Evaluation ([[ ]]) methodology. [[ ]] bias and uncertainty developed from an instrumented prototype steam dryer is applied to the design basis. [[ ]]
   b. Demonstrate that the fatigue analysis results for the as-designed steam dryer maximum calculated alternating stress intensity meet or exceed a recommended Minimum Alternating Stress Ratio (MASR) of 2.0 to the allowable alternating stress intensity of 13,600 psi.
   c. Demonstrate that the primary stress results for the as-designed steam dryer meet the acceptance criteria for the normal, upset, emergency, and faulted load combinations.
   d. If needed, revise steam dryer design in high stress areas to meet criteria in I.b and I.c above.

II. As-built Steam Dryer
   a. Address any changes between the as-designed and as-built steam dryer.
   b. For a prototype dryer, perform dynamic testing, "frequency response testing", of the fabricated steam dryer to compare the predicted versus measured frequency response. Define [[ ]] Dynamic testing of the as-built dryer is not necessary if the RSD design is similar to

prototypic designs or designs that have been dynamically tested. The [[ ]] bias and uncertainty from the prototype dryer benchmarking and [[ ]] previously performed in the analyses are sufficient to address the difference in structural response between the analytical model and the as-built dryer.

c. Verify that the fatigue analysis results for the as-built steam dryer maximum calculated alternating stress intensity meet or exceed an MASR of 2.0 to the allowable alternating stress intensity of 13,600 psi.

d. Verify that the primary stress results for the as-built steam dryer meet the acceptance criteria for the normal, upset, emergency, and faulted load combinations.

e. Identify on-dryer instrumentation sensor specifications, sensor locations, [[ ]], and bias and uncertainties of sensors and data acquisition system.

f. Define steam dryer instrument acceptance limits that maintain peak alternating stress amplitude of 13,600 psi for the steam dryer.

III. [[ ]] Power Ascension Monitoring and Inspection

a. Develop a steam dryer power ascension monitoring and inspection program that reflects industry experience with the performance of steam dryer power ascension testing.

b. Instrument and monitor the steam dryer during power ascension to [[ ]] to assure that adequate steam dryer fatigue margin is maintained.

c. Perform a confirmatory structural analysis based [[ ]] and benchmarked against the structural measurements to confirm that the dryer will maintain structural integrity over its design life.

IV. [[ ]]

Power ascension testing of [[ ]] will follow the same flow-induced vibration (FIV) monitoring process using [[ ]] incorporating lessons learned from power ascension of previous BWR RSD plants as applicable. The power ascension acceptance limits for [[ ]] are based on assuring that the stresses remain less than 13,600 psi. Limits are based on [[ ]] The limit curve factor is determined based on the ratio of 13,600 psi over the projected peak stress on [[ ]] steam dryer after adjustment for bias and uncertainty. Confirmatory structural evaluations [[ ]]

V. Inspections

Conduct steam dryer inspections during the first two refueling outages and develop a long-term steam dryer inspection program based on the results of those steam dryer inspections.

The overall structural evaluation methodology and power ascension testing for the BWR RSD is presented in this report, and is not plant-specific. This methodology has been successfully used in previous RSD projects. A detailed FEM is used to perform the structural dynamic analyses in order to predict the steam dryer's susceptibility to fatigue under FIV during normal operation. The same FEM is used to predict the stresses resulting from transient and accident events. When EPU power is obtained, the results of these analyses are confirmed by updating the projected peak stress projections using the EPU power test data.

This overall methodology description is supported by other appendices. The supporting appendix list is below:

- Appendix A – BWR RSD Structural Evaluation: General Methodology (the present document).
- Appendix B - Plant Based Load Evaluation Methodology - PBLE01 Model Description.
    - [[ ]]
- Appendix C - Plant Based Load Evaluation Methodology - PBLE02 Model Description.
    - [[ ]]
- Appendix D - Browns Ferry RSD FIV Supplemental Information.
- Appendix E - Power Ascension Test Plan.
    - [[ ]]

2.0 STEAM DRYER DESIGN AND OPERATING ENVIRONMENT

2.1 Physical Description

The BWR RSD consists of an upper support ring with dryer banks on top and a skirt below to make up the steam dryer assembly. A typical steam dryer is shown in Figure 2.2-1. The steam dryer units, made up of steam dryer vanes and perforated plates, are arranged in six parallel rows called dryer banks. The support ring is supported by reactor pressure vessel (RPV) support brackets. The steam dryer assembly does not physically connect to the steam separator assembly. The cylindrical skirt attaches to the support ring and projects downward to form a water seal around the array of steam separators. Normal operating water level, approximately mid-height on the steam dryer skirt, is provided as input to the analysis.

During normal refueling outages, the BWR RSD is supported from the floor of the equipment pool by the lower skirt ring that is located at the bottom edge of the skirt. The steam dryer is installed and removed from the RPV by the reactor building overhead crane. A steam dryer lifting device, which attaches to four steam dryer lifting rod eyes, is used for lifting the steam dryer. Guide rods in the RPV are used to aid steam dryer installation and removal. Upper and lower guides on the steam dryer assembly are used to interface with the guide rods.

2.2 BWR RSD Plant Operating Conditions for Steam Dryer Design Basis Analyses

This section defines the plant operating conditions that will be assumed for the BWR RSD design basis analyses. The relevant plant parameters that determine the operating conditions for the steam dryer structural analyses are the reactor power, the RPV pressure, the RPV water level and reactor core flow. These parameters are interrelated and have both primary and secondary effects that influence the steam dryer structural response.

The BWR is a forced circulation plant and there is active control of the core flow. The core power level can be changed without moving control rods by changing recirculation flow.

The BWR RSD structural analyses will assume the maximum steam generation rate at 100% rated EPU power as described in the rated reactor heat balance. [[

]]

The bases for the assumed operating conditions are provided in the following sections.

2.2.1 Reactor Power

The FIV and acoustic pressure loading conditions are governed by the reactor steam generation rate and steam flow velocities in the main steam system. [[

]] There is a range of core

recirculation values over which full power operation is licensed. The BWR RSD structural analyses will assume the maximum steam generation rate at full rated power. [[

]] discussed in detail in the next section.

2.2.2 Reactor Dome Pressure

The reactor dome pressure determines the steam density and, therefore, the steam flow velocities at a given steam generation rate. [[

]] This effect was observed in dryer response measurements taken during power ascension testing of an instrumented RSD when [[

]]

The reactor dome pressure will vary during normal operation for two reasons: the pressure fluctuations during steady-state operation and the allowed tolerance for the pressure regulator setpoint. The pressure fluctuations during normal operation are small (typically less than ±2 psi) which will have only a small effect on the steam flow velocities and dryer pressure loading. [[

]]

There is an allowed tolerance in the turbine inlet pressure regulator setpoint with respect to the reactor system pressure. Under normal circumstances, the pressure regulator setpoint is adjusted early in the reactor system pressurization so that the reactor will be at nominal pressure when full power is achieved and is not readjusted during the cycle. In addition, the plant thermal efficiency (electrical generation as a function of thermal power) is maximized by operating the reactor system at the high end of the allowable pressure range.

[[

]]

2.2.3 RPV Water Level

The RPV water level [[

]] Similar to the reactor dome pressure, the vessel water level will vary during normal operation for two reasons: the level fluctuations during steady-state operation and the allowed tolerance for the level controller setpoint. [[

]] in the next section.

2.2.4 Reactor Core Flow

Power ascension testing of an instrumented RSD showed [[

]]

The BWR is a forced circulation plant and there is active control of the core flow. The effects of those core flow variations on the steam dryer structural response are discussed below.

2.2.5 Core Flow Variation over the Fuel Cycle

The rated reactor heat balance for 100% EPU power provides a core flow range for plant operation. This range does not consider both the uncertainties in the predicted core flow and the effect of core exposure over the cycle. Therefore, [[

]]

As described in Section 10.2, the final dryer stress analysis predictions will be benchmarked at full power operation against on-dryer measurements taken over the range of steady state plant operating conditions during the prototype plant startup.

[[ ]]

Figure 2.2-1: Typical Steam Dryer Installed in RPV

3.0 MATERIAL PROPERTIES

The steam dryer will be manufactured from [[ ]] stainless steel [[ ]] stainless steel castings conforming to the requirements of GE Hitachi Nuclear Energy (GEH) material and fabrication specifications. Typical material properties that are used in the analysis are modulus of elasticity, density, and poisson's ratio. Specific material properties at operating temperature will be used (Reference A.3). Specifics of how material properties are used in the FEM are discussed in Section 5.0.

4.0 DESIGN CRITERIA

The steam dryer, including the steam dryer units, is a nonsafety-related item and is classified as an Internal Structure as defined in the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III (Reference A.4) Subsection NG, Paragraph NG-1122. The steam dryer is not a component governed by ASME Boiler and Pressure Vessel Code, Section III, however the design will comply with stress and fatigue criteria for core support structures defined in ASME Code Subsection NG-3000, [[ ]] as discussed in Subsections 4.2 and 4.3. The other exception to Subsection NG-3000 is that no temperature adjustment for the modulus of elasticity is performed when comparing the calculated alternating stress intensity against the fatigue acceptance criterion. This is discussed further in Section 4.1.

4.1 Fatigue Criteria

The steam dryer 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 limits. [[

]]

4.2 Fatigue Strength Reduction Factors

[[

]]

[[ ]]

Figure 4.2-1: Weld Fatigue Strength Reduction Factor Flow Diagram

[[ ]]

Figure 4.2-2: Schematic of Weld Joint Showing Geometric Nomenclature

4.3 Weld Quality Factor

For the case of the steam dryer, which is not a core support structure, it was [[

]]

5.0 STEAM DRYER FINITE ELEMENT MODEL AND APPLIED LOADS

5.1 Full Steam Dryer Shell Finite Element Model

[[

]]

5.1.1 Elements and Model Simplification

[[

]]

[[ ]]

Figure 5.1-1: An Example of Steam Dryer Finite Element Model (element edges not shown for clarity)

[[ ]]

Figure 5.1-2: Example of Stress Recovery Components for the Steam Dryer FEM

5.1.2 Substructuring

[[

]]

[[ ]]

Figure 5.1-3: Vane Bundle Construction

[[ ]]

Figure 5.1-4: Typical Vane Bundle FEM showing Master DOFs

5.1.3 Water Modeling

[[

]]

[[ ]]

Figure 5.1-5: Modeling Water

[[ ]]

Figure 5.1-6: Schematics of Bubbly Water and Steam

[[ ]]

Figure 5.1-7: Speed of sound in [[ ]]

5.1.4 Perforated Plate

[[

]]

[[ ]]

Figure 5.1-8: Modeling Perforated Plates

5.1.5 Shell-Solid Element Connections

[[

]]

5.1.5.1 Moment Transfer Shell Elements

[[

]]

[[ ]]

Figure 5.1-9: Moment Transfer Shells used in the RSD FEM
(support ring is translucent to better show the imbedded shells)

5.1.5.2 General Constraint Equations

[[

]]

[[ ]]

Figure 5.1-10: Shell-to-Solid Connection within the Tie Bars

5.1.5.3 Multi-Point Constraint Algorithm

[[

]]

[[ ]]

Figure 5.1-11: Lower Ring Splice MPCs

5.1.6 Global FEM Convergence

[[

]]

5.1.7 FE Submodel Convergence

[[

]]

[[ ]]

Figure 5.1-12: Global Model Mesh Converged

[[ ]]

Figure 5.1-13: Mesh Convergence in Refinement Study

[[ ]]

Figure 5.1-14: Mesh Convergence by Extrapolation Method

5.2 Dynamic Pressure Loads

[[

]]

5.2.1 Load Development

The plant measurements ([[ ]]) are sufficient for capturing the plant-specific frequency and amplitude content for use in developing PBLE load definitions (See Appendices B and C) for the power levels at which the measurements were taken. [[ ]] This section briefly describes the methodology for load definition.

5.2.2 SRV Acoustic Sources

Regulatory Guide (RG) 1.20, Revision 3, Section C 2.0 (Reference A.1) indicates studies of past failures have determined that flow-excited acoustic resonances within the valves, stand pipes and branch lines in the MSLs of BWRs can play a significant role in producing mid- to high-frequency pressure fluctuations and vibration that can damage MSL valves, the steam dryer and other reactor pressure vessel (RPV) internals and steam system components. The SRV sidebranch acoustic resonances are the main contributor to the mid- to high-frequency pressure fluctuations. Therefore, these SRV resonance loads are modeled in the load definition and analysis.

[[

]]

[[ ]]

Figure 5.2-1: [[ ]] Predicted versus Measured Loads

[[
]]

Figure 5.2-2: [[ ]] **Predicted versus Measured Loads**

5.2.3 Design Basis FIV Loads

[[
]] The design basis FIV loading time history and any necessary loading scale factors are taken from Appendix C. [[
]]

5.2.4 Power Ascension FIV Loads

For the [[ ]], the pressure loading on the face of the steam dryer will be measured [[ ]] during power ascension. [[

]] These loads will be used to adjust the predicted structural model responses [[

]] Section 6 provides additional details on the application of bias and uncertainty.

For [[ ]] The models will use [[ ]] bias and uncertainties developed from the [[ ]]

5.2.5 Full Power FIV Loads

For the [[ ]], following completion of the power ascension program, a set of full power BWR RSD-specific FIV loads will be developed [[ ]] These full power loads will be used to perform a structural evaluation [[

]] will be applied to the structural model predictions to determine the final peak stress values for the RSD at full power conditions. Section 6 provides additional details on the application of bias and uncertainty.

[[ ]] The models will use [[ ]]

5.3 Acoustic Load Mapping

The load mapping process generates the load step files for solution processing. [[

]]

Figure 5.3-1 shows the structural FE mesh for which acoustic pressure loading is typically applied. [[

]] Figure 5.3-2 shows pressure contour plots for the acoustic FEM (left) and the structural FEM (right). These contour plots show the input and output of the load mapping process.

[[ ]]

Figure 5.3-1: Pressure Surfaces for Which to Map the Acoustic Pressure Loads

[[ ]]

Figure 5.3-2: Pressure Load Mapping Input (Left) and Output (Right)

6.0 VIBRATION ANALYSIS AND PREDICTED COMPONENT STRESSES

This section describes the process used to perform the FIV structural analysis. The commercial finite element software ANSYS is used in the solution. For the flow-induced vibration of steam dryers, GEH applies the ANSYS [[

]]

6.1 Dynamic Analysis Approach

6.1.1 Dynamic FIV Analysis

[[

]]

6.1.2 Structural Damping

[[

]]

[[ ]]

Figure 6.1-1: [[ ]]

6.1.3 Stress Recovery from the Global Results

[[

]]

[[ ]]

Figure 6.1-2: Stress Intensity Contour at Max Stress Intensity (SI) Time Step
[[ ]]

6.2 Submodel Analysis and Local Stress

Submodeling is a finite element technique to obtain more accurate results in a particular region of a larger model. [[

]]

[[ ]]

Figure 6.2-1: Illustration of a Submodel [[ ]]

[[ ]]

Figure 6.2-2: Boundary Conditions of a Submodel [[ ]]

[[ ]]

Figure 6.2-3: Calculation of Fillet Weld Nominal Stress [[ ]]

6.3 Adjustments to the Steam Dryer FIV Stress

To provide an adequately bounding stress analysis and to account for uncertainties in the overall methodology, a series of bias and uncertainties and adjustments are applied to the predicted peak stress. The following sections summarize the high level methodology for making bias and uncertainty adjustments. Section 6.3.1 defines how these values are applied to the dryer structural response to determine the sensor response and peak stress.

[[

]]

Table 6.3-1: [[ ]]

Term Name	How it is Applied
[[	
	]]

[[ ]]

Figure 6.3-1: Overview of Final Stress Adjustment Process

As can be seen in Figure 6.3-1 and Table 6.3-1, a number of terms are applied to the final peak stress value for each component and weld in order to account for known bias and uncertainty, as well as other items like anticipated SRV resonances or other impacts anticipated for EPU from items like higher steam velocities.

6.3.1 Methodology Bias and Uncertainty

Methodology bias and uncertainty is described in more detail in [[ ]] In general both load methodologies predict the loads, and biases/uncertainties are developed by benchmarking the process to measured data. [[ ]] These references also provide an example implementation of the methodology.

[[

]]

6.3.2 FEM Bias and Uncertainty

[[

]]

6.3.3 Maximum Response for FIV Assessment

The FIV loading used in the FE stress analysis considers highest stress intensities that occur at frequencies as low as approximately 1 cycle per 100 seconds. [[

]]

Table 6.3-2: Typical Time Domain Strain Gauge Data Statistics

[[

]]

Assume that [[

]]

The BiasFactor in Equation 6.3-7 is a [[

]]

Therefore, it is assumed the same relation follows [[

]]

6.3.4 Scaling Factors for EPU Conditions ([[ ]])

[[

]]

6.3.5 Instrumentation Bias and Uncertainty

The instrumentation bias and uncertainty is accounted for in the methodology when comparing predictions to measured values and also when establishing limits. The instrumentation bias and uncertainty addresses the overall accuracy of the total measurement system which includes [[

]] Instrumentation bias and uncertainty is determined [[

]]

Each sensor signal goes through several devices, so for a given sensor sensitivity, [[

]] For strain gauges, additional factors are included in the overall measurement accuracy [[
]]

The overall random instrumentation uncertainty is determined from [[

]]

For more discussion, refer to Appendix C.

7.0 FATIGUE PREDICTION

[[

]] These stresses will then be compared to the criteria from Section 4.1.

