ENCLOSURE 2

MFN 08-827

NEDC-33408P, Supplement 1

Non-Proprietary Version

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GE Hitachi Nuclear Energy

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Licensing Topical Report

ESBWR Steam Dryer - Plant Based Load Evaluation Methodology Supplement 1

Non-Proprietary Version

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Acronyms and Abbreviations

Acronym / Abbreviation	**Description**
1D	One Dimensional
3D	Three Dimensional
BWR	Boiling Water Reactor
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
ESBWR	Economic Simplified Boiling Water Reactor
FE / FEM	Finite Element / Finite Element Method / Finite Element Model
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
OLTP	Original Licensed Thermal Power
NRC	Nuclear Regulatory Commission
PBLE	Plant Based Load Evaluation
PSD	Power Spectral Density
PT	Pressure Transducer / Pressure Sensor
PWR	Pressurized Water Reactor
QC2	Quad Cities Unit 2

Acronym / Abbreviation	Description
RG	Regulatory Guide
RMS	Root Mean Squared
RPV	Reactor Pressure Vessel
SG	Strain Gage
SF	Singularity Factor
SRSS	Square Root of the Sum of the Squares
SRV	Safety / Relief Valve
SSES	Susquehanna Steam Electric Station
StDev	Standard Deviation

Abstract

NEDC-33408P, *Licensing Topical Report- ESBWR Steam Dryer – Plant Based Load Evaluation Methodology*, provides a methodology termed Plant Based Load Evaluation (PBLE) for defining the fluctuating pressure loads acting upon the Economic Simplified Boiling Water Reactor (ESBWR) steam dryer. This supplement to NEDC-33408P provides additional benchmarking results of the PBLE against data taken during startup testing of an instrumented replacement steam dryer at the Susquehanna Steam Electric Station (SSES). The supplement also provides a description of the additional modeling and methodology as well as the benchmarking results for the PBLE when using [[ ]] instrumentation data as input.

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 [2]. 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. NEDC 33408P [1] provides the theoretical basis of the PBLE method that will be applied for determining the fluctuating loads on the ESBWR steam dryer, describes the PBLE analytical model, describes the PBLE analytical model, and provides benchmark and sensitivity results of the PBLE with [[ ]] pressure data.

This report is a supplement to NEDC 33408P [1]. The initial report focused on a load solution that uses [[ ]] NEDC 33408P, Supplement 1 describes the load solution obtained from [[ ]] In addition, this supplement provides the results of benchmarking and sensitivity studies of the PBLE against measured [[ ]] pressure data taken during power ascension test of a replacement steam dryer installed at the Susquehanna Steam Electric Station Unit 1 (SSES). Finally, this supplement describes the application of the PBLE method to the evaluation of the ESBWR steam dryer and describes the method to be used to assess bias plus uncertainty of the resulting loads with [[ ]].

2.0 MODEL DESCRIPTION

Section 2.1 provides a brief overview of the PBLE model. Section 2.2 provides a summary of the steam dome acoustic model presented in detail in the [[ ]] PBLE report [1]. The steam dome acoustic model [[ ]] Section 2.3 develops the methodology for the [[ ]] formulation for the PBLE.

2.1 OVERVIEW

The PBLE can be [[ ]] This is the methodology to be used in the ESBWR evaluation and is described in [1]. [[

]]

[[

]]

Figure 1 PBLE process flow

As operating experience is gained with the ESBWR steam dryer and steam line configuration, the [[ ]] PBLE will provide a less invasive means of monitoring the acoustic pressure loads for follow-on plants. 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 [[on-dryer instrumentation{3}]] for the ESBWR 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 topical report supplement.

The lower chart in Figure 1 outlines the PBLE solution path when using [[ ]]

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

- An acoustic finite element model (3D) representing [[ ]] as described in [1]).
- A [[ ]]

Referring to the lower chart in Figure 1, on the top left corner, [[ ]] These [[ ]] This is the [[ ]] component of the PBLE shown in Figure 1 and is described in further detail in Section 2.3.1. The [[ ]] This is the [[ ]] component of the PBLE shown in Figure 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® [3] and SYSNOISE® [4]. 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 2.3.1).

The vessel acoustic response is calculated with SYSNOISE®. 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, SYSNOISE® is used to calculate the sound wave propagation through an acoustic finite element model of the steam regions in the reactor. This 3D acoustic model is described in detail in Section 2 of Reference 1.

2.2 DOME ACOUSTIC MODEL

The dome acoustic model is described in detail in the initial report [1]. This section summarizes the key aspects of the dome model.

The dome FE mesh (Figure 3) comprises all RPV steam volumes [[ ]] The SYSNOISE® [4] program was used to generate the models and benchmarking provided here. Alternate FE programs as described in Appendix J can also be used.

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

]]

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

The PBLE is formulated under the [[

]] (Figure 2). [[

]] Validation of the [[

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

[[

]]

Figure 2 [[ ]]

[[

]]

**Figure 3 Modeled Steam Region (left)
and Details of Typical Vessel Meshes (right)**

The [[

]]

(Figure 4). The total vessel response can then [[

]]

Figure 4 [[ ]]

[[

]]

2.3 PBLE FROM [[ ]]

The PBLE model described in Reference 1 used [[ ]]. This section describes the PBLE modeling used to determine the [[ ]]

2.3.1 [[ ]] Equations

[[ ]] which was initially described by Seybert and Ross [5] and Chung and Blaser [6]. The more recent [[ ]] are Jones and Stiede [7], Jones and Parrott [8] and Chu [9].

[[

]] From the momentum equation given by Munjal [10] in Section 1.4 (moving medium), [[

]] by Morse and Ingard [12]: [[

]]

2.3.2 [[ ]] with RPV

The approach in the previous section describes [[

]] which is the topic of the next section (Section 2.3.3).

[[

]]

2.3.3 [[ ]]

[[

]]

Figure 5 provides a depiction of the average [[

]]

Figure 5 [[

]]

2.3.3.1 General Formulation of Equations

[[

2.3.3.2 Incorporating the [[ ]]

This section describes the [[

]]

2.3.3.3 *[[*

]]

2.3.4 Singularity Factor

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

]]

as seen in Figure 6. A large [[

]]

Figure 6 [[

]] (Figure 7). Using [[

]] for the plant specific PBLE application is contained in Section 4.4.3.1.

]]

Figure 7 [[

]]

[[

]]

Figure 8 [[ ]]

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 initial LTR [1]. [[

]]

This section first addresses these [[

]]

2.4.1 [[ ]]

The variable nomenclature for this section is in Table 1.

Table 1 Variables in Equations (38) through (41)

[[			
			]]

Ingard and Singhal [15] propose a model for [[

]]

The friction factor *f*, also known as Darcy-Weisbach friction factor, is an empirical factor tabulated in Moody's diagram [16]. For flow with Reynolds numbers Re > 4000, the friction factor can also be determined by the Colebrook equation (which approximates Moody's diagram), presented here in the explicit version of Haaland [26]:

$$(40) \qquad f = \left(1.8\log\left(\left(\frac{\xi / D}{3.7}\right)^{1.11} + \frac{6.9}{\mathrm{Re}}\right)\right)^{-2}$$

From which unfolds: [[

]]

2.4.2 [[ ]]

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

]] are included in Table 2.

Table 2 [[

				]]

The four resulting points are plotted in Figure 9 as asterisks. The relation [[

]] As shown in Figure 9, [[

]]

The red curve in Figure 9 is a [[

]]

Table 3 [[

[[

]]

Figure 9 [[ ]]

3.0 MODEL QUALIFICATION: BWR PLANT VALIDATION

Two GEH BWR units went through steam dryer replacement programs in the recent years:

- Quad Cities Unit 2 (QC2) in 2005;
- Susquehanna Unit 1 (SSES) in 2008.

The replacement dryers were instrumented with a significant number of on-dryer pressure sensors. The units were also equipped with MSL instrumentation (strain gage bridges). Several measurement campaigns provided MSL and RPV datasets, used here to benchmark the PBLE predictions.

[[

]]

The QC2 benchmarks are PBLE predictions [[ ]] These QC2 Benchmark results are presented in Section 3.2. The SSES benchmarks are PBLE predictions [[ ]] and provide additional benchmarking of the PBLE method that complements the previous QC2 benchmarks from [[ ]] in report NEDC 33408P [1]. These SSES benchmark results are presented in Section 3.3.

3.1 PROCEDURE FOR BENCHMARKS

3.1.1 Instrumentation at QC2 and SSES

The QC2 dryer instrumentation comprised 27 pressure sensors, labeled P:1 through P:27 (See Figure 10). Pressure sensor P:26, which was installed on the stream dryer temporary instrumentation mast, is not considered in this benchmark since the main interest is in pressure on the dryer surface.

The SSES dryer instrumentation had [[

]]

[[

]]

Figure 10 QC2 Replacement Dryer Instrumentation

[[

]]

Figure 10 QC2 Replacement Dryer Instrumentation

[[

]]

Figure 11 SSES Replacement Dryer Instrumentation

[[

]]

Figure 11 SSES Replacement Dryer Instrumentation

The QC2 MSLs were instrumented with strain gage assortments at three locations per line; only the upper two (elevation 651-foot and elevation 621-foot) are used in the following benchmarks. These two positions are upstream of all valves and included four circumferentially oriented gages at each location. The lower locations had two strain gages at each location.