[[

]]

7.1 Analysis 1 – [[ ]]

[[

]]

7.2 Analysis 2 – [[ ]]

[[

]]

7.3 Analysis 3 – [[ ]]

[[

]]

7.4 Analysis 4 – [[ ]]

[[

]]

8.0 PRIMARY STRESS EVALUATION

8.1 ASME Approach for the RSDs

The steam dryer is a nonsafety-related component and performs no active safety function; however, the dryer must maintain structural integrity during normal, transient and accident conditions and not generate loose parts that may interfere with the operation of safety systems. Sections 6 and 7 of this appendix describe the fatigue evaluation process used to demonstrate that the dryer alternating stresses are sufficiently low to preclude the initiation of high cycle fatigue cracking during normal plant operation. This section describes the input loads and load combinations used to evaluate the primary stresses during normal, transient and accident conditions and demonstrate that the dryer will maintain structural integrity during all modes of operation.

8.1.1 Description of Design Conditions

Plant operating conditions are defined in Chapter 15 of a plant's Updated Final Safety Analysis Report (UFSAR). These operating conditions are categorized and reflect varying probabilities of conditions, which are then compared against appropriate acceptance criteria. The main design conditions are defined as:

Normal	Normal steady-state operation
Upset	Anticipated operational transients (e.g., turbine trip, stuck open relief valve)
Emergency	Infrequent operational transients (e.g., inadvertent opening of Automatic Depressurization System (ADS) valves)
Faulted	Accident and rare transients (e.g., Loss-of-Coolant Accident (LOCA), Safe Shutdown Earthquake (SSE))

The limiting design basis condition for the steam dryer is the double-ended guillotine break of the MSL outside containment. For this event, the steam dryer must maintain its structural integrity and not generate loose parts that may interfere with the closure of the main steam isolation valves.

8.1.2 ASME Load Case for the Steam Dryer

The load combinations are plant-specific and are defined in the plant's design basis. These combinations are specified in a plant's steam dryer design specification and the analyses are performed over a range of conditions that support the licensed operating domain. The ASME load combinations for a typical plant are shown in Table 8.1-1. Definitions of the individual loads and calculation methodology are specified in the following section. Loads from independent dynamic events are combined by the square root sum of squares (SRSS) method per NUREG-0484. The dryer is at uniform temperature at normal and transient conditions, and therefore the thermal expansion stress is assumed zero. There is no radial constraint of the dryer, and differential expansion is accommodated by slippage.

Table 8.1-1: Typical Steam Dryer Load Combinations for Plants

Load Case	Service Conditions	Load Combination
A	Normal	[[
B-1	Upset	
B-2	Upset	
B-3	Upset	
B-4	Upset	
C-1	Emergency	
D-1	Faulted	
D-2	Faulted	
D-3	Faulted	
D-4	Faulted	
D-5	Faulted	
D-6	Faulted	]]

Definition of Load Acronyms:

[[

]]

8.1.3 Individual Load Term Definition and Source

8.1.3.1 Static Loads

The following loads are considered to be static loads that are applied during steady-state operating conditions.

8.1.3.1.1 Dead Weight (DW)

The stresses caused by the steam dryer weigth are obtained by applying gravity (*G*) loading to the steam dryer FEM.

8.1.3.1.2 Thermal Expansion

The steam and water temperatures at each dryer component are the same at saturated pressure/temperature conditions. The RPV transient temperature changes for all operating events are mild in the steam space where the dryer is located. The materials for the steam dryer components are of the same type of stainless steel and, therefore, have the same thermal expansion coefficient. Although the RPV is carbon steel and has a lower thermal expansion coefficient, the dryer support ring is not radially constrained by the RPV and therefore the loads due to thermal expansion effects on the dryer are negligible and do not need to be analyzed.

8.1.3.1.3 Differential Pressure Loads (DP_N, DP_U)

The operating pressure differentials across each dryer component are based on Reactor Internal Pressure Differences (RIPD) calculated for the applicable plant operating conditions. The DP loads assumed in the analysis depend on the service condition and event being analyzed. At normal conditions, the calculation of steady state pressure drops through the vane banks is performed using the "ISCOR" computer program. This method has been applied to the BWRs to calculate the Normal condition reactor internal pressure differentials (RIPD) (e.g., steam dryer, top guide, shroud). [[
]]

The static pressure drop across the steam dryer outer hoods is determined by the pressure drop through the vane banks plus the static pressure drop ($DP_{outer\ hood}$) along the steam dryer hoods at analyzed hood elevation. The pressure drop across the dryer outer hoods has generally been determined for BWRs at OLTP conditions. For operation at higher steam flows experienced during EPU, the increased steam flow will increase the pressure drop along the steam dryer hoods. [[ ]]

[[ ]] **Equation 8.1-1**

Where,

[[

]]

The differential pressure loads for the components other than dryer outer hood are conservatively estimated to be the same as the pressure drop through the vane banks. For perforated plates, an equivalent pressure drop can be estimated as:

An equivalent pressure = [[
]]

The distribution of pressure drop has been provided for [[
]] design as shown in Figure 8.1-1. It is proportional to the pressure drops through the vane banks. [[
]] The perforated plate designs for RSD are very similar to the BWR original steam dryer. Therefore, the pressure drop distribution factors for perforated plate used for OEM dryer could be used to estimate the pressure drop for RSD.

[[ ]]

Figure 8.1-1: Pressure Drop Distribution on Perforated Plate Used for BWR 4/5 Original Steam Dryer Design

The pressure drop resulting from Anticipated Operational Occurrences (AOO), or Upset Conditions, [[

]]

The stuck opening of a safety relief valve (one of the Upset events) can also result in loads on the steam dryer directly through the resulting pressure effects in the steamline. [[

]] did not consider the case of one stuck open relief valve and this must be evaluated separately to confirm or replace the generic increment factor.

The one stuck open SRV event methodology develops [[

Equation 8.1-2

]]

For accidents, or Faulted conditions, the pressure differentials across the steam dryer components [[

]]

8.1.3.2 Dynamic Loads

Dynamic loads result from various off-normal operating conditions for the plant. The most basic dynamic load is the result of FIV where small variations in the pressure field of the steam flow are caused by turbulence, acoustic resonances and other sources. Other dynamic loads are the result of plant operational transient and accident conditions. The following sections provide a discussion of the various dynamic loads and the methodology for calculation of the steam dryer loading.

8.1.3.2.1 Flow-Induced Vibration (FIV_N, FIV_U)

The primary concern for the steam dryer structure is fatigue failure of the components from the FIV loading during normal operation. There are two primary sources of flow-induced vibration loads on the dryer. The first load is an acoustic pressure loading caused by the steam flow through the steam piping system. Based on in-plant measurements, the acoustic pressure loading is the dominant FIV load on the steam dryer. The second load is turbulent buffeting caused by the steam flow through and across the steam dryer structure. The velocities through the dryer are low; therefore, the contribution of the buffeting load to the total FIV load is negligible.

The detailed methodologies for determining the FIV loads for the steam dryer are outlined in Appendices B and C. The FIV primary bending stresses and maximum primary membrane stresses for different components of the steam dryer are calculated with consideration for biases and uncertainties as discussed in Section 6 of this Appendix. Because the ASME Code load combination stress analysis is the primary structural stress assessment, the weld factor effect is not included in the final FIV loading (FIV_N).

The FIV load for the Upset Condition (FIV_U), [[

]]

8.1.3.2.2 Turbine Stop Valve Loads ([[ ]])

A Turbine Stop Valve (TSV) closure produces [[ ]] loads on the steam dryer. [[

]] The [[ ]] TSV loads are well separated in time and are therefore applied separately.

The key assumptions of the methodology are summarized as follows;

[[

]]

The TSV and Turbine Control Valves (TCVs) are basically in series, with connecting headers to equalize the pressure both in front and behind the TSVs. The Turbine Bypass Valves (TBVs) are on a header that connects to the MSLs in a manner similar to that shown in Figure 8.1-3.

[[ ]]

Figure 8.1-2: Typical TSV Closure Characteristics

[[ ]]

Figure 8.1-3: Typical Turbine Valve Schematic

The rate of steam flow decrease during a valve closure event depends on the relative closing speeds and delay (if any) of the valves. If one valve closes faster than the other, the faster valve will control the flow. TBVs open after a delay time, and usually do not become effective until the flow to the turbine is almost shut off by TSVs or TCVs. [[

]]

8.1.3.2.2.1 [[

]]

[[ ]]

Figure 8.1-4: [[ ]]

[[

]]

Table 8.1-2: Peak Normalized Load Distribution for [[ ]]

[[						

]]

[[ ]]

Figure 8.1-5: Finite Element Model Component for [[ ]] **Pressure Load**

8.1.3.2.2.2 [[ ]]

[[

]]

[[ ]]

Figure 8.1-6: Projected [[ ]]**)**

8.1.3.2.3 Seismic Loads ([[ ]])

Seismic events transmit loads to the dryer through the vessel support brackets. Seismic loads for the Operating Basis Earthquake (OBE) and Safe Shutdown Earthquake (SSE) in the form of Amplified Response Spectra (ARS) at the reactor dryer support elevation are used in accordance with the data documented in plant design basis seismic loads evaluations. The horizontal seismic loads are selected from the horizontal seismic model at the appropriate node representing the dryer elevation. Vertical loads are selected per the vertical seismic model at the closest node to the steam dryer. Appropriate structural damping is applied to the response spectra. Spectral analyses are performed for the seismic loads. Seismic anchor motion effects do not need to be considered because they are negligible inside the RPV.

8.1.3.2.4 Differential Pressure Load during Emergency and Faulted Conditions

A general class of postulated reactor events are those where depressurization of the RPV is the limiting phenomenon. The rapid depressurization causes water in the RPV to flash into steam. The resulting two-phase level swell impacts the underside of the steam dryer, producing a transient differential pressure loading across the steam dryer. [[ ]] The Reactor Internals Pressure Differential (RIPD) calculations determine analytically the differential pressures during these conditions.

For Emergency and Faulted conditions, the pressure differentials across the steam dryer components are specifically calculated [[ ]] This blow-down can be the result of a postulated recirculation line, steam line, or feed water line break or depressurization through the primary system relief valves. [[ ]]

8.1.3.2.4.1 Differential Pressure Load during Emergency Operation (DPE)

The limiting event for the Emergency condition [[

]] The additional 2% power is assumed per RG 1.49. The NRC withdrew this RG in April 2008. [[
]] The blow-down LAMB model is used to calculate the RIPDs for the steam dryer hood and vane banks during the postulated event.

8.1.3.2.4.2 Differential Pressure Load during Faulted Condition ([[
]])

The Faulted category addresses accidents or limiting faults, which are postulated as part of the plant's design basis. For the steam dryer, the design basis Faulted event is the [[
]] The steam dryer must be shown to maintain structural integrity and not generate loose parts that may interfere with the closure of the main steam isolation valves. Three reactor operating conditions are analyzed for this event:

[[

]] The blow-down model is used to calculate the RIPDs for the steam dryer hood and vane banks during the postulated event.

8.1.3.2.5 Acoustic Loads due to MSLB Outside Containment ([[
]])

The flow transient produced by rapid opening of the break generates a decompression wave in the MSL that impacts the steam dryer. The methodology for calculating the acoustic loads on the steam dryer outer hood [[ ]] was modified to determine the acoustic loads on the steam dryer outer hood due to the faulted MSLB outside containment event because the acoustic wave imposing the load on the outer hood is similar for both events.

[[

]]

Table 8.1-3: Typical Peak Normalized Acoustic Loads for MSLB

[[										

]]

8.1.4 Analysis Approach

The structural responses of the steam dryer to the ASME load combinations will be evaluated using the ANSYS finite element code. The results of the individual load analyses are then combined for each event as specified in Table 8.1-1. The type of finite element structural analysis for each load type is identified in Table 8.1-4. The analyses are performed assuming normal reactor operating temperature.

Table 8.1-4: Type of Analysis for the Load Terms in ASME Load Combinations

Load Term	Description	Type of Analysis for the Load
[[		

]]

8.1.5 ASME Load Case Stress Results

The results of the individual load analyses are then combined for each event as specified in Table 8.1-1. The resulting stresses are then compared to the ASME Code stress limits from Subsection NG (Reference A.4). These criteria are presented in Table 8.1-5. For each RSD component and load combination, the maximum primary stress values and minimum stress margins are calculated and then tabulated.

Table 8.1-5: ASME Code Stress Limits for the Steam Dryer

Service Level	Stress Category	Core Support Structures Stress limits (NG)
Service Levels A&B	P_m	S_m
	$P_m + P_b$	$1.5S_m$
Service Levels C	P_m	$1.5S_m$
	$P_m + P_b$	$2.25S_m$
Service Level D	P_m	Min(.7S_u or 2.4 S_m)
	$P_l + P_b$	1.5(P_m Allowable)

Legend:

P_m: General primary membrane stress intensity
P_b: Primary bending stress intensity
P_l: Local primary membrane stress intensity
S_m: ASME Code Design Stress Intensity
S_u: Ultimate strength

Note: Service Level Limits for Service Levels A, B and C are according to NG-3220 and Appendix F Paragraph F-1331 for Level D. Upset condition stress limits are increased by 10% above the limits shown in this table per NG-3223(a).

9.0 STARTUP TEST DESIGN AND ANALYSIS

9.1 Instrumentation for Monitoring Steam Dryer Response

The lead unit RSD is instrumented with temporary vibration sensors to obtain FIV data during power operation. The primary function of this vibration measurement program is to verify that the steam dryer can adequately withstand stresses from FIV pressure fluctuations for the design life of the steam dryer. Strain gauges and accelerometers are used to monitor the structural response during power ascension and to validate the fatigue stress predictions in Section 7.0 for normal operation. Accelerometers are also used to identify potential rocking and to measure the accelerations resulting from support and vessel movements.

[[

]]

In addition [[

]]

9.2 Startup Testing Acceptance Criteria

The structural analysis performed for the steam dryer design consists of a dynamic FEA. [[

]]

For one-dimensional (uni-axial) structural responses, the determination of strain measurement acceptance criteria would be:

$$\varepsilon = \sigma / (E)$$ **Equation 9.2-1**

where

σ = highest stress intensity allowable limit

E = Young's Modulus, 1.78 x 10^5 MPa (25.8 x 10^6 psi) at 288°C (550°F) for steam dryer material.

With a highest stress intensity allowable limit of 13,600 psi, the strain acceptance limit with the strain gauge at the maximum stress location, is calculated as follows:

$$\varepsilon = \sigma/(E) = 527\ \mu\varepsilon \text{ (zero-peak) or } 1054\ \mu\varepsilon \text{ (peak-peak)}$$

[[

]]

10.0 COMPREHENSIVE VIBRATION ASSESSMENT PROGRAM FOR THE REPLACEMENT STEAM DRYER

The series of steps outlined in Section 1.0 describe the high level analysis and test related tasks that represent the GEH implementation of RG 1.20 requirements for the RSD. The focus of this report is the structural FIV analysis and test (i.e., measurement) requirements, which make up two of the three main elements of the comprehensive vibration assessment program described in the guide (the third element is inspection). This section describes the RG requirements as they relate to the RSD.

As discussed in Section 1.0, each RSD is subject to predictive analyses and verification through instrumentation during power ascension at initial startup. For the analysis, the acceptance limits are 13,600 psi. For additional conservatism in the design basis predictive analysis, the analysis stress results will meet a recommended MASR of 2.0 between the analysis results and the fatigue acceptance limit. The startup testing then uses the fatigue limit stress amplitude of 13,600 psi with a MASR of 1.0 as the basis for acceptance limits for the on-dryer instrument measurements during power ascension. A confirmatory stress analysis is performed based on the on-dryer measurements following startup testing.

The lead unit RSD will be classified per RG 1.20 (Reference A.1). Because of the evolutionary nature of the dryer design, a RSD is typically similar to a previous valid prototype design, leading to a non-prototype designation. However, if the changes to the steam dryer design are significant, this can lead to a prototype designation. Once a prototype RSD design has been validated, subsequent applications of that RSD design are classified as Non-prototype Class I referencing the valid prototype design.

The following regulatory positions of RG 1.20 (Reference A.1) for prototype steam dryers address the program elements applicable to the BWR RSDs:

- Position 2.1 provides a description of the vibration and stress analysis program, including specific items that should be included in the vibration and stress analysis submittal prior to implementation of the vibration measurement program.
- Position 2.2 provides a description of the vibration and stress measurement program, which is to verify the structural integrity of reactor internals, determine the margin of safety, and confirm results of the vibration analysis.
- Position 2.3 describes the inspection program for inspection both prior to and following plant operation.
- Position 2.4 describes documentation of results of the program.
- Position 2.5 describes the schedule for conducting the vibration assessment program.

The following sections describe the analyses, reporting requirements, and conformance associated with the first three RG 1.20 positions above:

1) Vibration and stress analysis program
2) Vibration and stress monitoring program

3) Inspection program

Again, typically a RSD will be designed similar to previous plant designs, leading to a non-prototype designation. The following section discusses how the RSD methodology meets the RG 1.20 requirements.

10.1 RSD Vibration and Stress Analysis Program

The elements that are to be included in a Steam Dryer Design Analysis Report (SDAR) are as follows, per RG 1.20 (Reference A.1):

a. Describe the theoretical structural and hydraulic models and analytical formulations or scaling laws and scale models used in the analysis, including all bias errors and uncertainties for reactor internals that, based on past experience, are not adversely affected by the flow-excited acoustic resonances and flow-induced vibrations.

   When following this RG, licensees of operating nuclear power plants should obtain plant-specific data to confirm the scale testing and analysis results for pressure fluctuations and vibration prior to submitting a power uprate request.

b. Describe the structural and hydraulic system natural frequencies and associated mode shapes that may be excited during steady-state and anticipated transient operation, for reactor internals that, based on past experience, are not adversely affected by the flow-excited acoustic resonances and flow-induced vibrations.

c. Describe the estimated random and deterministic forcing functions, including any very-low-frequency components, for steady-state and anticipated transient operation for reactor internals that, based on past experience, are not adversely affected by the flow-excited acoustic resonances and flow-induced vibrations.

d. Summarize the calculated structural and hydraulic responses for operation under steady-state and anticipated transient conditions for reactor internals that, based on past experience, are not adversely affected by the flow-excited acoustic resonances and flow-induced vibrations. This summary should identify the random, deterministic, and overall integrated maximum response, any very-low-frequency components of response, and the level of cumulative fatigue damage.

e. Summarize the calculated structural and hydraulic responses for preoperational and initial startup testing conditions, compared to those for normal operation. This summary should address the adequacy of the test simulation to normal operating conditions.

f. Identify the anticipated structural or hydraulic vibratory response [defined in terms of frequency, amplitude (displacement, acceleration, and/or strain), and modal contributions] that is appropriate to each of the sensor locations for steady-state and anticipated transient preoperational and startup test conditions.

g. Specify the test acceptance criteria with permissible deviations and the bases for the criteria. The criteria should be established in terms of maximum allowable response levels in the structure, and presented in terms of maximum allowable response levels at sensor locations.

The SDAR report and the Appendices cover the following as described in Section 1.0 of this Appendix, which is in compliance with RG 1.20 (Reference A.1):

a. Describe the as-designed BWR RSD dryer, dryer loading, and dryer stress analysis results.

b. Provide a definition of the methodology including previous application results.

c. Describe the bias and uncertainty application methodology that has been successfully used in the previous RSD projects.

d. Describe how the alternating peak stress intensities at the high stress locations are calculated and tabulate the predicted alternating peak stress intensities.

e. Demonstrate that compared to the fatigue acceptance criteria, the stress margins for all dryer components exceed the NRC-recommended MASR of 2.0.

f. Include spectra and cumulative stress plots for the top five stress locations.

g. Describe a dryer startup test plan including sensor locations sufficient to extract important resonances, with regional frequency response functions sufficiently resolved to establish regional bias and uncertainty for frequencies up to [[ ]]. These regional biases and uncertainties will then be combined into biases and uncertainties for the upper and lower dryer region, consistent with the [[ ]] bias and uncertainties used in the as-designed structural analyses.

h. Incorporate lessons learned from power ascension of previous BWR RSD plants, as applicable.

Table 10.1-1 provides the conformance of the SDAR and its Appendices to the requirements contained in Section 2.1 of RG 1.20 Revision 3 (Reference A.1). As can be seen in the table, the methodology addresses and conforms to all applicable RG 1.20 requirements. Note that the requirements below are for a "prototype" design, as specified in RG 1.20, Section 2. Being conservative, the methodology and reports meet all of these requirements, even if the RSD design is classified as a "non-prototype."

Table 10.1-1: RG 1.20 Requirement Conformance Table

RG 1.20 Section	Criteria	SDAR Conformance
2.1.(1)(a)	Determine the pressure fluctuations and vibration in the applicable plant systems under flow conditions up to and including the full operating power level. Such pressure fluctuations and vibration can result from hydrodynamic effects and acoustic resonances under the plant system fluid flow conditions.	Acceptable - The PBLE method is applicable up to the full power level of the plant. Benchmarking results contained in Appendix B and C show that the method is capable of accurately determining pressure fluctuations from both hydrodynamic and acoustic resonance sources under flow conditions up to the plant full operating power level.
2.1.(1)(b)	Justify the method for determining pressure fluctuations, vibration, and resultant cyclic stress in plant systems. Based on past experience, Computational Fluid Dynamics (CFD) analyses might not provide sufficient quantitative information regarding high-frequency pressure loading without supplemental analyses. Scale testing can be applied for the high-frequency acoustic pressure loading and for verifying the pressure loading results from CFD analyses and the supplemental analyses, where the bias error and random uncertainties are properly addressed.	Acceptable -The justification that the PBLE method is acceptable is based on the benchmarking shown in each PBLE Appendix. Biases and uncertainties are also quantified for both PBLE methods. CFD modeling is not applicable to the PBLE method.

RG 1.20 Section	Criteria	SDAR Conformance
2.1.(1)(c)	Address significant acoustic resonances that have the potential to damage plant piping and components including steam dryers, and perform modifications to reduce those acoustic resonances, as necessary, based on the analysis.	Acceptable – The SDAR determines conservative values of acoustic resonances that may be detrimental to the steam dryer based on theoretical analysis and measured plant values and includes them in the load definition PBLE02 method. PBLE01 method measures acoustic resonances directly. Modifications for reducing acoustic resonances are beyond the scope of this analysis.
2.1.(1)	Scale Model Testing	N/A - PBLE methodology uses real plant data from a prototype plant in place of a detailed scale model. Also, it may be noted that initial understanding of MSL phenomena was developed using scale model data.
2.1.(1)	Computational Fluid Dynamic Modeling	N/A - Simple acoustic modeling of MSL and the SRV cavity is utilized to determine SRV resonant frequencies in combination with historic past benchmark plant SRV resonance behavior. This level of modeling with available data sets has shown in past work that sufficient approximations for SRV resonance phenomena can be developed and used to apply conservative FIV dryer loads.

RG 1.20 Section	Criteria	SDAR Conformance
2.1.(2)	Describe the structural and hydraulic system natural frequencies and associated mode shapes that may be excited during steady-state and anticipated transient operation, for reactor internals that, based on past experience, are not adversely affected by the flow-excited acoustic resonances and flow-induced vibrations. Additional analyses should be performed on those systems and components, such as steam dryers and main steam system components in BWRs and steam generator internals in Pressurized Water Reactors (PWRs) that may potentially be adversely affected by the flow-excited acoustic resonances and flow-induced vibrations. These additional analyses are summarized below.	Acceptable - The PBLE method is capable of determining the acoustic mode shapes within the reactor steam dome. It will simulate the acoustic response of the steam dome from the significant excitation sources.
2.1.(2)	Determine the damping of the excited mode shapes, and the FRFs (i.e., vibration induced by unit loads or pressures, and stresses induced by unit loads or pressures), including all bias errors and uncertainties.	Acceptable – FRFs are developed by PBLE. Bias errors and uncertainties have been addressed in the PBLE Appendices. Structural damping and FRFs are discussed in the main SDAR and the Appendices; biases and uncertainties are included.

RG 1.20 Section	Criteria	SDAR Conformance
2.1.(3)	Describe the estimated random and deterministic forcing functions, including any very-low-frequency components, for steady-state and anticipated transient operation for reactor internals that, based on past experience, are not adversely affected by the flow-excited acoustic resonances and flow-induced vibrations. Additional analyses should be performed on those systems and components, such as steam dryers and main steam system components in BWRs and steam generator internals in PWRs that may potentially be adversely affected by the flow-excited acoustic resonances and flow-induced vibrations. These additional analyses are summarized below.	Acceptable – PBLE method is capable of determining the forcing functions in the frequency range important to BWR dryers.
2.1.(3)	Evaluate any forcing functions that may be amplified by lock-in with an acoustic and/or structural resonance (sometimes called self-excitation mechanisms). A lock-in of a forcing function with a resonance strengthens the resonance amplitude. The resulting amplitudes of the forcing function and resonance response can therefore be significantly higher than the amplitudes associated with non-lock-in conditions.	N/A - Lock in assessment is not required for PBLE02 loads [[ ]]

RG 1.20 Section	Criteria	SDAR Conformance
2.1.(3)	The applicant/licensee should determine the design load definition for all reactor internals, including the steam dryer in BWRs up to the full licensed power level, and should validate the method used to determine the load definitions based on scale model or plant data. BWR applicants should include instrumentation on the steam dryer to measure pressure loading, strain, and acceleration to confirm the scale model testing and analysis results. BWR licensees should obtain plant data at current licensed power conditions for use in confirming the results of the scale model testing and analysis for the steam dryer load definition prior to submitting a power uprate request.	Acceptable – The PBLE uses plant data, [[ ]], for the determination of the steam dryer load definition. Scale model data is not used in the PBLE methodology. Load definitions are validated by benchmarks and bias/uncertainties comparing predictions to on-dryer measured plant data (typically strain, acceleration and pressure). Previous measured plant data is used to predict all load conditions from CLTP to EPU.

RG 1.20 Section	Criteria	SDAR Conformance
2.1.(3)	In recent BWR EPU requests, some licensees have employed a model to compute fluctuating pressures within the RPV and on BWR steam dryers that are inferred from measurements of fluctuating pressures within the MSLs connected to the RPV. Applicants should clearly define all uncertainties and bias errors associated with the MSL pressure measurements and modeling parameters. The bases for the uncertainties and bias errors, such as any experimental evaluation of modeling software, should be clearly presented. There are many approaches for measuring MSL pressures and computing fluctuating pressures within the RPV and the MSLs. Although some approaches reduce bias and uncertainty, they still have a finite bias and uncertainty, which should be reported. Based on historical experience, the following guidance is offered regarding approaches that minimize uncertainty and bias error:	Acceptable –The PBLE methodology in the appendices demonstrates the methodology to determine bias errors and uncertainties associated with the PBLE methodology.
2.1.(3)(a)	At least two measurement locations should be employed on each MSL in a BWR. However, using three measurement locations on each MSL improves input data to the model, particularly if the locations are spaced logarithmically. This will reduce the uncertainty in describing the waves coming out of and going into the RPV. Regardless of whether two or three measurement locations are used, no acoustic sources should exist between any of the measurement locations, unless justified.	Acceptable – The PBLE02 methodology described in the Appendix requires the use of at least [[ ]]

RG 1.20 Section	Criteria	SDAR Conformance
2.1.(3)(b)	Strain gauges (at least four gauges, circumferentially spaced and oriented) may be used to relate the hoop strain in the MSL to the internal pressure. Strain gauges should be calibrated according to the MSL dimensions (diameter, thickness, and static pressure). Alternatively, pressure measurements made with transducers flush-mounted against the MSL internal surface may be used. The effects of flow turbulence on any direct pressure measurements should be accounted for in a bias error and uncertainty estimate.	Acceptable – The PBLE02 Appendix describes [[ ]] Bias and uncertainty associated with the [[ ]] system is described.
2.1.(3)(c)	The speed of sound used in any acoustic models should not be changed from plant to plant, but rather should be a function of temperature and steam quality.	Acceptable – The speed of sound used in the analyses is a function of the steam fluid conditions [[ ]].
2.1.(3)(d)	Reflection coefficients at any boundary between steam and water should be based on rigorous modeling or direct measurement. The uncertainty of the reflection coefficients should be clearly defined. Note that simply assuming 100-percent reflection coefficient is not necessarily conservative.	Acceptable – The reflection coefficients are based on the fluid conditions of the steam water interface. The associated uncertainty is developed for the PBLE02 method.
2.1.(3)(e)	Any sound attenuation coefficients should be a function of steam quality (variable between the steam dryer and reactor dome), rather than constant throughout a steam volume (such as the volume within the RPV).	Acceptable – The PBLE method formulation uses the steam quality in the reactor steam dome, within [[ ]] to determine the sound attenuation coefficients in those regions.

RG 1.20 Section	Criteria	SDAR Conformance
2.1.(3)(f)	Once validated, the same speed of sound, attenuation coefficient, and reflection coefficient should be used in other plants. However, different flow conditions (temperature, pressure, quality factor) may dictate adjustments of these parameters.	Acceptable – The formulations for the speed of sound and damping used in the PBLE are not changed between plant applications. The plant-specific values for these parameters are based on the plant-specific thermodynamic properties of steam [[ ]].
2.1.(4)	The calculated responses should include vibrations for components that have maximum vibration limits, as well as stresses for components that have maximum stress criteria (such as the fatigue stress limits specified in Section III of the ASME Boiler and Pressure Vessel Code, Reference A.3). The margins against violating the criteria should be reported. Based on the uncertainties and bias errors identified in items 1–3 above, an end-to-end uncertainty and bias error should be reported, along with a clear explanation of how the individual uncertainties and bias errors have been combined.	Acceptable –Limit curves, margins, and biases, uncertainties, and [[ ]] biases and uncertainties are reported. The FIV load is benchmarked against previously instrumented dryer data. Methods have a description of all biases, uncertainties, and their combinatorial methodology.

RG 1.20 Section	Criteria	SDAR Conformance
2.1.(4)	Since the transfer functions (or FRFs) described in item 2, and forcing functions described in item 3, have an uncertainty associated with the frequencies of the response peaks attributable to resonant modes, the vibration and stress calculations should address those uncertainties by shifting either the FRFs or forcing functions in frequency to span the uncertainty in the response peak frequencies…. … the worst case vibration or stress should be reported, since the frequency uncertainty leads to a negative (non- conservative) bias in the vibration and stress when any modal peaks are misaligned with any forcing function peaks.	Acceptable - Methodology calculates time/frequency shift of structural response and reports the worst case vibration or stress.
2.1.(5)	Summarize the calculated structural and hydraulic responses for preoperational and initial startup testing conditions, compared to those for normal operation. This summary should address the adequacy of the test simulation to normal operating conditions.	Acceptable – Methodology predicts response at a variety of conditions, and the limiting condition is used. Limit curves and margins are reported.
2.1.(6)	Identify the anticipated structural or hydraulic vibratory response [defined in terms of frequency, amplitude (displacement, acceleration, and/or strain), and modal contributions] that is appropriate to each of the sensor locations for steady-state and anticipated transient preoperational and startup test conditions.	Acceptable – Methodology predicts response at a variety of conditions, and the limiting condition is used. Limit curves and margins are reported.

RG 1.20 Section	Criteria	SDAR Conformance
2.1.(7)	Specify the test acceptance criteria with permissible deviations and the bases for the criteria. The criteria should be established in terms of maximum allowable response levels in the structure, and presented in terms of maximum allowable response levels at sensor locations.	Acceptable –Power Ascension Test Plan is provided with limit curves and margins.
2.1.(7)	Based on steam dryer and MSL valve failures that have occurred in BWR plants operating at EPU conditions, the following test acceptance criteria are provided for future BWR license applications. After developing a steam dryer load definition, an applicant for the construction and operation of a BWR nuclear power plant (or a licensee using this regulatory guide in planning a power uprate for an operating BWR nuclear power plant) should apply the load definitions to vibration and stress models to determine the vibrations of the valves and stresses within the steam dryer, with justified damping assumptions and applicable weld factors and stress intensities. After including applicable bias errors and random uncertainties, the applicant/licensee should compare valve vibrations against applicable limits, and peak stresses at critical steam dryer locations to the fatigue limits in the ASME Boiler & Pressure Vessel Code (Reference A.3).	Acceptable - Peak stresses at critical steam dryer locations, are compared to the fatigue limits in the ASME Boiler & Pressure Vessel Code. These values are reported in the SDAR.

RG 1.20 Section	Criteria	SDAR Conformance
2.1.(7)	The applicant/licensee should also compare stresses, at any locations that might have experienced fatigue cracking, with the ASME Code fatigue limits to validate the stress model. The applicant/licensee should also compare the primary and secondary stresses that the steam dryer may experience as a result of plant transients to the applicable ASME Code service level limits. The BWR applicant/licensee should also implement modifications to the BWR steam dryer based on the design stress margin or to any components responsible for high excitation to reduce that excitation, so that none of the resulting stresses exceed the Code allowable limits.	Acceptable – Methodology outlined in Section 8.0 in Appendix A as well as the results in Section 4.2.4 and 5.0 in the SDAR show that the stresses for all structural components are below the ASME Code allowable limits at EPU operating conditions for Normal, Upset and Emergency service levels. All components meet the requirements for the Faulted service levels with the exception of the seismic blocks. The justification for acceptance of seismic blocks is provided in Section 4.2.4.

RG 1.20 Section	Criteria	SDAR Conformance
2.1.(7)	The BWR applicant/licensee should also develop a vibration limit curve for valves and a stress limit curve for the steam dryer for power ascension to provide assurance that the valve vibrations and stress in the individual steam dryer components will not exceed the ASME Code fatigue limits. The limit curves, while including the bias errors and uncertainties from the end-to-end vibration and stress analyses, should also include those associated with the vibration and stress measurement program (in particular, those associated with the data acquisition systems and instrumentation). The BWR applicant/licensee should also develop a method for collecting plant data during power ascension and full licensed power conditions that can be used to calculate the valve vibrations steam dryer stress, including appropriate bias errors and random uncertainties. As the steam dryer is not a Code component, the applicant/licensee may justify different stress acceptance criteria.	Acceptable –The Power Ascension Test Plan (PATP) is provided with limit curves and margins. The method for collecting plant data during power ascension is summarized in the SDAR and Appendix A, and the PATP will have the specifics of the data collection during power ascension.

10.2 RSD Power Ascension Monitoring Program

The FIV PATP describes the planned course of action for monitoring, evaluating, and taking prompt action in response to potential adverse flow effects as a result of power uprate operation on the RSD during power ascension testing and operation from the current licensed thermal power to the full EPU level.

The PATP covers power ascension up to the full EPU condition to verify acceptable structural performance and steam dryer integrity. Through the establishment of acceptance limits, data collection and analysis, and any subsequent actions, the PATP will ensure that the integrity of the steam dryer will be maintained. An important element of the plan during the power ascension to the previous licensed thermal power is the benchmarking of the PBLE load definition and structural analysis methodology at CLTP using plant-specific measured data.

The plan includes specific hold points and durations during power ascension above CLTP, activities to be accomplished during hold points, data to be collected, data evaluation methods, and acceptance criteria for monitoring and trending plant parameters. Detailed procedures are developed to implement this plan.

The vibration and stress monitoring may be accomplished using [[

]] The sensors will be calibrated and have associated biases and uncertainties included in the monitoring and stress analyses.

The basic components of the the vibration and stress measurement program are describe here. The test plan itself is plant-specific and requires integration with the overall plant power ascension test plan and, therefore, is not included here as it is beyond the scope of this document.