The MSL and RPV data used in QC2 benchmarks was acquired simultaneously [18]. The SSES dataset comprises [[ ]] that was obtained during the March 2008 power ascension testing [24]. Datasets are summarized in Table 4 below.

Table 4 Datasets Used in QC2 and SSES Benchmarks

Benchmark	[[ ]] Data			[[ ]] Data		
	Power	Instruments	Date	Power	Instruments	Date
	Quad Cities Unit 2 Cases					
1	[[	3 locations per line [[ ]], 4 strain gages per location	2005	[[	27 pressure transmitters on dryer	2005
2						
3						
4	]]			]]		
	Susquehanna Unit 1 Cases					
1				[[	[[ ]] pressures transmitters on dryer	2008
2				]]		

For the SSES benchmarks from [[ ]] the following configuration of input pressure sensors are used: [[ ]]

3.1.2 [[

]]

[[

]]

Figure 12 [[ ]] Benchmark [[

]]

]]

[[

]]

Figure 13 [[

]] are shown in Figure 14, Figure 15 and Figure 16 for both

[[

]]

Figure 17 includes the benchmark PSD comparisons between predictions using these

[[

]]

Figure 18 depicts the benchmark predictions limiting the [[

]] are described in Figure 19 and Figure 20. As shown in Figure 19, the [[

]]

[[

]]

Figure 14 Comparison of [[

]]

[[

]]

Figure 15 Plot of the [[ ]]

[[

]]

Figure 16 [[ ]]

[[

]]

Figure 17 [[

]]

[[

]]

Figure 18 [[

]]

[[

]]

Figure 19 [[ ]]

[[

]]

Figure 20 [[ ]]

3.1.3 Benchmark Presentation

The results presented below for the [[ ]] are all obtained using the [[ ]] (Figure 19 and Figure 20). [[

]]

Error Calculation

[[

]] are computed and displayed in bar charts (Sections 3.2 and 3.3 for each benchmark): [[

]] are calculated and displayed in bar charts (Sections 3.2 and 3.3 for each benchmark): [[

]]

The last segment PSDs at all sensors locations are plotted in Appendix A through Appendix D for the QC2 cases. The last segment PSDs at all sensors locations are plotted in Appendix E and Appendix F for the SSES cases. A comparison of the PSD plots from SSES and QC2 indicates that there is [[

]] QC2 and SSES plants represent a good test case for the PBLE benchmark because together they provide [[

]]

Table 5 Frequency Bands for Main Acoustic Peaks

QC2				SSES	
[[ ]] EPU Power		[[ ]] EPU Power		[[ ]] EPU Power	
Begin Frequency (Hz)	End Frequency (Hz)	Begin Frequency (Hz)	End Frequency (Hz)	Begin Frequency (Hz)	End Frequency (Hz)
8	10	8	10	5	10
13	16	13	16	11	20
22	26	22	26	21	28
29	31	28	34	29	39
32	35	38	46	40	50
44	48	48	58	51	62
49	60	61	69	63	69
61	69	70	76	70	75
70	76	77	82	76	89
77	82	82	88	90	99
82	88	89	95	100	109
89	95	96	102	110	122
96	102	103	110	123	131
103	110	111	116	132	149
130	136	117	128	150	168
137	142	129	146	169	181
147	149	147	153	182	194
150	153	154	158	195	205
154	158	159	168	206	225
150	158	146	158	226	250

3.2 QC2 BENCHMARKS FROM [[ ]]

3.2.1 At [[ ]] EPU

]]

Figure 21 QC2 [[ ]] EPU benchmark overview

3.2.2 At [[ ]] EPU

]]

Figure 22 QC2 [[ ]] EPU benchmark overview

3.2.3 At [[ ]] EPU

]]

Figure 23 QC2 [[ ]] EPU benchmark overview

3.2.4 At [[ ]] EPU

]]

Figure 24 QC2 [[ ]] EPU benchmark overview

3.3 SSES BENCHMARKS FROM [[ ]]

3.3.1 At [[ ]] EPU

]]

Figure 25 SSES [[ ]] EPU benchmark overview: [[
]]

3.3.2 At [[ ]] EPU

]]

Figure 26 SSES [[ ]] EPU benchmark overview

[[

]]

3.4 BENCHMARK CONCLUSIONS

As shown in Figure 27, the PBLE predictions from [[

]]

Overall the four QC2 benchmarks are well balanced and validate the [[
]] The PBLE from [[ ]] emerges as a viable tool for developing dryer load definitions. The frequency content and the spatial distribution are well matched, the amplitude predictions are generally conservative and pressures away from the MSL nozzles are consistent with plant test data from other dryers.

As shown in Figure 28, the PBLE predictions from [[

]]

The SSES benchmarks at two test conditions using the PBLE [[ ]] demonstrate the good behavior of the acoustic dome model and source assumptions and complement the results of the two QC2 cases depicted in Reference 1.