10.2.1 Power Ascension Test Plan

The power ascension test plan describes the monitoring that will be performed to assure that the dryer stresses will remain within the acceptance criteria during plant operation. The PAT plans are different [[

]] The PAT plan will include the following:

- Level 1 and Level 2 acceptance limits for instrumentation measurements.
- Specific hold points and their duration during power ascension.
- Activities to be accomplished during hold points.
- Plant parameters to be monitored.
- Actions to be taken if acceptance criteria are not satisfied.
- Verification of the completion of commitments and planned actions.

10.2.1.1 [[ ]] Power Ascension Test Plan

Power ascension monitoring for [[
]] At the initial hold point during the power ascension (i.e., CLTP power level):

a. Record pressures, strains, and/or accelerations from the available instrumentation. Process/evaluate the data and compare to acceptance limits.

b. Develop a Plant Based Load Evaluation (PBLE)-based FIV load definition based on available instruments. Using appropriate methods, [[
]] and the above PBLE-based RSD load definition; predict the steam dryer strain and acceleration response at this condition.

c. Compare the predicted steam dryer strain and acceleration against the measured data and determine [[ ]] bias and uncertainty values.

Adjust the predicted strain and acceleration responses using the [[ ]] bias and uncertainty values.

d. Define [[ ]]

e. Update [[ ]]

f. Trend [[ ]]

g. Monitor [[ ]]

h. Make available to the NRC the RSD analysis summary, updated stress analysis results (including [[ ]] bias and uncertainty), limit curves, and data projections for higher power levels.

Power ascension above initial hold point will proceed in increments of no more than [[ ]] The data will be evaluated, including comparison of measured dryer strains and accelerations to acceptance limits. Power will remain steady during this evaluation to determine if any actions need to be taken before proceeding to the next assessment point. If a Level 1 limit curve is exceeded, the power will be reduced to a previous power level where Level 1 is not exceeded and the limit curves will be reassessed. If necessary, a stress analysis will be performed to develop new limit curves.

After full EPU power has been achieved, a report for confirmatory stress analysis will be provided to the NRC within 90 days of reaching the EPU power level. The report will include the minimum stress ratio and the final dryer load definition using steam dryer instrumentation, and associated bias errors and uncertainties, to demonstrate that the steam dryer will maintain its structural integrity over its design life.

10.2.1.2 Power Ascension Test Plan [[ ]]

The power ascension for the [[ ]]. The [[ ]] curves will be developed as follows:

1. Develop the [[ ]] These limit curves are made using the same 2 minute time record as the confirmatory analysis load definition. [[ ]]
2. If needed, develop and implement an additional [[ ]]
3. Develop a total pressure limit value to accommodate [[ ]]

[[ ]] At the initial hold point during the power ascension (i.e., CLTP power level):

a. Record [[ ]] and develop on-dryer loads.
b. Compare [[ ]]
c. Trend the [[ ]]
d. Calculate adjusted stresses based [[ ]]
e. If necessary, update [[ ]]
f. Make available to the NRC the RSD analysis summary, updated stress analysis results, limit curves, and data projections for higher power levels.

Power ascension above initial hold point will proceed in increments of no more than [[ ]] The data will be evaluated, including comparison of dryer loads to acceptance limits. Power will remain steady during this evaluation to determine if any actions need to be taken before proceeding to the next assessment point. If a Level 1 limit curve is exceeded, the power will be reduced to a previous power level where Level 1 is not exceeded and the limit curves will be reassessed. If necessary, a stress analysis will be performed to develop new limit curves.

After full EPU power has been achieved, a report for confirmatory stress analysis will be provided to the NRC within 90 days of reaching the EPU power level. The report will include the minimum stress ratio and the final dryer load definition [[ ]] to demonstrate that the steam dryer will maintain its structural integrity over its design life.

10.3 RSD Inspection Program

A periodic steam dryer inspection program will be implemented with the following key elements:

1. During the first two scheduled refueling outages after reaching full power conditions, a visual inspection will be conducted of all accessible areas and susceptible locations of the steam dryer in accordance with accepted industry guidance on steam dryer inspections. The results of these baseline inspections will be provided to the NRC within 60 days following startup after each outage.
2. At the end of the second refueling outage following full power operation, an updated steam dryer monitoring program (SDMP) reflecting a long-term inspection plan based on plant-specific and industry operating experience will be provided to the NRC within 180 days following startup from the second refueling outage.

11.0 CONCLUSIONS

This report describes the generic GEH RSD analysis methodology that will be used to evaluate the structural response to demonstrate that the RSD will maintain structural integrity during normal plant operation and under transient, and accident conditions. The analyses must show that the dryer will maintain its structural integrity (and not generate loose parts) when subjected to acoustic and hydrodynamic fluctuating pressure loads during normal operation. This report also provides the overall dryer analysis framework, which includes the PBLE01 and PBLE02 load definition method; the structural analyses including the application of bias and uncertainty, and design margin; and the power ascension test program.

The structural analysis follows a staged or phased approach, which leverages information that will be made available as the design process progresses (especially through the power ascension test program). The culmination of the analysis and test program will be a validated design, supported by a benchmark as a basis for bias and uncertainty. The PBLE Method 1, Method 2 and structural analysis approach have been applied to a RSD under power uprate conditions as an example of a successful implementation of the GEH methodology. This methodology satisfies RG 1.20 (Reference A.1).

The structural analysis approach, design criteria, and integrated power ascension test program provide adequate assurance that the RSD will maintain its structural integrity and not generate loose parts under normal, transient, and accident conditions.

12.0 REFERENCES

A.1 U.S. Nuclear Regulatory Commission, Regulatory Guide 1.20, "Comprehensive Vibration Assessment Program for Reactor Internals During Preoperational and Initial Startup Testing," Revision 3, March 2007.

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Appendix B

Steam Dryer Plant Based Load Evaluation Methodology PBLE01 Model Description

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LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

Term	Description
3D	Three Dimensional
ASME	American Society of Mechanical Engineers
BFNP	Browns Ferry Nuclear Plant
BWR	Boiling Water Reactor
CAD	Computer-Aided Design
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
CLTP	Current Licensed Thermal Power
E2E	End to End
EPU	Extended Power Uprate
FE / FEM	Finite Elements / Finite Element Method / Finite Element Model
FIV	Flow Induced Vibration
FRF	Frequency Response Function
GDC	General Design Criteria
GEH	GE Hitachi Nuclear Energy
[[	]]
Hz	Hertz
[[	]]
MSL	Main Steam Line
NRC	Nuclear Regulatory Commission
OLTP	Original Licensed Thermal Power
PBLE	Plant Based Load Evaluation
PBLE01	Plant Based Load Evaluation Method 01 ([[ ]])
PBLE02	Plant Based Load Evaluation Method 02 ([[ ]])

Term	Description
PSD	Power Spectral Density
PT	Pressure Transducer
RG	Regulatory Guide
RMS	Root Mean Square
RPV	Reactor Pressure Vessel
SF	Singularity Factor
SG	Strain Gauge
SRV	Safety / Relief Valve
U	Unit
VPF	Vane Passing Frequency

ABSTRACT

A methodology, termed Plant Based Load Evaluation (PBLE01), is presented for defining the fluctuating loads that are imposed upon the boiling water reactor (BWR) steam dryer. The PBLE01 load definition can be applied to a structural finite element model of the steam dryer in order to determine the steam dryer alternating stresses. The overall steam dryer methodology is applied to an operating BWR replacement steam dryer as an example of the successful implementation of the methodology.

1.0 INTRODUCTION

As a result of steam dryer issues at operating Boiling Water Reactors (BWRs), the United States (US) Nuclear Regulatory Commission (NRC) has issued revised guidance concerning the evaluation of steam dryers (Reference B.1). Analysis must show that the dryer will maintain its structural integrity during plant operation due to acoustic and hydrodynamic fluctuating pressure loads. This demonstration of steam dryer structural integrity comes in three steps:

Predict the fluctuating pressure loads on the dryer,

Use these fluctuating pressure loads in a structural analysis to qualify the steam dryer design, and

Implement a startup test program for confirming the steam dryer design analysis results as the plant performs power ascension.

The PBLE (Plant Based Load Evaluation) is an analytical tool developed by GEH to perform the prediction of fluctuating pressure loads on the steam dryer. [[

]] This report provides the theoretical basis of PBLE01 that will be applied for determining the fluctuating loads on the Browns Ferry steam dryer, describes the PBLE01 analytical model, determines the biases and uncertainties of the PBLE01 formulation, and describes the application of the PBLE01 method to the evaluation of the steam dryer.

This report also provides an example implementation of the Flow-Induced Vibration (FIV) analysis methodology. The overall structural evaluation for the Browns Ferry steam dryer is described in Appendix A of this document.

2.0 MODEL DESCRIPTION

2.1 Overview

[[ ]]

Figure 2.1-1: PBLE01 Process Flow

The PBLE01 [[

]] This is the methodology to be used in the Browns Ferry power ascension evaluation and is described in this report. [[

]]

PBLE01 is built on the commercial software packages Matlab (Reference B.2) and Virtual.Lab/Sysnoise (Reference B.3). Matlab is a software package designed for engineering computations. The general architecture of the PBLE01 scripts makes use of the Matlab programming language and graphical interface.

The vessel acoustic response is calculated with Virtual.Lab/Sysnoise software. Virtual.Lab/Sysnoise is a program for modeling acoustic wave behavior in fluids, using implementations of the finite element and boundary element methods. In the PBLE01 context, Virtual.Lab/Sysnoise calculates how sound waves propagate through a FEM model of the RPV dome steam volumes. This 3D acoustic model is described in detail in Section 2.2 below. Alternate Finite Element (FE) programs as described in Appendix B7 can also be used.

2.2 Dome Acoustic Model

2.2.1 Acoustic Modeling Principles

Virtual.Lab/Sysnoise (Reference B.3) models acoustics as a wave-phenomenon. The modeling is carried out in the frequency domain, thus using the so-called Helmholtz form of the wave equation (see e.g., References B.4 and B.5). [[

]] The following linear system of equations is solved:

$$\left[K + i\omega C - \omega^2 M\right]\{p\} = \{F_A\}$$

Equation 2.2-1

Where F_A is the vector of nodal acoustic forces and is proportional to the normal velocity boundary conditions imposed on the faces of the mesh. The stiffness *[K]*, damping *[C]* and mass *[M]* matrices are computed at each frequency. The system of equations is thus set up and solved to obtain the pressure distribution *{p}*. The velocity field is obtained by differentiation of the pressure field at the Gauss points of the elements and then extrapolation and averaging at the nodes.

2.2.2 Geometry Modeling

The dome FE mesh (Figure 2.2-1) comprises all RPV steam volumes [[
]]

In all GEH BWRs, there are two steam zones with different steam qualities, upstream and downstream of the dryer. [[

]]

[[ ]]

Figure 2.2-1: Modeled Steam Region (left) and Details of Typical Vessel Meshes (right)

[[

]]

[[ ]]

Figure 2.2-2: [[
]]

Table 2.2-1: Example of First Ten RPV Acoustic Modes

Mode No.	Modal Frequency (Hz)
1	[[
2	
3	
4	
5	
6	
7	
8	
9	
10	]]

2.2.3 Finite Element Model

[[

]]

[[ ]]

Figure 2.2-3: [[
]]

[[

]]

[[ ]]

Figure 2.2-4: [[ ]]

[[

]]

[[ ]]

Figure 2.2-5: [[
]]

2.2.4 Fluid Properties and Boundary Conditions

[[

]]

Steam and water properties including impedance boundary conditions are described in detail in Section 2.4.

[[ ]]

Figure 2.2-6: [[ ]]

2.3 PBLE01 from [[ ]]

2.3.1 Solution Formulation

The pressure at any dryer point P [[

]]

These considerations make PBLE01 [[ ]] a quite powerful tool.

2.3.2 Singularity Factor

The Singularity Factor (SF) is a tool to understand the mathematical limitations in PBLE01. It is calculated as:

[[

]]

[[ ]]

[[ ]]

Figure 2.3-1: [[ ]]

2.4 Steam and Water Acoustic Properties

This section describes all steam and water characteristic properties used in PBLE01 models:

[[

]]

Dry steam properties, including speed of sound and density, are readily known from standard steam tables published by the International Association for the Properties of Water and Steam (Reference B.7). Petr (Reference B.8) developed the wet steam model used in PBLE01.

[[

]] by Karplus (Reference B.9).

2.4.1 Wave Propagation in Wet Steam

The following summary follows the description given in Section 2 of Reference B.8. The variable nomenclature for this section is in Table 2.4-1.

[[

]]

Table 2.4-1: Variables in Equations 2.4-1 through 2.4-8

[[	
	]]

[[

]]

[[ ]]

Figure 2.4-1: [[ ]]

2.4.2 Vane Upstream Droplet Wetness Correlation

During development of PBLE01, [[ ]]

[[ ]]

Figure 2.4-2: [[ ]]

2.4.3 Steam-Water Interface

[[ ]]

[[ ]]

Figure 2.4-3: Steam-Water Interfaces

Table 2.4-2: Impedances in a Typical BWR RPV Environment

[[				
				]]

[[ ]]

Figure 2.4-4: Speed of Sound in [[ ]] **(Figure 5 in Karplus (Reference B.9))**

The solution that was adopted for the PBLE01 is to model [[

]]

3.0 MODEL QUALIFICATION: BWR PLANT VALIDATION

A BWR/4 replacement steam dryer, installed in 2008, was instrumented [[ ]]. This section presents the steam dryer fluctuating load definitions obtained with the PBLE01 method using the BWR/4 benchmark plant data.

3.1 BWR/4 RPV - Steam Dryer Acoustic Model

[[

]]

3.2 Steam Dryer Instrumentation

To monitor the steam dryer pressure loads, the BWR/4 steam dryer was instrumented with [[ ]] (Figure 3.2-1). [[ ]]

The locations of the PTs are described in Figure 3.2-1. The regional layout of the BWR/4 PT sensors is also shown in Appendix B1. [[

]]

The PBLE01 benchmark reported in this report was performed at several power levels. Four test conditions are reported (Table 3.2-1):

These conditions were selected to span the range of steam flows from [[

]]

Table 3.2-1: BWR/4 Test Conditions Associated with Steam Dryer Benchmark Cases

Test Condition	**Power** [MWth]	**Power** [% OLTP*]	**Power** [% EPU*]	**Steam Flow** [Mlbs/hr]	**Core Flow** [Mlbs/hr]
[[					

]]

The on-dryer pressure transducer data was then used with the acoustic model described above and the methodology defined in Section 2.0 to predict acoustic loads on the steam dryer.

[[ ]]

Figure 3.2-1: [[ ]]

3.3 PBLE01 Benchmark Process

For each PBLE01 benchmark case, [[

]]

Pressure PSD Comparison: Measured vs. PBLE01 Projected

The comparisons of the measured and projected PSDs for each individual dryer pressure sensor for [[ ]] are plotted in Appendices B2 and B3 for [[ ]] (Table 3.2-1) respectively. Also is included the PSD comparison for the differential pressure benchmark [[

]]

3.4 PBLE01 Benchmark Bias and Uncertainty Results

[[

]]

[[ ]]

Figure 3.4-1: [[ ]]

[[ ]]

Figure 3.4-2: [[ ]]

3.5 PBLE01 Validation Conclusions

PBLE01 [[ ]] is formulated under the assumption that [[ ]] The objective of PBLE01 is to produce [[ ]] that best explain the measurements given the vessel acoustic environment. [[ ]]

Overall, PBLE01 from [[ ]] emerges as a viable tool for developing dryer load definitions. The comparison plots in Appendices B2 and B3 demonstrate that the PBLE01 methodology is capable of adequately capturing the frequency content across the dryer. [[ ]]

4.0 APPLICATION METHODOLOGY

4.1 Scope of Application and Licensing Requirements

4.1.1 Scope of Application

The scope of the application for the PBLE engineering report is to provide a methodology for determining the fluctuating pressure loads that the Browns Ferry steam dryer will experience during Extended Power Uprate (EPU) operation. This fluctuating load definition can then be applied to a FE model of the Browns Ferry steam dryer in order to determine the structural qualification of the dryer.

4.1.2 Specific Licensing Requirements

Plant components, such as the steam dryer in a BWR nuclear power plant, perform no safety function but must retain their structural integrity to avoid the generation of loose parts that might adversely impact the capability of other plant equipment to perform their safety function. Potential adverse flow effects must be evaluated for the steam dryer to meet the requirements of GDC 1 and 4 in Appendix A of 10 CFR 50.

Section 3 of the Standard Review Plan (Reference B.10) requires that the dynamic responses of structural components with the reactor vessel caused by steady-state and operational flow transient conditions should be analyzed for prototype (first of a design) reactors. The analytical assessment of the vibration behavior of the steam dryer includes the definition of the input-forcing function including bias errors and uncertainty. Reference B.10 and Reference B.11 contain specific acceptance criteria related to formulating forcing functions for vibration prediction. Reference B.1 provides guidance on acceptable methods for formulating the forcing functions for vibration prediction.

4.2 Proposed Application Methodology

The PBLE01 method for formulating the forcing function for vibration prediction for the steam dryer is in conformance with the guidance contained in Regulatory Guide (RG) 1.20 Revision 3 (Reference B.1).

4.2.1 Conformance with RG 1.20 Revision 3

The PBLE01 load definition methodology was developed to satisfy the analysis and vibration program recommendations identified in RG 1.20 Revision 3 (Reference B.1).

A detailed assessment of the comprehensive vibration assessment program for the replacement steam dryer which includes PBLE01 with respect to the RG 1.20 recommendations is provided in Section 10 of Appendix A.

4.3 Range of Application

The PBLE01 method described in this report is capable of determining the vibratory forcing function for the entire operating range of the BWR steam dryer.

4.4 Plant-Specific Application Methodology

4.4.1 Vessel Model Inputs

The vessel [[

]]

Acoustic Finite Element Model Mesh

A FE model of the [[

]]

Table 4.4-1: Parameters in the Computation of FRFs

Phenomena	Parameter
[[	
	]]

4.4.2 Plant Input Measurements

Sensor Type and Location

For PBLE01 [[

]]

Error in Measured Dryer Pressures

This error, [[

]]

In addition, for the on-dryer instrumentation, the strain gauge manufacturer will be involved to ensure proper installation and calibration of the strain gauges used in the measurement program during plant startup testing, including a "pipe and beam" calibration effort, as applicable. If instrumentation is similar to strain gauges used in the past, [[

]] Uncertainties will be evaluated for the specific strain gauges and will be accounted for in the final assessment.

The installation and data acquisition procedures for the on-dryer instrumentation will follow the procedures used at the latest BWR/6 replacement dryer, to the extent applicable to the specific gauges, and will incorporate operating experience from those measurement sessions. To the extent applicable to the type and model of strain gauges used in the measurements, [[

]] The installation procedure, data acquisition procedure, instrumentation acceptance criteria, and instrumentation startup report from the previous work will be updated as part of the implementation of the RG 1.20 comprehensive vibration assessment program.

4.4.3 Plant Specific Load Definition

The following steps are involved in the calculation of dryer loads with PBLE01:

[[

]]

4.5 Example Implementation of Methodology

The Browns Ferry steam dryer methodology using PBLE01 has been applied to a BWR/4 replacement steam dryer at EPU conditions as an example of the successful implementation of the methodology to satisfy RG 1.20. This example implementation includes the fatigue analysis, the development of end-to-end defined bias and uncertainties as well as consideration of lessons learned from issues identified during the analysis of the steam dryer data.

At a high level, the steam dryer fatigue analysis consists of four steps:

(1) Input signal processing, where a time segment or sample of [[ ]] data is selected for input into the acoustic model;

(2) An acoustic load definition where fluctuating pressures are determined from an acoustic FEM of the reactor steam dome containing the dryer;

(3) A dynamic structural evaluation of the dryer, driven from the acoustic loads (i.e., the global model analysis using an ANSYS model;

(4) Post-processing of stress, strain or acceleration results. In the post-processing step, [[

]]

[[ ]] These results are referred to as the projected data at each dryer location (e.g., location of peak stress or location of on-dryer sensor).

The following sections discuss the details of the fatigue evaluations for the BWR/4 replacement steam dryer at EPU conditions as an example implementation of the BWR steam dryer methodology and in particular, the determination and application of the methodology's end-to-end bias and uncertainties.

4.5.1 Structural Model

The BWR/4 replacement steam dryer structural FE model was developed in accordance with the guidelines defined in Appendix A.

The three-dimensional shell FE model of the BWR/4 replacement dryer was constructed from the replacement dryer design drawings using the ANSYS finite element analysis code. [[

]]

The full FE model of the BWR/4 replacement dryer is illustrated in Figure 4.5-1, [[

]]

[[ ]]

Figure 4.5-1: [[ ]]

4.5.2 FIV Analysis

The ANSYS FE code was used to obtain the structural responses of the steam dryer to the FIV loads at the plant conditions where measured data was obtained. The dynamic analysis was performed [[ ]] To achieve better [[

]]

4.5.3 End-to-End Bias and Uncertainties

The final test condition performed during the BWR/4 EPU power ascension is defined as [[ ]] (Table 3.2-1). [[ ]]

As discussed above, pressure loads were generated for this test condition using the PBLE01 Method I based on [[ ]] data at that test condition. These loads were then used to drive the ANSYS FE model to produce the structural response of the steam dryer and the projected strain or acceleration at each on-dryer sensor location.

To monitor the dryer dynamic response [[ ]] were installed. [[ ]]

The accelerometers and strain gauge locations were selected to monitor the global response of [[ ]] The strain and acceleration instruments are well distributed over different dryer regions. Where possible, locations were selected where the sensor would see [[ ]] The regional layout of the BWR/4 accelerometers and strain gauge sensors is summarized in Appendix B1. [[ ]] For the same time segment selected for the generation of the steam dryer loads data was obtained for the on-dryer strain gauges and accelerometers (measured data).

The end-to-end bias values are based on the comparison of the measured PSD data over the projected PSD data at each of the on-dryer sensor locations. For each instrument, [[ ]] seconds of measured PSD data in [[ ]] are compared with the ANSYS-predicted strain and acceleration PSD results based on [[ ]]

Figure 4.5-2 and Figure 4.5-3 show plots of the end to end mean bias and uncertainty [[ ]]. PSD comparisons of the ANSYS predictions from the BWR/4 [[ ]] and the measured data for the analysis time interval are included in Appendix B5 for each sensor. Tabular values of the [[ ]] end-to-end bias and uncertainty are provided in Appendix B6 as a function of frequency.

The comparison plots in Appendix B5 demonstrate that the PBLE01 loads applied to the structural model are capable of adequately capturing the frequency content across the dryer. [[ ]] (Figure 4.5-2 and 4.5-3).

It should be noted that in the present benchmark, [[ ]]

[[ ]]

Figure 4.5-2: [[ ]]

[[ ]]

Figure 4.5-3: [[ ]]

5.0 CONCLUSIONS

The PBLE methodology [[ ]] is available to predict steam dryer pressure loads and their associated uncertainty.

The PBLE01 technique is validated by the BWR/4 application case. From comparison between measurements and projections, PBLE01 predicts good frequency content and spatial distribution. The SRV resonances are well captured. The methodology has been benchmarked by applying the PBLE01 generated loads to an ANSYS finite element model and comparing the predicted strains and accelerations to measured values for on-dryer strain gauges and accelerometers.

The PBLE01 addresses a wide range of load cases:

- MSL valve resonance (SRV/branch line) or broadband excitations (venturi)
- Sources in the vicinity of nozzles
- Hydrodynamic loading (pseudo-pressures)

The effects from the last two types of sources can be advantageously modeled by [[ ]]; for this reason PBLE01 from [[ ]] is adequate to predict fluctuating dryer loads at any BWR plant.

The BWR steam dryer methodology using PBLE01 has been applied to the BWR/4 replacement steam dryer at EPU conditions as an example of the successful implementation of the methodology to satisfy RG 1.20. This example implementation includes the fatigue analysis to develop the end-to-end bias and uncertainties as well as consideration of lessons learned from issues identified during the analysis of the steam dryer data.

6.0 REFERENCES

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B.11 U.S. Nuclear Regulatory Commission, NUREG-0800, Revision 3, March 2007, Section 3.9.5, "Reactor Pressure Vessel Internals."

APPENDIX B1: BWR/4 STEAM DRYER INSTRUMENTATION LOCATIONS

Table B1-1: [[ ]]

[[ ]]

[[ ]]

Figure B1-1: [[ ]]

[[ ]]

Figure B1-2: [[ ]]

[[ ]]

Figure B1-3: [[ ]]

[[ ]]

Figure B1-4: [[ ]]

APPENDIX B2: [[

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Figure #	PT Location
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[[ ]]

Figure B2-1: [[ ]]

[[ ]]

Figure B2-2: [[ ]]

[[ ]]

Figure B2-3: [[ ]]

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Figure B2-4: [[ ]]

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Figure B2-5: [[ ]]

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Figure B2-6: [[ ]]

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Figure B2-7: [[ ]]

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Figure B2-8: [[ ]]

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Figure B2-9: [[ ]]

[[ ]]

Figure B2-10: [[ ]]

[[ ]]

Figure B2-11: [[ ]]

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Figure B2-12: [[ ]]

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Figure B2-13: [[ ]]

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Figure B2-14: [[ ]]

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Figure B2-15: [[ ]]

APPENDIX B3: [[

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Figure #	PT Location
[[	
	]]

[[ ]]

Figure B3-1: [[ ]]

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Figure B3-2: [[ ]]

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Figure B3-3: [[ ]]

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Figure B3-4: [[ ]]

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Figure B3-5: [[ ]]

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Figure B3-6: [[ ]]

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Figure B3-7: [[ ]]

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Figure B3-8: [[ ]]

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Figure B3-9: [[ ]]

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Figure B3-10: [[ ]]

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Figure B3-11: [[ ]]

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Figure B3-12: [[ ]]

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Figure B3-13: [[ ]]

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Figure B3-14: [[ ]]

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Figure B3-15: [[ ]]

APPENDIX B4: [[ ]]

Table B4-1: [[
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APPENDIX B5: [[

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Figure #	PT Location
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[[ ]]

Figure B5-1: [[ ]]

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Figure B5-2: [[ ]]

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Figure B5-3: [[ ]]

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Figure B5-4: [[ ]]

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Figure B5-5: [[ ]]

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Figure B5-6: [[ ]]

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Figure B5-7: [[ ]]

[[ ]]

Figure B5-8: [[ ]]

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Figure B5-9: [[ ]]

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Figure B5-10: [[ ]]

APPENDIX B6: [[

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Table B6-1: [[

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APPENDIX B7: ACOUSTIC FINITE ELEMENT PROGRAM REQUIREMENTS FOR PBLE ACOUSTIC FRF

[[

]]

Appendix C

Steam Dryer Plant Based Load Evaluation Methodology PBLE02 Model Description

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

Term	Description
1D	One Dimensional
3D	Three Dimensional
BFN	Browns Ferry Nuclear Plant
BWR	Boiling Water Reactor
BWR/3	Boiling Water Reactor Version 3
BWR/4	Boiling Water Reactor Version 4
CAD	Computer-Aided Design
CLTP	Current Licensed Thermal Power
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
DAS	Data Acquisition System
DOE	Design of Experiments
EPU	Extended Power Uprate
FE / FEM	Finite Element / Finite Element Method / Finite Element Model
FIV	Flow Induced Vibration
FRF	Frequency Response Function
GDC	General Design Criteria
GEH	GE Hitachi Nuclear Energy
[[	]]
Hz	Hertz
ID	Inside Diameter
[[	]]
LTR	Licensing Topical Report
MSIV	Main Steam Isolation Valve
MSL	Main Steam Line
NRC	Nuclear Regulatory Commission
PBLE	Plant Based Load Evaluation
PBLE01	Plant Based Load Evaluation [[ ]]

Term	Description
PBLE02	Plant Based Load Evaluation [[ ]]
PSD	Power Spectral Density
PT	Pressure Transducer / Pressure Sensor
RG	Regulatory Guide
RMS	Root Mean Squared
RPV	Reactor Pressure Vessel
SF	Singularity Factor
SG	Strain Gauge
SRSS	Square Root of the Sum of the Squares
SRV	Safety / Relief Valve
StDev	Standard Deviation
TMM	Two Microphone Method
TVA	Tennessee Valley Authority
VPF	Vane Passing Frequency

Abstract

NEDC-33824P, *Browns Ferry Nuclear Steam Dryer Analysis Report*, provides the results and methodology for the Steam Dryer Analysis related to the Browns Ferry power uprate. This appendix describes methodology and provides benchmark results for what is termed Plant Based Load Evaluation (PBLE02) for defining the fluctuating pressure loads on replacement steam dryers [[ ]] This supplement provides additional benchmarking results for the PBLE against data taken during startup testing of an instrumented replacement steam dryer at a ([[ ]]), where [[ ]] data is used to predict strain measured during EPU Power Ascension [[ ]] This supplement also provides a detailed description of the related modeling and methodology used to develop loads with PBLE02.

1.0 INTRODUCTION

As a result of steam dryer issues at operating Boiling Water Reactors (BWRs), the US Nuclear Regulatory Commission (NRC) has issued revised guidance concerning the evaluation of steam dryers (Reference C.1). As part of that guidance, the analysis must demonstrate that the dryer will maintain its structural integrity without failing due to fatigue during normal plant operation when subjected to the vibrations resulting from acoustic and hydrodynamic fluctuating pressure loads. This demonstration of steam dryer structural integrity requires three steps:

- Prediction of the fluctuating pressure loads on the dryer,
- Application of the fluctuating pressure loads in a structural analysis to qualify the steam dryer design
- Implementation of a startup test program for confirming the steam dryer design as the plant performs power ascension.

The Plant Based Load Evaluation (PBLE) is an analytical tool developed by GEH to perform the prediction of fluctuating pressure loads on the steam dryer. PBLE01 provides the theoretical basis of the PBLE method that will be applied for determining the fluctuating loads on the Browns Ferry steam dryer, describes the PBLE analytical model, and provides benchmark results of the PBLE with [[ ]] pressure data.

This report is a separate supplement from the PBLE01 description, found in Appendix B. The PBLE01 appendix focuses on a load solution that [[ ]] This appendix for PBLE02 describes the load solution obtained from [[ ]] In addition, this supplement provides the results of benchmarking studies of the PBLE against measured [[ ]] pressure data taken during power ascension testing of a replacement steam dryer installed at a [[ ]].

In summary, PBLE is a methodology to predict acoustic pressure loading on BWR Nuclear Power Plant Steam Dryers for use in predicting vibratory stress for comparison against fatigue limits. This can be done based on either pressure data [[ ]] This section specifically covers the use of PBLE02 with [[ ]] to analyze the Browns Ferry Steam Dryer and discusses related benchmark work that includes comparing the use of [[ ]] from a [[ ]] Benchmark Plant utilized [[ ]] In particular, this section presents [[ ]] bias and uncertainty results based on using [[

]]

2.0 MODEL DESCRIPTION

Section 2.1 provides a brief overview of the PBLE model (with process flow depicted in Figure 2.1-1). Section 2.2 provides a summary of the steam dome acoustic model presented in detail in the [[ ]] PBLE01 Appendix B. The steam dome acoustic model [[ ]]. Section 2.3 develops the methodology for the [[ ]] formulation for PBLE02.

2.1 Overview

The PBLE methodology can be [[ ]]. This is the methodology to be used when [[ ]] data is availiable and is described in Appendix B. [[ ]].

[[ ]]

Figure 2.1-1: PBLE Process Flow

In comparison to [[ ]] measurements, [[ ]] PBLE02 provides a [[ ]] so as to ensure that the dryer has sufficient margin to fatigue limits prior to the confirmatory phase, where instrumented steam dryer data is used during the initial Power Ascension Test (PAT). The [[ ]] system has an associated high cost for design and installation since the [[ ]]. The instrumentation used for the [[ ]] has better long-term reliability than the [[ ]]. The operating lifetime of [[ ]] also provides a backup for the [[ ]] for the lead plant applications in case there is an extended power ascension test period. Therefore, an additional formulation of the PBLE methodology that uses [[ ]] measurements is provided in this licensing supplement.

The lower chart in Figure 2.1-1 outlines the PBLE02 solution path when using the [[ ]].

The PBLE02 from [[ ]] has two main components:

- An acoustic finite element model (3D) representing [[ ]] as described in Appendix B).
- A [[ ]].

Referring to the lower chart in Figure 2.1-1, on the top left corner, [[ ]]. These [[ ]]. This is the [[ ]] component of the PBLE shown in Figure 2.1-1 and is described in further detail in Section 2.3.1. The [[ ]]. This is the [[ ]] component of the PBLE shown in Figure 2.1-1, and described in further detail in Section 2.2.

The [[ ]]. (Section 2.3.2). [[ ]] – see Section 2.3.3). Additional [[ ]] (Section 2.3.3).

Both the PBLE from [[ ]] solution paths are developed based on the commercial software packages MATLAB® and Virtual.Lab/Sysnoise. MATLAB® is a software package designed for engineering computations and is used for performing the [[ ]] in the PBLE. The general architecture of the PBLE scripts makes use of the MATLAB® programming language and graphical interface. The [[ ]] is also implemented in MATLAB® (Section 203.1).

The vessel acoustic response is calculated with Virtual.Lab/Sysnoise. Virtual.Lab/Sysnoise is a program for modeling acoustic wave behavior in fluids, using implementations of the finite element and boundary element methods. In the PBLE application, Virtual.Lab/Sysnoise is used to calculate the sound wave propagation through an acoustic finite element model of the steam regions in the reactor. The general 3D acoustic model is described in detail in Section 2 of Appendix B.

Virtual.Lab/Sysnoise models acoustics as a wave-phenomenon. The modeling is carried out in the frequency domain, thus using the so-called Helmholtz form of the wave equation (see e.g. Reference C.2 and Reference C.3). [[

]]

As stated, the PBLE02 Finite Element Method uses a direct response frequency analysis (as opposed to a solution using modal superposition, which is inadequate when there is frequency-dependent damping and boundary conditions as is the case here). The following system of equations is solved:

$$\left[K + i\omega C - \omega^2 M\right]\{p\} = \{F_A\}$$

Equation 2-1

Where *FA* is the vector of nodal acoustic forces, proportional to the normal velocity boundary conditions imposed on the faces of the mesh. The stiffness *[K]*, damping *[C]* and mass *[M]* matrices are computed at each frequency. The system of equations is thus set up and solved to obtain the pressure distribution *{p}*. The velocity field is obtained by differentiation of the pressure field at the gauss points of the elements and then extrapolation and averaging at the nodes.

2.2 Dome Acoustic Model

The dome acoustic model is described in detail in the PBLE01 report in Appendix B. This section summarizes the key aspects of the dome model.

The dome FE mesh (Figure 2.2-2) comprises all RPV steam volumes [[

]]. The Virtual.Lab/Sysnoise program was used to generate the models and benchmarking provided here.

In all GEH BWRs, there are two basic steam zones with different steam qualities; upstream of the dryer [[

]]. Validation for the use of [[ ]] is performed through the benchmarking process in Section 3.0 of this appendix and confirms this assumption.

The PBLE02 method is formulated under the [[

]]. Validation of the [[
]] is performed through the benchmarking process in Section 3.0 and confirms this location.

[[ ]]

Figure 2.2-1: [[ ]]

[[ ]]

Figure 2.2-2: **Modeled Steam Region (on left) and Details of Typical Vessel Meshes (on right)**

[[

]]

[[ ]]

Figure 2.2-3: [[ ]]

[[

]].

2.3 PBLE From [[ ]]

The PBLE model described in Appendix B used [[ ]]. This section describes the PBLE modeling used to determine the [[ ]].