It should be noted that the [[

]] as can be observed from the PSD comparisons included in Appendices E and F. [[
]]

[[

]]

Figure 27 Benchmark Summary – PBLE with [[ ]]

[[

]]

Figure 28 Benchmark Summary – PBLE with [[ ]]

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 is to provide a methodology for using plant measurements to determine the fluctuating pressure loads that the ESBWR steam dryer will experience during normal operation. This fluctuating load definition can then be applied to a finite element model of the ESBWR steam dryer in order to determine the structural qualification of the dryer. This section describes the methodology that will be used in applying the PBLE to develop the dryer load definition.

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 [22], 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 [23], 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. References 22 and 23 contain specific acceptance criteria related to formulating forcing functions for vibration prediction. Reference 2 provides guidance on acceptable methods for formulating the forcing functions for vibration prediction.

4.2 PROPOSED APPLICATION METHODOLOGY

The PBLE method for formulating the forcing function for vibration prediction for the ESBWR steam dryer is in conformance with the guidance contained in Regulatory Guide 1.20 Revision 3 [2].

4.2.1 Conformance with Regulatory Guide 1.20 Rev 3

The following table provides the conformance of the PBLE to the requirements contained in Section 2.1 of Regulatory Guide 1.20 Revision 3 [2].

RG 1.20 Section	Criteria	PBLE 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 Section 3.0 of this report 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.	The justification that the PBLE method is acceptable is based on the benchmarking shown in Section 3.0 of this report. The stress analysis is outside the scope of this LTR. CFD modeling is not applicable to the PBLE method.
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 PBLE is capable of determining acoustic resonances that may be detrimental to the steam dryer. Modifications for reducing acoustic resonances are beyond the scope of this LTR.
2.1.(1)	Scale Model Testing	Not applicable - Scale model testing is not used in the PBLE for determination of the steam dryer loads.
2.1.(1)	Computational Fluid Dynamic (CFD) modeling	Not applicable - CFD modeling is not used in the PBLE for determination of the steam dryer loads.

RG 1.20 Section	Criteria	PBLE 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 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 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 frequency response functions (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 determined by the PBLE. Bias errors and uncertainties have been addressed in Sections 3 and 4. Structural mode shapes and FRFs are outside the scope of this LTR.
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 – the PBLE 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.	Lock in assessment is not required for PBLE loads developed using main steam line data. [[ ]]

RG 1.20 Section	Criteria	PBLE 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 in plant data, [[ ]], for the determination of the steam dryer load definition. Scale model date is not used in the PBLE methodology. Steam dryer strain and acceleration measurements are outside the scope of this LTR.
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 this report demonstrates the methodology to determine bias errors and uncertainties associated with the PBLE methodology when [[ ]]

RG 1.20 Section	Criteria	PBLE Conformance
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 PBLE methodology described in this report requires the use of at least two measurement locations for each MSL. As discussed in this report, the main steam line instrumentation sensors are placed such that no acoustic sources exist between the measurement locations.
2.1.(3)((b)	Strain gages (at least four gages, circumferentially spaced and oriented) may be used to relate the hoop strain in the MSL to the internal pressure. Strain gages 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 – This report describes the configuration of main steam line strain gages used for MSL measurements. Bias and uncertainty associated with the MSL measurement system is described in this report.
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 in the PBLE is a function of the steam fluid conditions within the RPV and the MSLs.
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 PBLE 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 formulation uses the steam quality in the reactor steam dome, within the steam dryer, and in the MSLs to determine the sound attenuation coefficients in those regions.

RG 1.20 Section	Criteria	PBLE 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 in the RPV and the MSLs.
Other	Model Benchmarking	Acceptable – The PBLE is benchmarked against previously instrumented dryer data.
Other	Determination of Biases and Uncertainty	Acceptable – The biases and Uncertainty have been calculated for the PBLE.

Note that other sections of Reference 2 refer to structural analysis of the steam dryer or preoperational/startup testing that is outside of the scope of this Licensing Topical Report.

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 ESBWR steam dryer.

4.4 PLANT-SPECIFIC APPLICATION METHODOLOGY

4.4.1 [[ ]] Model Inputs

The vessel [[

]]

Further information on the vessel model is provided in Reference 1.

4.4.2 [[ ]] Model

The [[ ]] model. Parameters for this model are listed in Table 6. All the input parameters identified in Table 6 are specified in the PBLE script input file. The PBLE scripts assemble the [[ ]]

4.4.3 Plant Input Measurements

4.4.3.1 Sensor Type and Location

MSL Instrumentation

For use with MSL instrumentation, the minimum PBLE configuration requires two sensor locations per steam line. [[ ]] If strain gauge bridges are used, the MSL pressures are calculated from the pipe hoop stress measurements.