2.3.1 [[ ]] Equations

[[ ]], which was initially described by Seybert and Ross (Reference C.2) and Chung and Blaser (Reference C.4). The more recent [[ ]] are Jones and Stiede (Reference C.5), Jones and Parrott (Reference C.6), and Chu (Reference C.7).

[[

]].

2.3.2 [[ ]] with RPV

The approach in the previous section describes [[

]].

2.3.3 [[ ]]

[[

]]

2.3.3.1 General Formulation of [[ ]]

[[

]]

2.3.4 Singularity Factor

The Singularity Factor (SF) is a tool to understand the mathematical limitations in the PBLE. It is calculated as:

[[

]]

This is one of the considerations when choosing MSL strain gauge locations. In addition, this is a consideration for utilizing a coupled PBLE solution to lessen the singularities in each of the individual uncoupled MSLs. The impact of this mathematical constraint on the PBLE solution can be seen in Figure 2.3-1.

[[ ]]

Figure 2.3-1: [[ ]]

[[

]]

2.4 Steam Acoustic Properties

The steam and water characteristic properties used in PBLE models are:

- [[

]]

Properties for the vessel model are described in detail in the PBLE01 documentation from Appendix B. [[ ]].

[[

]].

This section first addresses these [[

]].

2.4.1 [[ ]]

The variable nomenclature for this section is in Table 2.4-1.

Table 2.4-1: Variables Used to Describe Steam Acoustic Properties

[[			
			]]

Ingard and Singhal (Reference C.10) propose a model for [[

]].

2.4.2 [[ ]]

The dryer is designed to remove large moisture droplets from the steam. [[

]]

The four resulting points are plotted in (Figure 2.4-1) as asterisks. The relation [[

]] As

shown in Figure 2.4-1, [[

]]

The red curve in Figure 2.4-1 is a [[

]]

[[ ]]

Figure 2.4-1: [[ ]]

3.0 MODEL QUALIFICATION: BWR PLANT VALIDATION

[[ ]] GEH BWR units went through steam EPU steam dryer replacement programs in the recent years:

[[

]]

The replacement dryers were each instrumented with [[ ]] The units were also equipped with [[

]]

These data sets were utilized for two primary purposes in developing the preliminary vibratory stress analysis for Browns Ferry application. In particular, the existing data sets were utilized in the overall processes to develop:

[[

]]

3.1 Procedure for Benchmark Cases

3.1.1 Instrumentation at [[ ]]

The [[ ]] dryer instrumentation comprised [[

]]

The [[ ]] dryer instrumentation had [[

]]

The [[ ]] dryer was instrumented with [[

]]

The [[ ]] MSLs were instrumented [[

]]

The [[ ]] dataset comprises [[

]]

Table 3.1-1: Datasets Used in Benchmarks

Plant	Instruments	Date	Data Source
[[			
			]]

Table 3.1-2: Plant Conditions Associated with Dryer Benchmark Cases

Test Condition	Power MWTH	Steam Flow Mlbs/hr	Steam Velocity* Ft/sec	Core Flow Mlbs/hr
[[				
				]]

[[

]].

3.1.1.1 MSL Data Processing

The [[ ]] data is processed prior to being utilized as a [[ ]] in PBLE02 [[ ]]. Before being used in PBLE02 [[ ]]

3.1.2 [[ ]]

[[

]]

3.1.3 Procedure for [[ ]]

In addition to the pressure benchmark, the [[ ]] was utilized to develop pressure loads for input to the FIV Finite Element model. This was done to characterize the ability of the overall methodology to project dryer response. [[

]] The load cases were analyzed to determine the predicted strain for the instrumented strain gauges on the dryer. [[

]]

3.2 [[ ]] and PBLE02 Benchmark Results

This section reviews the [[ ]] This includes showing [[ ]]

3.2.1 [[ ]]

[[

]]

[[ ]]

Figure 3.2-1: [[**]]**

[[ ]]

[[ ]]

Figure 3.2-2: [[ ]]

[[ ]]

Figure 3.2-3: [[ ]]

[[ ]]

Figure 3.2-4: [[ ]]

[[ ]]

Figure 3.2-5: [[ ]]

[[ ]]

Figure 3.2-6: [[ ]]

[[ ]]

Figure 3.2-7: [[ ]]

3.2.2 PBLE02 Pressure Loading Results

The comparisons of the measured and projected RMS Pressure [[ ]] are plotted in Appendix C2 for the [[ ]]

[[ ]]

Figure 3.2-8 to Figure 3.2-13 show specific [[ ]]

[[ ]]

Figure 3.2-8: [[ ]]

[[ ]]

Figure 3.2-9: [[ ]]

[[ ]]

Figure 3.2-10: [[ ]]

[[ ]]

Figure 3.2-11: [[ ]]

[[ ]]

Figure 3.2-12: [[ ]]

[[ ]]

Figure 3.2-13: [[ ]]

3.3 PBLE02 Validation Conclusions

Overall the benchmarks indicate that PBLE technology, and the related methodology to be applied to Browns Ferry for projecting loads [[

]]

In the [[ ]] PBLE / FE stress analysis benchmark with the [[ ]], the regional PBLE load combined with the GEH finite element model provides a conservative estimate of dryer response and stress as evidenced by the [[ ]] bias and uncertainty values provided in Table C5-1 in Appendix C-5. This comparison indicates that the GEH FE model structural response predictions are conservative when based on PBLE-defined loads. The loads adjusted [[ ]] with frequency based [[ ]] bias and uncertainty provided a conservative projection of the dryer structural response (See Section 4.5 below).

To assure that the PBLE methodology is applied rigorously GEH will apply [[ ]] These values will be applied with other adjustment terms per section 4.2.5 of the main document. A sample of predicted versus measured sensor response [[ ]] is shown in Appendix C4.

If a dryer [[

]]

4.0 APPLICATION METHODOLOGY

4.1 Scope of Application and Licensing Requirements

4.1.1 Scope of Application

The purpose of the Plant Based Load Evaluation and PBLE02 specifically is to provide a methodology for [[ ]] to determine the fluctuating pressure loads that the TVA Browns Ferry steam dryers will experience after reaching EPU conditions. The fluctuating loads developed using this methodology are applied to a finite element model, in this case the Browns Ferry steam dryer, in order to determine the structural qualification of the replacement steam dryer. This section describes the methodology that is used in applying PBLE02 to [[ ]] to develop the dryer load definition for both the [[ ]] and the Browns Ferry steam dryer stress analysis EPU qualification.

4.1.2 Specific Licensing Requirements

Plant components such as the steam dryer in a BWR nuclear power plant perform no safety function but must retain their structural integrity to avoid the generation of loose parts that might adversely impact the capability of other plant equipment to perform their safety function. Potential adverse flow effects must be evaluated for the steam dryer to meet the requirements of GDC 1 and 4 in Appendix A of 10 CFR Part 50.

Standard Review Plan (Reference C.13), Section 3 requires that the dynamic responses of structural components with the reactor vessel caused by steady state and operational flow transient conditions should be analyzed for prototype (first of a design) reactors. Similarly, Standard Review Plan (Reference C.14), Appendix A requires rigorous assessments of the potential for adverse flow effects for minor modifications to components susceptible to flow-excited acoustic and structural resonances in non-prototype plants. The analytical assessment of the vibration behavior of the steam dryer includes the definition of the input-forcing function including bias errors and uncertainty. The Standard Review Plan (Reference C.13 and Reference C.14) contains specific acceptance criteria related to formulating forcing functions for vibration prediction. RG 1.20 (Reference C.1) provides guidance on acceptable methods for formulating the forcing functions for vibration prediction.

4.2 Application Methodology

The PBLE02 method for formulating the forcing function for vibration prediction for the steam dryer is in conformance with the guidance contained in Regulatory Guide 1.20 Revision 3 (Reference C.1).

4.2.1 Conformance with Regulatory Guide 1.20 Rev 3

The PBLE02 load definition methodology was developed to satisfy the analysis and vibration program recommendations identified in RG 1.20 Revision 3 (Reference C.1).

A detailed assessment of the comprehensive vibration assessment program for the replacement steam dryer which includes PBLE02 with respect to the RG 1.20 recommendations is provided in Section 10 of Appendix A (Reference C.1).

4.3 Range of Application

The PBLE method described in this report is capable of determining the vibratory forcing function for the entire operating range of the Browns Ferry steam dryer.

4.4 Plant-Specific Application Methodology

[[

]]

Further information on the vessel model is provided in Appendix B.

4.4.1 Plant Input Measurements

4.4.1.1 Sensor Type and Location

MSL Instrumentation

The [[ ]]. Parameters for this model are listed in Reference C.15. All the input parameters identified in Reference C.15 are specified in the PBLE script input file. The PBLE scripts assemble the [[ ]].

[[

]] This information and benchmarking shall be submitted to the NRC staff for approval before implementation.

[[

]]. Further information on the conversion of strain to pressure and strain gauge accuracy is presented in Appendix C6.

[[

]].

The distance between [[

]].

[[ ]] ***Instrumentation***

[[

]] in Appendix B.

From previous benchmarks found in Appendix B, it was concluded that [[

]]

4.4.1.2 Plant Measurement Uncertainty

The PBLE uses [[ ]] as input to the steam dryer pressure load predictions. Uncertainties in these inputs will be propagated through the PBLE calculations, resulting in uncertainties in the pressure load predictions or the resulting structural vibration predictions.

Uncertainties in [[ ]]

The [[ ]] pressures (used for [[ ]]) have errors due to:

[[ ]].

[[ ]].

4.4.1.3 Uncertainties in Measured [[ ]]

In practice, [[ ]] This error is evaluated in Appendix C6 and C8.

4.4.2 Plant-Specific Load Definition

The following steps are involved in the calculation of dryer loads with the PBLE [[ ]]

[[

]] the PBLE MATLAB® scripts are run and dryer loads are obtained.

The above is a basic overview of the process for developing loads using PBLE02. The particulars for developing these loads for Browns Ferry and applying them to the FIV model are found in the main body of this document and other Appendices as referenced in the main body. The PBLE model needs a number of inputs, such as listed in Table 4.4-1.

Table 4.4-1- Input parameters to the PBLE02

[[			
			]]

[[

]]

4.5 [[ ]] Benchmark

The ability to predict [[

]]

Structural Model

The [[ ]] replacement steam dryer structural FE model was developed in accordance with the guidelines in Appendix A.

The three-dimensional shell FE model of the [[ ]] replacement dryer was constructed from the replacement dryer design drawings using the ANSYS finite element analysis code. [[

]]

4.5.1 FIV Analysis

The ANSYS FE code was used to obtain the structural responses of the steam dryer to the FIV loads at the plant conditions where measured data was obtained. The dynamic analysis was performed [[

]]

For the final Browns Ferry analysis, the maximum stress intensity was extracted on every component for each dynamic solution. The maximum values of stress intensity [[ ]] The maximum stress intensity results from [[ ]]

4.5.2 [[ ]] Bias and Uncertainties

The [[ ]] load benchmark analyses are based on comparisons of the [[ ]]

Figure 4.5-1 and Figure 4.5-2 display the graphs that summarize the bias and uncertainty terms that were calculated by using the equations below:

[[ ]]

Appendix C4 displays plots of the FIV predicted strains and accelerations [[ ]]

[[ ]]

Figure 4.5-1: [[ ]]

[[ ]]

Figure 4.5-2: [[ ]]

5.0 CONCLUSIONS

The Plant Based Load Evaluation methodology for plants with either [[ ]] is available to predict dryer pressure loads and their associated bias and uncertainty.

The PBLE incorporates a [[ ]].

The PBLE02 technique for determining dryer loading with [[ ]]. This case involved the full application of Pre-EPU [[ ]] From comparison between measurements and projections, the PBLE with FEM predicts frequency content and spatial distribution adequately for use to predict EPU dryer responses. The SRV valve resonances are covered by [[ ]]

The PBLE methodology presented in this report has two strengths:

- Accurate predictions of MSL phenomena occurring downstream of the MSL sensors: valve whistling (SRV/branch line) and broadband excitations (venturi, MSIV turbulence);
- Modeling of vessel hydrodynamic phenomena through [[ ]].

[[ ]]

6.0 REFERENCES

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C.19 Wylie, Streeter, and Suo, *Fluid Transients in Systems,* Prentice Hall, 1993.

Appendix C1: [[ ]] **Sensor Location Figures**

[[ ]]

Figure C1-1-[[ ]]

[[ ]]

Figure C1-2-[[ ]]

[[ ]]

Figure C1-3-[[ ]]

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Figure C1-4-[[ ]]

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Figure C1-5-[[ ]]

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Figure C1-6-[[ ]]

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Figure C1-7-[[ ]]

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Figure C1-8-[[ ]]

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Figure C1-9-[[ ]]

Appendix C2: [[

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Figure C2-1-[[ ]]

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Figure C2-2-[[ ]]

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Figure C2-3-[[ ]]

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Figure C2-4–[[ ]]

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Figure C2-5–[[ ]]

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Figure C2-6-[[ ]]

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Figure C2-7–[[ ]]

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Figure C2-8-[[ ]]

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Figure C2-9–[[ ]]

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Figure C2-10-[[ ]]

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Figure C2-11–[[ ]]

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Figure C2-12–[[ ]]

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Figure C2-13–[[ ]]

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Figure C2-14–[[ ]]

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Figure C2-15-[[ ]]

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Figure C2-16-[[ ]]

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Figure C2-17-[[ ]]

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Figure C2-18-[[ ]]

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Figure C2-19-[[ ]]

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Figure C2-20-[[ ]]

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Figure C2-21-[[ ]]

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Figure C2-22-[[ ]]

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Figure C2-24-[[ ]]

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Figure C2-25-[[ ]]

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Figure C2-26-[[ ]]

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Figure C2-27-[[ ]]

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Figure C2-28-[[ ]]

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Figure C2-29-[[ ]]

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Figure C2-30-[[ ]]

Appendix C3: [[ ]]

Table C3-1- [[ ]]

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Figure C3-1-[[ ]]

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Figure C3-2-[[ ]]

Appendix C4: [[
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[[ ]]

Figure C4-1-[[

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[[ ]]

Figure C4-2-[[

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Figure C4-3-[[

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Figure C4-4-[[

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Figure C4-7-[[

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Figure C4-7-[[

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Figure C4-9-[[ ]]

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Figure C4-10-[[ ]]

Appendix C5 – [[

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Table C5-1- [[ ]]

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Appendix C6: Correlation of Strain Gauge Data to Acoustic Pressure Experimental Testing

C6.1 Introduction

This section summarizes the analysis of strain gauge and pressure transducer data from the GEH test performed in January 2008. The GEH test used high-pressure air to test the [[ ]] to measure the acoustic pressure inside the pipe. [[ ]]

C6.2 Experimental Setup

[[ ]]

Figure C6-1: Photograph of Test Section

[[ ]] as seen in Figure C6-1 with the drawing dimensions presented in Figure C6-3. Each station consists of 8 strain gauges orientated in the hoop direction equally spaced circumferentially around the pipe as shown in Figure C6-5. There was a corresponding pressure transducer mounted [[ ]]. A photograph of the test section and the downstream piping system, with associated schematic, is presented in Figure C6-5. [[ ]].

[[

]]. A more technical explanation is included below.

[[ ]]

Figure C6-2: Schematic of Experimental Setup for Strain Gauge/Acoustic Pressure Test

[[

]].

[[ ]]

Figure C6-3: Drawing Dimensions for Test Article.

[[ ]]

Figure C6-4: Strain Gauge Orientation and Numbering

[[ ]]

[[ ]]

Figure C6-5: Piping Layout and Supports

C6.3 Conversion of Strain Gauge data to Pressure Data

[[

]] The modulus of elasticity for the pipe as a function of temperature is presented in Table C6-2. The strain to pressure conversions (Table C6-3) are performed with the [[
]] from each location.

Table C6-1: Pipe Thickness as a Function of Azimuth, for Both Strain Gauge Locations.

[[									
									]]

Table C6-2: Modulus of Elasticity of A106 GrB Pipe

E: Modulus of Elasticity of A106 GrB Pipe				
Temp (Deg F)	-100	70	200	300
Modulus (psi)	3.02E+07	2.95E+07	2.88E+07	2.83E+07

Table C6-3: Calculation of Pressure to Strain Ratio

[[							
							]]

C6.4 Description of Test Equipment and Data Sets

The main focus of the testing was for evaluating [[

]] over the suite of test runs.

There were three data acquisition systems used,

[[

]].

C6.5 Description of Test Data

Out of the [[ ]], there were three test cases (Table C6-4) that included temporal strain pressure and accelerometer data necessary for assessing strain gauge performance. The three test cases were:

Table C6-4: Test Cases

SG Test Name	Test Name
Case 1	t31nt2s1
Case 2	t31r2t2s3
Case 3	t8b180tr1

The following three figures depict the transient flow (Figure C1-6), pressure (Figure C1-7) and temperature (Figure C1-8) data during these tests. Each test included a slow up and down ramp in flow velocity. [[ ]]. An accumulator was used as the air source for the test. The air was passed through a heat exchanger to provide temperature moderation. Due to the large volume air used during the test there was still a decrease in temperature over the period of each test. Flow control valves upstream and downstream of the test assemblies were adjusted to maintain a system pressure of approximately 300 psia and to provide the desired flow ramps.

[[ ]]

Figure C6-6: Flow as a Function of Time for the Three Tests

[[ ]]

Figure C6-7: Pressure as a Function of Time for the Three Tests

[[ ]]

Figure C6-8: Temperature as a Function of Time for the Three Tests

The air pressure and flow variations noted in Figure C1-6 and Figure C1-7 will have [[ ]].

The air temperature in the pipe dropped less than 40°F during the tests. The room temperature remained constant at approximately 70°F. [[ ]].