[[ ]] Therefore, the sensors should be mounted directly downstream of the vessel nozzle in a region where side branches, valves, and venturis will not be located between the upper and lower sensor locations. These components may impact the transmission of acoustic waves. [[

]]

When strain gages are used, each location should be instrumented with a minimum of four strain gages. The gages must be located away from [[

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

The distance between [[

]]

Dryer Instrumentation

[[

]] From benchmarks on the QC2 data, it was concluded that [[

]]

4.4.3.2 Plant Measurement Uncertainty

The PBLE uses in-plant measurements 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.

Uncertainties in Measured Dryer Pressures

The measured dryer pressures have errors due to: [[

]]

An example of these uncertainties is documented in Reference 21 for QC2. However the above effects have a [[

]]

Uncertainties in Measured MSL Pressures

In practice, input MSL pressures are measured with strain gage setups rather than pressure sensors. The use of strain gauges to monitor MSL pressures introduces uncertainties in the determination of the MSL pressures. On a given MSL, at least two measurement locations are instrumented with a minimum of [[

]] when converting measured strain to pressure. This error is evaluated in Appendix I.

4.4.4 Plant-Specific Load Definition

The following steps are involved in the calculation of dryer loads with the PBLE from MSL measurements: [[

]] the PBLE

MATLAB® scripts are run and dryer loads are obtained.

4.5 APPLICATION UNCERTAINTIES AND BIASES

This section describes the process to calculate the uncertainty associated with the PBLE dryer load definition for a plant-specific application.

The methodology presented here is based on two elements:

- The PBLE plant benchmark evaluations presented in Section 3.0 ([[ ]]) and Reference 1 ([[ ]])
- A plant-specific sensitivity assessment for the PBLE input parameters.

The PBLE plant benchmark evaluations form the basis for the generic PBLE application bias and uncertainty values. The plant-specific sensitivity assessment is performed to establish the applicability of the generic PBLE application bias and uncertainty values to the plant under consideration and, if necessary, determine the appropriate PBLE [[ ]]

Section 4.5.1 describes the methodology used for performing the sensitivity assessment on the PBLE inputs. Best estimate values of the input parameters are used to calculate a nominal case, e.g., [[ ]] The input parameters are then varied within a range that bounds the expected parameter variation during operation or the parameter measurement uncertainty, as appropriate. The perturbed results are then compared to the nominal case. This comparison demonstrates the overall PBLE sensitivity to variations in the input parameters and identifies the contribution of each input parameter to the overall uncertainty in the predicted dryer pressure loads.

Section 4.5.2 summarizes the generic sensitivity assessments performed for the QC2 [[ ]] and for the SSES [[ ]] The details of these sensitivity assessments are described in Appendices G and H, respectively.

Section 4.5.3 describes the plant-specific application methodology for evaluating the plant-specific sensitivity assessment results relative to the generic results. The methodology also describes the conditions under which [[ ]]

4.5.1 Overall Methodology

This section describes constituting elements of the sensitivity assessment: the specifications for the nominal case, the input parameter variations for the sensitivity assessment, the Design of Experiment (DOE) method employed, and the process for calculating the deviations from the nominal case.

Parameters in the Sensitivity Analysis

[[

]]

Table 6 Input parameters to the PBLE

[[			

]]

Analysis Technique: Design of Experiment (DOE)

A Design of Experiment (DOE) is a structured, organized method for determining the relationship between parameters affecting a process and the output of that process. Changes are made methodically to the input parameters and the impact on the results is assessed.

The variations in the PBLE results are assumed to be reasonably linear with respect to the variations in the input parameters. In this case only the extreme values of parameters need to be evaluated.

For each input parameter, a number of possible values are defined: in the present case, the maximum value and the minimum value are considered. [[

]]

Evaluating multiple sub-groups of parameters is a more conservative approach compared to a single DOE that varies all the parameters at once. When all the parameters are evaluated together, a significant response caused by one parameter may be canceled out by opposing variations due to another parameter. The other advantage of multiple evaluations of smaller sized DOEs is that the most sensitive parameters are highlighted.

Deviations from Nominal Case

The nominal case uses all input parameters at their nominal or best-estimate values for parameters that are constant (e.g., MSL pipe diameter); the sensitivity range for these parameters is usually governed by tolerances or measurement uncertainties. For parameters that may be varying over the course of an operating cycle (e.g., moisture fraction upstream of the dryer), the nominal value represents an average value over the cycle, with sensitivity range determined by expected range of variation over the course of the cycle. The nominal PBLE calculations are performed following the guidelines outlined in Section 4.4. [[

]]

4.5.1.1 Vessel [[ ]]

[[

]] prior to performing the plant-specific sensitivity evaluations.

4.5.1.2 [[ ]] Sensitivity Evaluation

Once all the necessary [[ ]] have been pre-computed, the overall sensitivity in the PBLE loads can be evaluated.

[[

]] The experiments listed in Table 7 were used to study the [[ ]]

Table 7 Experiments for [[

]]

4.5.2 Generic Sensitivity Assessment

Generic bias and uncertainty values for the [[ ]] are established by the PBLE qualification benchmark comparisons in Section 3.2. Generic bias and uncertainty values for the [[ ]] are established by the PBLE qualification benchmarks in Reference 1 and Section 3.3 of this LTR supplement.

For plant-specific applications of the PBLE, the generic bias and uncertainties established by these benchmarks can be applied to the load definition provided the [[

]] values presented in Tables 9a and 9b. This approach will assure that any potential under prediction in the plant-specific load definition will be bounded by the generic benchmark bias and uncertainty.

4.5.2.1 QC2 [[ ]] Sensitivity Assessment

The following summarizes the results of the sensitivity assessment addressed in Appendix G and recommendations for the application of the PBLE model for use at other BWRs:

[[

]]

The major causes of uncertainty in the PBLE loads are the [[

]]

4.5.2.2 SSES [[ ]] Sensitivity Assessment

Appendix H documents the sensitivity assessment for SSES using [[

]]

4.5.3 Plant Specific Application Methodology

The QC2 benchmark deviation from measured data (bias and uncertainty) is covered in the benchmark section (Section 3.2.2). The bias (Equation (48)) indicates any [[

]]

The bias for the four QC2 benchmark [[ ]] conditions are summarized as shown in Table 8a. [[

]]

Table 8a PBLE with [[ ]] – Mean Bias and Uncertainty

[[			
			]]

Table 8b summarizes statistical data for the two QC2 benchmarks using [[ ]] presented in Section 3.3 of this report. [[ ]]

Table 8b PBLE [[ ]] – Mean Bias and Uncertainty

[[			
			]]

Using [[ ]], the maximum and minimum bias and uncertainty results from Appendix G are summarized in Table 9a below. The values in Table 9a show the results for the limiting frequency band (out of all the bands) for each parameter. Based on these results, [[ ]]

Table 9a PBLE with [[ ]] – Maximum and Minimum Bias and Uncertainty

[[		
		]]

Using [[ ]] the maximum and minimum bias and uncertainty results from Reference 1 and Appendix H are summarized in Table 9b below, again showing the limiting frequency band for all frequency spans. Based on these results, [[ ]]

Table 9b PBLE with [[ ]] – Maximum and Minimum Bias and Uncertainty

[[		
		]]

[[

]]

The sensitivity studies performed in Appendix G, Appendix H and Reference 1 were [[ ]] The results for the PBLE using [[ ]] are summarized in Tables 10a and 10b. Tables 10a and 10b [[

]] Therefore, it is concluded that these [[ ]]

For plant-specific applications, the applicable range for each of these parameters will be determined and a plant-specific sensitivity assessment will be performed. [[

]] This approach will ensure that the plant-specific PBLE load definition predictions are sufficiently conservative.

Table 10a PBLE [[ ]] – Bounding Sensitivity Assessment Results

Sensitivity Study Results using [[ ]]	Minimum Deviation
[[	
	]]

Table 10b PBLE [[ ]] – Bounding Sensitivity Assessment Results

Sensitivity Study Results using [[ ]]	Minimum Deviation
[[	
	]]

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 PBLE technique for determining dryer loading with [[ ]] From comparison between measurements and projections, the PBLE predicts good frequency content and spatial distribution. The SRV valve resonances are well captured.

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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APPENDIX A QC2 BENCHMARK PSDS: [[ ]] EPU

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APPENDIX B QC2 BENCHMARK PSDS: [[ ]] EPU

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APPENDIX C QC2 BENCHMARK PSDS: [[ ]] EPU

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APPENDIX D QC2 BENCHMARK PSDS: [[ ]] EPU

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APPENDIX E SSES BENCHMARK PSDS [[ ]] EPU

(PBLE from [[ ]])

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APPENDIX F SSES BENCHMARK PSDS [[ ]] EPU

(PBLE from [[ ]])

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APPENDIX G QC2 SENSITIVITY ASSESSMENT

G.1. VARIATIONS IN PBLE INPUT PARAMETERS

Table 11 provides the [[ ]] for all the input parameters.