C6.6 Analysis of Results

Figure C6-9 and Figure C6-10 depict the individual strain gauge signals and the averaged signals at each location. The strain has been converted to pressure using the conversion factors shown in Table C6-3. In these plots, strain gauges on opposite sides of the pipe are plotted in the same color in dashed and solid lines. [[ ]].

[[ ]]

Figure C6-9: SG1 Location, Individual Strain Gauge Signals Case 1

[[ ]]

Figure C6-10: SG2 Location, Individual Strain Gauge Signals Case 1

[[

]].

For Case 1, Figure C6-11 provides a power spectral density plot for PT1, PT2, and coherence between PT1 and PT2. Figure C6-11 also provides the PSDs for SG1, SG2, and coherence between SG1 and SG2 for the same time interval. [[

]].

Figure C6-12 include PSD plots and coherence data for PT1, PT2, and PT3. This data indicates that two of the three transmitters have good coherence at acoustic peaks.

[[

]].

[[ ]]

Figure C6-11: PT and SG ([[ ]]) PSD and Coherence Data (Case 1)

[[ ]]

Figure C6-12: PT1, PT2, PT3 PSDs and Coherence Data (Case 1)

Figure C6-13 provides a comparison of the PSD data for the strain gauge and adjacent pressure transmitter. [[ ]]. Therefore the maximum normalized value is 1. The coherence shown is between the SG and adjacent PT.

In general there is good coherence between the SG and adjacent PT at acoustic peaks. [[ ]].

[[ ]]

Figure C6-13: Comparison of PT and SG ([[ ]]) PSD and Coherence Data

[[

]]

Figure C6-14: [[ ]]

[[

]] plot in Figure C6-15.

[[ ]]

Figure C6-15: [[

]]

Figure C6-16 represents a comparison of the [[

]].

Figure C6-17 represents a comparison of the PT data compared with the [[

]]

[[ ]]

Figure C6-16: Pressure Based on [[ ]]

[[ ]]

Figure C6-17: Pressure Based on PT Sensor [[ ]]

[[ ]] are identified in Figure C6-18.

[[ ]].

If all frequency bands are combined, the resulting errors for all frequency and time intervals are as shown in Table C6-5 below.

Table C6-5: Summary of Error for all Frequency and Time Intervals

Test Case No.	Mean Error	STD Error
1	5%	38%
2	15%	35%
3	0%	33%

[[ ]]

Figure C6-18: Test Case 1: Error in Peak Pressure Response from SG Versus PT

Figure C6-19 provides a plot of the error associated with the PT data. In this figure, the RMS value for the PT1 and PT2 is compared with the RMS value based on the [[ ]].

[[ ]]

Figure C6-19: Test Case 1: Error in RMS as a Function of Frequency Band Pressure Response [[ ]]

Figure C6-20 and Figure C6-21 compare the RMS response of pressure from the [[ ]]. Figure C6-22 through Figure C6-25 provides these same plots for test Cases 2 and 3. For all frequency intervals of Cases 1, 2, and 3 (Figure C6-20, Figure C6-22, and Figure C6-24), the [[ ]].

[[ ]]

Figure C6-20: Case 1: Error in RMS as a Function of Frequency Band Pressure Response from [[ ]]

[[ ]]

Figure C6-21: Test Case 1: Average RMS as a Function of Frequency Band Pressure Response [[ ]]

[[ ]]

Figure C6-22: Test Case 2: Error in RMS as a Function of Frequency Band Pressure Response [[ ]]

[[ ]]

Figure C6-23: Test Case 2: Average RMS as a Function of Frequency Band Pressure Response [[ ]]

[[ ]]

Figure C6-24: Test Case 3: Error in RMS as a Function of Frequency Band Pressure Response [[ ]]

[[ ]]

Figure C6-25: Test Case 3: Average RMS as a Function of Frequency Band Pressure Response [[ ]]

C6.7 PBLE Dryer Loads Bias Using SG Signals for Unsteady MSL Pressure

[[ ]].

C6.8 Predicted Response as Function Circumferential SGs Used in Averaging

The error assessments done to this point have been performed using the [[ ]] from the 8 strain gauges at location SG1 and SG2. [[ ]].

There were 19 combinations of [[ ]] used in this investigation. These are summarized in Table C6-6.

Table C6-6: Strain Gauges Combinations Used in Strain Gauge Combination Study

SG1comb1=[1 2 3 4 5 6 7 8];	SG2comb1=[9 10 11 12 13 14 15 16];
SG1comb2=[1 3 5 6 7 8];	SG2comb2=[9 11 13 14 15 16];
SG1comb3=[1 3 5 7];	SG2comb3=[9 11 13 15];
SG1comb4=[2 4 6 8];	SG2comb4=[10 12 14 16];
SG1comb5=[1 3];	SG2comb5=[9 11];
SG1comb6=[1 2 3 4 5 6 7];	SG2comb6=[9 10 11 12 13 14 15];
SG1comb7=[1 2 3 4 5 6];	SG2comb7=[9 10 11 12 13 14];
SG1comb8=[1 2 3 4 5];	SG2comb8=[9 10 11 12 13];
SG1comb9=[1 2 3 4];	SG2comb9=[9 10 11 12];
SG1comb10=[1 2 3];	SG2comb10=[9 10 11];
SG1comb11=[1 2];	SG2comb11=[9 10];
SG1comb12=[1];	SG2comb12=[9];
SG1comb13=[2];	SG2comb13=[10];
SG1comb14=[3];	SG2comb14=[11];
SG1comb15=[4];	SG2comb15=[12];
SG1comb16=[5];	SG2comb16=[13];
SG1comb17=[6];	SG2comb17=[14];
SG1comb18=[7];	SG2comb18=[15];
SG1comb19=[8];	SG2comb19=[16];

Figure C6-26 summarize the error in peak response in [[

]]

[[ ]]

**Figure C6-26: Error in Peak Response as a Function of SG [[ ]]
(All Frequency and Time Intervals)**

Table C6-7: [[ ]]

[[						
						]]

Note: [[ ]].

Figure C6-27 through Figure C6-29 provide PSD comparisons of pressure calculated using [[ ]]. This is also reflected in Figure C6-30 through Figure C6-32 that provide the [[ ]]

[[ ]]

Figure C6-27: 8 Strain Gauge [[ ]]

[[ ]]

Figure C6-28: 4 Strain Gauge [[ ]]

[[ ]]

Figure C6-29: 2 Strain Gauge [[ ]]

[[ ]]

Figure C6-30: Frequency Band [[ ]]

[[ ]]

Figure C6-31: Frequency Band [[ ]]

[[ ]]

Figure C6-32: Frequency Band [[ ]]

C6.9 Stain Gauge Arrangement and the Impact to PBLE Loads

In calculating acoustic pressure [[ ]] provides pressure predictions commensurate [[ ]] There is a substantial increase in error [[ ]]

C6.10 References

C6.1 Advanced Strength and Applied Elasticity, by Ugural and Fenster, Elsevier, 1975

C6.2 Theory and Design of Modern Pressure Vessels, Second Edition, by John F. Harvey, Van Nostrand Reinhold, 1974

C6.3 A.D. Piece: Acoustics. An Introduction to Its Physical Principles and Applications Acoustic Society of America. 1994.

Appendix C7: Strain to Pressure Conversion

The Browns Ferry strain gauge data was processed using the same process and routines that were utilized [[ ]] This process includes notch filtering of electrical noise ([[ ]]) and adjusting measured strain per Equation C7-1.

[[ ]] The strain gauges were tested with three different DAS packages and different bridges. [[ ]]

Strain gauges utilized to measure acoustic pressures in the [[ ]] The Browns Ferry strain gauges are of the same design as those previously utilized by [[ ]] These strain gauges were previously tested and after review of [[ ]]

The final equation for converting strain gauge data to pipe pressure data is:

[[

]]

The strain gauge data was filtered using a standard routine to notch filter targeted frequencies for [[

]]

Table C7-1: [[ ]]

Station	Adjustment Factor	Station	Adjustment Factor	Station	Adjustment Factor
[[					
					]]

Appendix C8: Strain Gauge Accuracy Test

It has been established through industry experience and direct testing that strain gauges welded to main steam line piping result in measurement values that are a repeatable fraction of calculated values. This testing estabilished that welding of the strain gauges, and in particular [[ ]] This testing included using both [[ ]] to correlate measurement bias to theoretically expected values. This report also compares noted bias values to those seen during in [[ ]]

Finally, these tests included comparing both [[ ]] in order to determine any impact this variable may have on results and any bias between [[ ]]

[[ ]]

Figure C8-1- Beam 2 Results for Different Gauge Types [[

]]

A picure of strain gauges can be seen in Figure C8-2 Picture of Strain Gauges on Beam for Testing. This shows the general layout and a comparison of the basic strain gauge sizes.

Table C8-1: Table of Mean and Standard Deviation [[
]]

[[											
											]]

[[ ]]

Figure C8-2- Picture of Strain Gauges on Beam for Testing

As noted, work was done at the manufacturer site using their weld procedure to ensure that beam and pipe testing were done with the appropriate weld procedure. [[

]]

Appendix D

Supplemental Information

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ACRONYMS AND ABBREVIATIONS

Term	Description
με	Micro Strain (10^{-6} length/length)
Browns Ferry	Browns Ferry Nuclear Plant
BFN	Browns Ferry Nuclear Plant
BWR	Boiling Water Reactor
CLTP	Current Licensed Thermal Power
DAS	Data Acquisition System
DIR	Design Input Request
EPU	Extended Power Uprate
FEM	Finite Element Model
FIV	Flow Induced Vibration
FRF	Frequency Response Function
FF	Full Frequency Spectrum
GEH	GE Hitachi Nuclear Energy
[[	]]
Hz	Hertz
[[	]]
MASR	Minimum alternating stress ratio
Mlbs/hr	Millions pounds per hour
MSIV	Main Steam Isolation Valve
MSL	Main Steam Line
MW_t	Megawatt Thermal
NRC	Nuclear Regulatory Commission
OLTP	Original Licensed Thermal Power
OOS	Out of Service
Pa	Pascal
PATP	Power Ascension Test Program
PBLE	Plant Based Load Evaluation
PBLE01	PBLE Input [[ ]]

Term	Description
PBLE02	PBLE Input [[ ]]
PSD	Power Spectral Density
psi	Pounds per square inch
psia	Pounds per square inch absolute
psid	Pounds per square inch differential
RMS	Root-Mean-Squared
RPV	Reactor Pressure Vessel
RSD	Replacement Steam Dryer
SDAR	Steam Dryer Analysis Report
SF	Singularity Factor
SG	Strain Gauge
SRV	Safety Relief Valve
TC	Test Condition
VFD	Variable Frequency Drive
VPF	Vane Passing Frequency

1.0 EXECUTIVE SUMMARY

The scope of this appendix is to document additional supplementary information. The supplementary information consists of analysis inputs and plot series that were output from the analysis calculations.

2.0 BROWNS FERRY PLANT GENERAL INFORMATION

This section is intended to provide a quick reference of Browns Ferry information. Most of this section comes directly from Browns Ferry Design Input Requests (DIRs).

Summary Table 2-1 provides [[ ]]

Table 2-1: [[ ]]

	Power, MWth	**% CLTP**
[[		
		]]

3.0 BROWNS FERRY STRAIN GAUGE (SG) INSTALLATION INFORMATION

3.1 Browns Ferry Plant Data Set Tables

Table 3-1: [[ ]]

Power (%)	Dome Pressure (psig)	FW Temp (F)	Total Steam Flow (Mlb/hr)	Core Flow (Mlb/hr)	Recirc Loop	Recirc Flow A/B (Mlb/hr)	VFD Frequency A/B (Hz)	Recirc Pump Speed A/B (rpm)	VPF (Hz)
[[									
								]]

Power (%)	Dome Pressure (psig)	FW Temp (F)	Total Steam Flow (Mlb/hr)	Core Flow (Mlb/hr)	Recirc Loop	Recirc Flow A/B (Mlb/hr)	VFD Frequency A/B (Hz)	Recirc Pump Speed A/B (rpm)	VPF (Hz)
[[									
								]]

Table 3-2: [[ ]]

Power (%)	**Dome Pressure (psig)**	**FW Temp (F)**	**Total Steam Flow (Mlb/hr)**	**Core Flow (Mlb/hr)**	**Recirc Loop**	**Recirc Flow A/B (Mlb/hr)**	**VFD Frequency A/B (Hz)**	**Recirc Pump Speed A/B (rpm)**	**VPF (Hz)**
[[									
									]]

Power (%)	Dome Pressure (psig)	FW Temp (F)	Total Steam Flow (Mlb/hr)	Core Flow (Mlb/hr)	Recirc Loop	Recirc Flow A/B (Mlb/hr)	VFD Frequency A/B (Hz)	Recirc Pump Speed A/B (rpm)	VPF (Hz)
[[									
									]]

Table 3-3: [[ ]]

Power (%)	Dome Pressure (psig)	FW Temp (F)	Total Steam Flow (Mlb/hr)	Core Flow (Mlb/hr)	Recirc Loop	Recirc Flow A/B (Mlb/hr)	VFD Frequency A/B (Hz)	Recirc Pump Speed A/B (rpm)	VPF (Hz)
[[									
								]]

Power (%)	Dome Pressure (psig)	FW Temp (F)	Total Steam Flow (Mlb/hr)	Core Flow (Mlb/hr)	Recirc Loop	Recirc Flow A/B (Mlb/hr)	VFD Frequency A/B (Hz)	Recirc Pump Speed A/B (rpm)	VPF (Hz)
[[									
									]]

4.0 BROWNS FERRY MSL DATA PLOT SERIES

The following plot series (Figure 4-1 through Figure 4-13) is a complete presentation of the available plots generated to support the Steam Dryer Analysis Report (SDAR), Main Report Section 4.1.3. For all the plots in this section, [[ ]]

[[ ]]

Figure 4-1: [[ ]]

[[ ]]

Figure 4-2: [[ ]]

[[ ]]

Figure 4-3: [[ ]]

[[ ]]

Figure 4-4: [[ ]]

[[ ]]

Figure 4-5: [[ ]]

[[ ]]

Figure 4-6: [[ ]]

[[ ]]

Figure 4-7: [[ ]]

[[ ]]

Figure 4-8: [[ ]]

[[ ]]

Figure 4-9: [[ ]]

[[ ]]

Figure 4-10: [[ ]]

[[ ]]

Figure 4-11: [[ ]]

[[ ]]

Figure 4-12: [[ ]]

[[ ]]

Figure 4-13: [[ ]]

5.0 SUPPLEMENTARY TRENDING PLOTS

The following section presents supplementary information supporting SDAR Main Report [[ ]] as well as Appendix A [[ ]] Table 5-1 summarizes the Test Conditions (TCs) used in the trending calculation. It is then followed by a series of plots (Figure 5-1 through Figure 5-20) that illustrates the trending [[ ]] Then lastly a plot series that presents [[ ]]

Table 5-1: Test Condition [[ ]]

Test Condition	Mass Flow (Mlbs/hr)	MSL Velocity (ft/sec)
[[		
		]]

[[ ]]

Figure 5-1: [[ ]]

[[ ]]

Figure 5-2: [[ ]]

[[ ]]

Figure 5-3: [[ ]]

[[ ]]

Figure 5-4: [[ ]]

[[ ]]

Figure 5-5: [[ ]]

[[ ]]

Figure 5-6: [[ ]]

[[ ]]

Figure 5-7: [[ ]]

[[ ]]

Figure 5-8: [[ ]]

[[ ]]

Figure 5-9: [[ ]]

[[ ]]

Figure 5-10: [[ ]]

[[ ]]

Figure 5-11: [[ ]]

[[ ]]

Figure 5-12: [[ ]]

[[ ]]

Figure 5-13: [[ ]]

[[ ]]

Figure 5-14: [[ ]]

[[ ]]

Figure 5-15: [[ ]]

[[ ]]

Figure 5-16: [[ ]]

[[ ]]

Figure 5-17: [[ ]]

[[ ]]

Figure 5-18: [[ ]]

[[ ]]

Figure 5-19: [[ ]]

[[ ]]

Figure 5-20: [[ ]]

6.0 BROWNS FERRY TOP FIVE HIGH STRESS COMPONENTS FROM FIV ANALYSIS

The following section illustrates the [[ ]] high stress components from ANSYS FIV analysis, as summarized in Table 6-1. Additional plot information presented [[

]]

Table 6-1: [[ ]]

FEM Group #	Component	Combined LF & HF (psi)	MASR
[[			
			]]

[[

]]

6.1 [[ ]]

[[ ]]

Figure 6-1: [[ ]]

[[ ]]

Figure 6-2: [[
]]

[[ ]]

Figure 6-3: [[
]]

[[ ]]

Figure 6-4: [[ ]]

6.2 [[ ]]

[[ ]]

Figure 6-5: [[ ]]

[[ ]]

Figure 6-6: [[ ]]

[[ ]]

Figure 6-7: [[ ]]

[[ ]]

Figure 6-8: [[ ]]

6.3 [[ ]]

[[ ]]

Figure 6-9: [[ ]]

[[ ]]

Figure 6-10: [[ ]]

[[ ]]

Figure 6-11: [[
]]

[[ ]]

Figure 6-12: [[
]]

6.4 [[ ]]

[[ ]]

Figure 6-13: [[ ]]

[[ ]]

Figure 6-14: [[ ]]

[[ ]]

Figure 6-15: [[ ]]

[[ ]]

Figure 6-16: [[ ]]

6.5 [[ ]]

[[ ]]

Figure 6-17: [[ ]]

[[ ]]

Figure 6-18: [[ ]]

[[ ]]

Figure 6-19: [[ ]]

[[ ]]

Figure 6-20: [[ ]]

Appendix E

Power Ascension Test Plan
Limit Curves (On-Dryer & MSL Based)

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ACRONYMS AND ABBREVIATIONS

Term	Description
με	Micro Strain (10^{-6} length/length)
ASR	Alternating Stress Ratio
Browns Ferry	Browns Ferry Nuclear Plant
BFN	Browns Ferry Nuclear Plant
B&U	Bias and Uncertainty
BWR	Boiling Water Reactor
CLTP	Current Licensed Thermal Power
DAS	Data Acquisition System
EPU	Extended Power Uprate
FEA	Finite Element Analysis
FIV	Flow Induced Vibration
FRF	Frequency Response Function
GEH	GE Hitachi Nuclear Energy
[[	]]
Hz	Hertz
LCF	Limit Curve Factor
[[	]]
MASR	Minimum alternating stress ratio
MSL	Main Steam Line
MW_t	Megawatt Thermal
NRC	Nuclear Regulatory Commission
OLTP	Original Licensed Thermal Power
Pa	Pascal
PATP	Power Ascension Test Program
PBLE	Plant Based Load Evaluation
PBLE01	PBLE Input [[ ]]
PBLE02	PBLE Input [[ ]]
PSD	Power Spectral Density

ACRONYMS AND ABBREVIATIONS

Term	Description
psi	Pounds per square inch
RFO	Refueling Outage
RMS	Root-Mean-Squared
RPV	Reactor Pressure Vessel
RSD	Replacement Steam Dryer
SDAR	Steam Dryer Analysis Report
SRV	Safety Relief Valve
VPF	Vane Passing Frequency

1.0 INTRODUCTION

The Power Ascension Test Plan (PATP) assesses the replacement steam dryer (RSD) structural performance for the Browns Ferry Extended Power Uprate (EPU) power ascension process. The power ascension will occur in two phases. [[

]]

The Browns Ferry EPU Flow Induced Vibration (FIV) PATP describes the planned course of action for monitoring, evaluating, and taking prompt action in response to potential adverse flow effects as a result of power uprate operation on plant structures, systems, and components such as the RSD during power ascension testing and operation from CLTP to the EPU plant condition power level.