Table 11 [[ ]]

	[[			
				]]

[[

]]

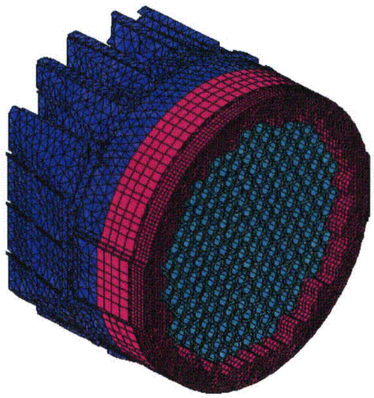
G.2 STEP 1 – PREPARATION OF FRF SETS

[[

]]

Table 12 [[ ]] in View of Sensitivity Assessment

	[[			
				]]



]]

Figure 29 FEM mesh Upstream of the Dryer Showing the Regions with [[ ]]

G.3. STEP 2 – SENSITIVITY IN PREDICTED DRYER PRESSURES

As described in Section 4.5.1.2, DOEs are run for all parameters in Table 11. For the sensitivity due to uncertainty [[ ]], the four analysis cases of Section 4.5.1.2 are considered. Deviations are calculated using the Equations (52) and (53) in Section 4.5.1. The results presented below in Table 13 are either detailed (all DOE combinations) or summarized (maximum and minimum deviations), which is more appropriate e.g. [[ ]] The most significant deviations are highlighted in violet.

The impact of changes in [[ ]]

G.4 RESULTS

[[

Table 14 provides a summary where the sensitivity assessment results for [[

]] The maximum absolute positive (+) and negative (-) bias from the sensitivity results in Table 13 was used in this summary. This summary demonstrates that with [[

]]

The results in Table 13 show that [[
]]

The results in Table 13 also show that [[

]]

Table 13 Sensitivity to Input Parameters of PBLE from [[ ]] – QC2 EPU Test Condition (Deviations are expressed in %)

Frequency Band (Hz) (→) Input parameters (↓)	8 -10	13 – 16	22 - 26	28 - 34	38 – 46	48 - 58	61 - 69	70 – 76	77 – 82	82 – 88	89 – 95	96 – 102	103 – 110	11 – 116	117 - 128	129 - 146	147 - 153	154 - 158	159 - 168	146 - 158
[[																				

Frequency Band	8 - 10	13 - 16	22 - 26	28 - 34	38 – 46	48 - 58	61 - 69	70 – 76	77 – 82	82 – 88	89 – 95	96 – 102	103 – 110	11 – 116	117 - 128	129 - 146	147 - 153	154 - 158	159 - 168	146 - 158

Frequency Band	8 -10	13 - 16	22 - 26	28 - 34	38 – 46	48 - 58	61 - 69	70 – 76	77 – 82	82 – 88	89 – 95	96 – 102	103 – 110	11 – 116	117 - 128	129 - 146	147 - 153	154 - 158	159 - 168	146 – 158

Frequency Band	8 - 10	13 - 16	22 - 26	28 - 34	38 – 46	48 - 58	61 - 69	70 – 76	77 – 82	82 – 88	89 – 95	96 – 102	103 – 110	11 – 116	117 - 128	129 - 146	147 - 153	154 - 158	159 - 168	146 – 158

Frequency Band	8 - 10	13 - 16	22 - 26	28 - 34	38 - 46	48 - 58	61 - 69	70 - 76	77 – 82	82 – 88	89 – 95	96 – 102	103 – 110	11 – 116	117 - 128	129 - 146	147 - 153	154 - 158	159 - 168	146 - 158
																				]]

Note: Most significant deviations are highlighted with violet shading.

Table 14 Sensitivity of PBLE for Variation in [[ ]] – QC2 EPU Test Condition (Deviations are expressed in percent)

Frequency Band	8 -10	13 - 16	22 - 26	28 - 34	38 – 46	48 – 58	61 - 69	70 - 76	77 – 82	82 – 88	89 – 95	96 – 102	103 – 110	11 – 116	117 - 128	129 - 146	147 - 153	154 - 158	159 - 168	146 – 158
[[																				
																				]]

APPENDIX H SSES SENSITIVITY ASSESSMENT

This section presents a sensitivity assessment for [[ ]], using the PBLE [[ ]] The related benchmark is presented in Section 3.3.1.

H.1. VARIATIONS IN PBLE INPUT PARAMETERS

Table 15 gives the [[ ]] the input parameters.

Table 15 [[ ]]

	[[			
				]]

The choice of input parameters is influenced by previous studies. [[

]]

H.2. SENSITIVITY IN PBLE PREDICTED DRYER PRESSURES

[[

]]

Only the parameter or group of parameters under study is modified. Other parameters remain at their [[ ]] in Table 16 are calculated, the [[ ]] are used.

The PBLE is run for [[ ]] in Table 16 and deviations from the nominal case are reported in Table 17. The deviations are calculated as described in Section 4.5.1.