The PATP covers power ascension up to the full EPU condition to verify acceptable structural performance and RSD integrity. Through the establishment of acceptance limits, data collection and analysis, and any subsequent actions, the PATP will ensure that the integrity of the RSD will be maintained. An important element of the PATP during the power ascension to the CLTP plant condition [[

]].

During the Refueling Outage (RFO), to prepare for EPU power ascension monitoring and data collection, [[

]].

[[			
			]]

The PATP in this appendix includes general hold points (plateaus) and durations during power ascension above CLTP, activities to be accomplished during hold points, data to be collected, data evaluation methods, and acceptance limits criteria for monitoring and trending plant parameters. Detailed procedures are developed for implementation during power ascension.

2.0 POWER ASCENSION TEST PLAN (PATP) SCOPE

This PATP assesses the steam dryer structural performance for the Browns Ferry EPU start-up power ascension process. The main steps for the power ascension testing include:

[[

]].

The power ascension will occur in two phases. [[

]]

There are three main elements of the first phase PATP, up to and including CLTP test points:

[[

]]

There are four main elements of the second phase PATP, EPU test points:

[[

]]

3.0 MONITORING AND ANALYSIS

The assessment of the RSD structural integrity for [[ ]] will be completed through the analysis of the measured [[ ]]. The assessment of the RSD structural integrity for [[ ]] will be completed through the analysis of the [[ ]]. Reactor parameters that have been indicative of past dryer structural failures will also be monitored during power ascension.

The detailed power ascension process for the [[ ]]. The power ascension process [[ ]]. During power ascension above CLTP, Browns Ferry will limit the EPU power ascension to test increments that do not exceed [[ ]].

[[ ]]

The time duration for holding at a power ascension test plateau will be determined by the time required to obtain the specified data, completion of data evaluation, and determination of the acceptability to continue with the power ascension.

3.1 Reactor Parameter Monitoring

The reactor parameters identified in GEH SIL 644 Rev. 2 (Reference E.1) that have been indicative of past dryer structural failures will be monitored and trended during power ascension. These reactor parameters are [[ ]]. These parameters will be trended and the trends reviewed to ensure that the individual values maintain [[ ]] relative to each other. Deviations from [[ ]] will be evaluated. The enhanced monitoring of selected plant parameters will be controlled by test procedure.

[[ ]] data will be obtained at the NRC review hold points[1] over [[ ]] and compared against the predetermined acceptance criteria. [[ ]] data collection will be performed via the implementation of existing station operating procedures. The subject acceptance criterion and the required action is:

[[ ]]

3.2 [[ ]]

During power ascension to EPU for [[ ]].

---

[1] [[ ]]

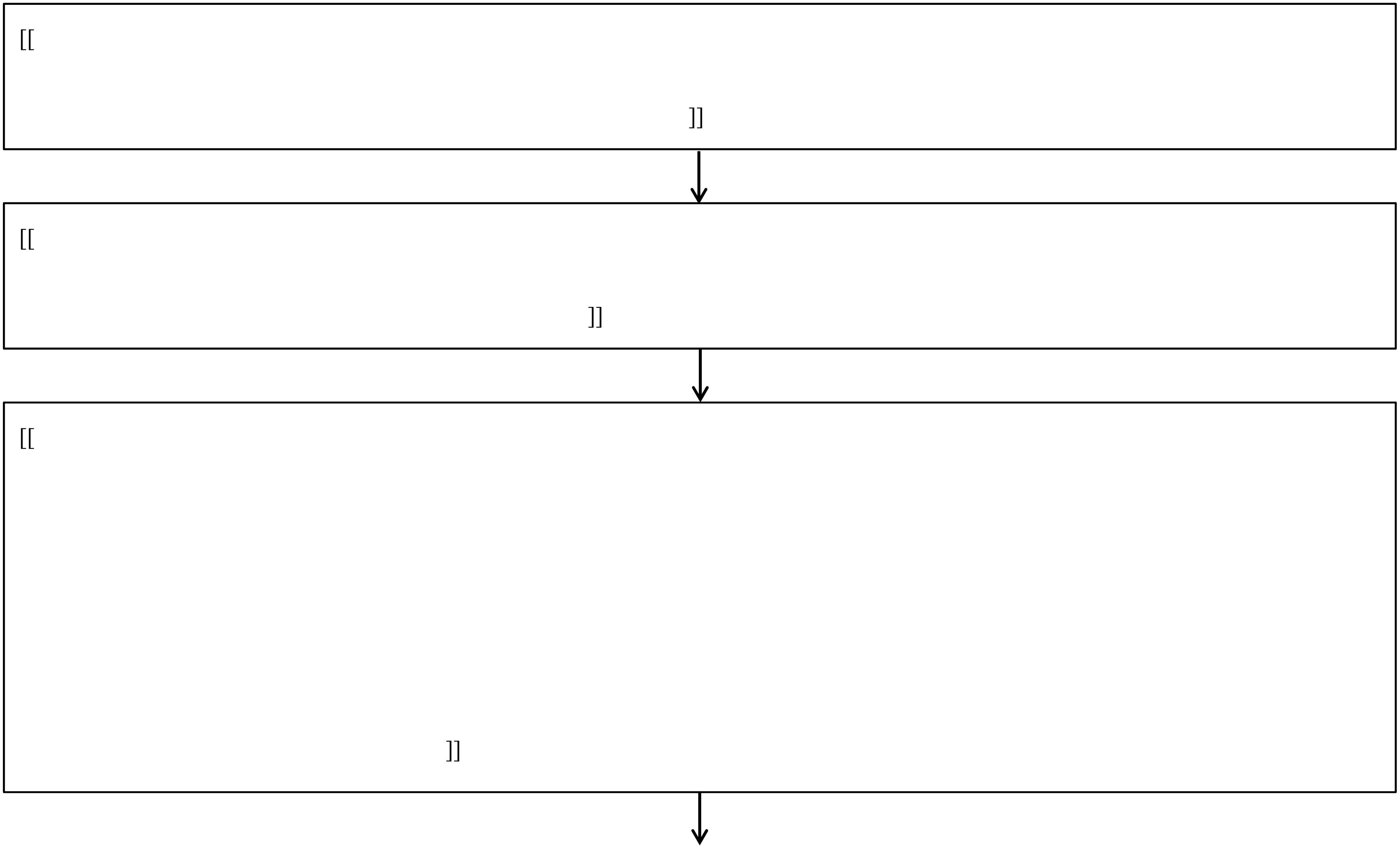
At full EPU power, the core flow will be varied over the licensed core flow operating flow range [[ ]]. Data will be taken at several core flows [[ ]]. The data collected in these measurements will be evaluated as part of the confirmatory stress analyses performed after the EPU power ascension is complete.

3.3 Regulatory Reporting

Browns Ferry will establish hold points for Nuclear Regulatory Commission (NRC) review of power ascension data, in increments [[ ]]. Browns Ferry will not increase power above each hold point until [[ ]] after the NRC confirms receipt of the evaluations, unless notified by the NRC that the NRC staff has no objections to the continuation of power ascension.

Once full EPU power is reached for [[ ]] stress analysis of the replacement dryer will be performed using [[ ]]. The results of this evaluation, including a recommended resolution of any identified issues and a demonstration of dryer integrity at EPU conditions, shall be provided to the NRC prior to return to EPU conditions.

Once full EPU power is reached [[ ]]. Should the results of this stress evaluation indicate the allowable stress in any part of the dryer is exceeded, TVA shall reduce power to a level at which the allowable stress is met, evaluate the dryer integrity, and resolve the discrepancy. The results of this evaluation, including a recommended resolution of any identified issues and a demonstration of dryer integrity at EPU conditions, shall be provided to the NRC prior to return to EPU conditions.



(continued on next page)

Figure 3.2-1: Browns Ferry [[ ]]

[[ ]]

[[ ]]

Figure 3.2-1: Browns Ferry [[ ]] **(continued)**

[[

]]

[[

]]

[[

]]

(continued on next page)

Figure 3.2-2: Browns Ferry [[ ]]

[[

]]

[[

]]

Figure 3.2-2: Browns Ferry [[ ]] **(continued)**

4.0 REPLACEMENT STEAM DRYER INSTRUMENTATION

4.1 Instrument Description

The RSD instruments [[

]]

4.2 Location of [[ ]]

To monitor the RSD dynamic response [[

]] These evaluations will be performed as part of the confirmatory stress analyses that will be performed after reaching full EPU power level.

[[ ]]

Figure 4.2-1: Browns Ferry [[
]]

4.3 Location of [[ ]]

To monitor [[

]]

This layout was selected to be [[

]]

[[ ]]

Figure 4.3-1: Browns Ferry [[ ]]

4.4 Location of [[ ]]

In the three Browns Ferry units, [[ ]]

The location of [[ ]]

[[ ]]

Figure 4.4-1: [[ ]]

Table 4.4-1: Browns Ferry Units [[ ]]

[[			
			]]

[[
]]

5.0 REPLACEMENT STEAM DRYER [[ ]] ACCEPTANCE LIMITS

Applicability of [[

]]

5.1 Raw Unadjusted Predicted [[ ]]

[[ ]] from the ANSYS structural model. [[

]]

Table 5.1-1: [[ ]]

[[ ]]										
[[										
										]]

Table 5.1-2: [[ ]]

[[ ]]										
[[										
										]]

5.2 Projected Strain Amplitude at [[ ]]

The finite element analysis (FEA) predicted [[

]]. The B&U is applied to the FEA predicted [[
]]

The B&U factors used to adjust the predicted [[

]]

Table 5.2-1: Applicable Bias and Uncertainty [[ ]]

Term Name	How it is applied to the projected sensor response
[[	

Term Name	How it is applied to the projected sensor response
	]]

Table 5.2-2: Adjusted Predicted [[ ]]

[[										]]
[[										
										]]

5.3 [[ ]] Acceptance Limits

The acceptance limits are calculated separately for [[

]]

Table 5.3-1: RSD [[
]]

[[				]]
[[				
				]]

5.4 [[ ]] Acceptance Limit Curves

[[ ]] from the ANSYS structural model was used to develop power spectral density (PSD) plots [[

]]

To define the projected PSD curve for each plant condition, [[

]]

To define the acceptance limit curves, each of the projected PSD curves [[

]]

To determine the L1 acceptance limit curve, [[

]]

The FEA projections at [[

]]

The PSD of the measured [[

]]

With the acceptance limits on [[ ]] will demonstrate that the analysis is providing a sound basis for [[ ]] acceptance limits further assuring that the dryer stresses resulting from FIV loading remain below the 13,600 psi threshold.

[[ ]]

Figure 5.4-1: Browns Ferry [[ ]]

[[ ]]

Figure 5.4-2: [[
]]

[[ ]]

Figure 5.4-3: Browns Ferry [[
]]

[[ ]]

5.5 Determination of [[ ]] Bias and Uncertainty at CLTP

[[ ]] will be compared against the measured data for the respective [[ ]]

Using the entire time record, [[ ]]

The B&U for calculated [[ ]]

The B&U for calculated stresses [[ ]]

The trending assessment will be updated with the [[ ]]

5.6 Adjustment of the Acceptance Limits during Power Ascension to EPU

Based on trending [[ ]], revised projections will be made to [[ ]]. This will be done in the same manner as described in the SDAR Appendix A for trending and projecting resonance and turbulence driven FIV loads. Based on the current measured data, the adjusted stresses at the current power level will be recalculated. With revised projections for the adjusted stress for current power level, the expected stress [[ ]] will be recalculated as described in SDAR Appendix A.

The [[ ]] B&U will be revaluated at each test plateau and updated as required.

Using revised adjusted stress projections [[

]]

6.0 REPLACEMENT STEAM DRYER [[ ]] ACCEPTANCE LIMIT CURVES

The monitoring of projected FIV loads experienced by the RSD based [[ ]] is described in the present section.

[[ ]]

6.1 Background

The Browns Ferry RSD was analyzed for PBLE loads at approximate CLTP power conditions projected to EPU condition based on [[ ]]

As discussed [[ ]]

Following the methodology outlined in Browns Ferry Appendix A, design basis stress analyses were performed using the Browns Ferry plant specific [[ ]]

The acceptance limit curves developed in the present section are applicable [[ ]]

The [[ ]] limit curve limit curve methodology presented in this Section is the same as the methodology described in the [[

]] from Section 4.1.3 of the main SDAR report.

6.2 Methodology for Development of Acceptance Limits

During power ascension above CLTP, [[

]]

[[ ]]

Figure 6.2-1: Browns Ferry [[ ]]

[[ ]]

Figure 6.2-2: Browns Ferry [[ ]]

[[ ]]

[[ ]] Maintaining these [[ ]] acceptance limits will assure the RSD peak stress amplitude remains below 13,600 psi, the ASME Curve C endurance limit for the RSD material.

[[ ]]

The projected stresses at EPU plant condition are summarized in [[ ]]. The projected stress includes [[ ]] as described [[ ]]

The Level 1 acceptance limit curve is established by factoring the projected EPU plant condition design load spectra by a Limit Curve Factor (LCF). [[ ]]

The Level 1 acceptance limit is depicted as the upper red curve[[ ]]. If a Level 1 limit is exceeded, power will be reduced to a level where the acceptance limits are satisfied. The goal during power accession is to maintain the RSD FIV [[ ]] acceptance limits.

During power ascension to EPU plant condition, [[

]]

Maintaining the [[ ]] below the acceptance limits will assure that the FIV peak stress amplitude on the Browns Ferry replacement RSD will remain below the ASME Code endurance limit.

6.3 Acceptance Limits for Operation above CLTP

The limits provided in this section shall be evaluated at all defined power ascension plateaus or hold points while the reactor steam flow and core thermal power are essentially constant. If a Level 1 limit is exceeded, power will be reduced to a level where the limit criteria are satisfied. The goal during the PAT is to not exceed the Level 1 limit.

[[ ]] monitored and trended. The trends should be used to extrapolate the [[

]]

At CLTP and during the EPU power ascension above CLTP the following acceptance limits shall be maintained:

[[

]]

[[ ]]

Figure 6.3-1: Browns Ferry [[

]]

[[ ]]

Table 6.3-1: [[ ]]

[[ ]]

[[					]]
[[					
					]]

6.4 Requirements for Defining [[ ]]

[[

]]

6.5 Determine Margin for Continued Power Ascension

At each power ascension plateau, the data trending [[

]]

6.6 Update Acceptance Limits

6.6.1 Prepare Steam Dryer [[ ]]

Based on trending data and [[

]]

6.6.2 Determine Adjusted Stress with Bias and Uncertainty

With the revised current power and EPU load projections, [[

]]

6.6.3 Updated Acceptance Limits

Using the updated [[

]]

7.0 REFERENCES

E.1 GEH Service Information Letter (SIL), BWR Steam Dryer Integrity, No. 644, Rev. 2, 2006.

APPENDIX E.1 BROWNS FERRY RSD [[
]]

[[ ]]

Figure E.1-1: [[ ]]

[[ ]]

Figure E.1-2: [[ ]]

[[ ]]

Figure E.1-3: [[ ]]

[[ ]]

Figure E.1-4: [[ ]]

[[ ]]

Figure E.1-5: [[ ]]

[[ ]]

Figure E.1-6: [[ ]]

[[ ]]

Figure E.1-7: [[ ]]

[[ ]]

Figure E.1-8: [[ ]]

[[ ]]

Figure E.1-9: [[ ]]

[[ ]]

Figure E.1-10: [[ ]]

[[ ]]

Figure E.1-11: [[ ]]

[[ ]]

Figure E.1-12: [[ ]]

APPENDIX E.2 BROWNS FERRY RSD [[
]]

[[ ]]

Figure E.2-1: [[ ]]

[[ ]]

Figure E.2-2: [[ ]]

[[ ]]

Figure E.2-3: [[ ]]

[[ ]]

Figure E.2-4: [[ ]]

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Figure E.2-5: [[ ]]

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Figure E.2-9: [[ ]]

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Figure E.2-10: [[ ]]

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Figure E.2-11: [[ ]]

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Figure E.2-12: [[ ]]