Table 16 [[ ]] in View of Sensitivity Assessment

	[[			
				]]

Table 17 Sensitivity to Input Parameters of PBLE – [[ ]] Test Condition
(Deviations are expressed in %)

Frequency bands [Hz] (→) Input Parameters (↓)	5 to 10	11 to 20	21 to 28	29 to 39	40 to 50	51 to 62	63 to 69	70 to 75	76 to 89	90 to 99	100 to 109	110 to 122	123 to 131	132 to 149	150 to 168	169 to 181	182 to 194	195 to 205	206 to 225	226 to 250
[[																				

Frequency bands [Hz] (→) Input Parameters (↓)	**5 to 10**	**11 to 20**	**21 to 28**	**29 to 39**	**40 to 50**	**51 to 62**	**63 to 69**	**70 to 75**	**76 to 89**	**90 to 99**	**100 to 109**	**110 to 122**	**123 to 131**	**132 to 149**	**150 to 168**	**169 to 181**	**182 to 194**	**195 to 205**	**206 to 225**	**226 to 250**
																				]]

Note: Most significant deviations are highlighted with violet shading.

H.3. CONCLUSIONS

Based on this assessment [[

]]

APPENDIX I CORRELATION OF STRAIN GAGE DATA TO ACOUSTIC PRESSURE EXPERIMENTAL TESTING

I.1. INTRODUCTION

This section summarizes the analysis of strain gage 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. Pressure from strain gages is used in the benchmarking of the PBLE. This report compares the response of the gages and pressure transmitters and presents an assessment of the bias and uncertainty associated with the use of strain gages for measuring acoustic pressure inside a pipe.

I.2. EXPERIMENTAL SETUP

[[

]]

Figure 30 Photograph of Test Section.

[[

]] as seen in Figure 31, with the drawing dimensions presented in Figure 32. Each station consists of 8 strain gages orientated in the hoop direction equally spaced circumferentially around the pipe as shown in Figure 33. There was a corresponding pressure transducer mounted [[

]] A photograph of the test section and the downstream piping system is presented in Figure 34, with a schematic of the piping system is shown in Figure 35. [[

]]

[[

]] A more technical explanation is included in Section I.3.

[[

]]

Figure 31 Schematic of Experimental Setup for Strain Gage/Acoustic Pressure Test.

[[

]]

[[

]]

Figure 32 Drawing Dimensions for Test Article.

[[

]]

Figure 33 Strain Gage Orientation and Numbering.

[[

]]

Figure 34 Piping Layout and Supports.

[[

]]

Figure 35 Schematic of Piping Layout and Supports.

I.3. CONVERSION OF STRAIN GAGE DATA TO PRESSURE DATA

[[

]] The modulus of elasticity for the pipe as a function of temperature is presented in Table 19. The strain to pressure conversions (Table 20) are performed with the [[
]] from each location.

Table 18 Pipe Thickness as a Function of Azimuth, for both Strain Gage Locations.

[[										
										]]

Table 19 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 20 Calculation of Pressure to Strain Ratio

[[							
							]]

I.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, [[

]]

I.5. DESCRIPTION OF TEST DATA

Out of the [[ ]], there were three test cases that included temporal strain pressure and accelerometer data necessary for assessing strain gage performance. The three test cases were:

Table 21 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 36), pressure (Figure 37) and temperature (Figure 38) 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 36 Flow as a Function of Time for the Three Tests.

[[

]]

Figure 37 Pressure as a Function of Time for the Three Tests.

[[

]]

Figure 38 Temperature as a Function of Time for the Three Tests.

The air pressure and flow variations noted in Figure 36 and Figure 37 will have [[

]]

The air temperature in the pipe dropped less than 40F during the tests. The room temperature remained constant at approximately 70F. [[

]]

I.6. ANALYSIS OF RESULTS

Figure 39 and Figure 40 depict the individual strain gage signals and the averaged signals at each location. The strain has been converted to pressure using the conversion factors shown in Table 20. In these plots, strain gages on opposite sides of the pipe are plotted in the same color in dashed and solid lines. [[

]]

[[

]]

Figure 39 SG1 Location, Individual Strain Gage Signals Case 1.

]]

Figure 40 SG2 Location, Individual Strain Gage Signals Case 1.

[[

]]

For Case 1, Figure 41 provides a power spectral density plot for PT1, PT2, and coherence between PT1 and PT2. Figure 41 also provides the PSDs for SG1, SG2, and coherence between SG1 and SG2 for the same time interval. [[

]]

Figure 42 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 41 PT and SG ([[ ]]) PSD and Coherence Data (Case 1).

[[

]]

Figure 42 PT1, PT2, PT3 PSDs and Coherence Data (Case 1).

Figure 43 provides a comparison of the PSD data for the strain gage 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 43 Comparison of PT and SG ([[ ]]) PSD and Coherence Data.

[[

]] plot in Figure 45.

[[

]]

Figure 45 [[

]]

Figure 46 represents a comparison of the [[

]]

Figure 47 represents a comparison of the PT data compared with the [[

]]

[[

]]

Figure 46 Pressure Based on [[

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[[

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Figure 47 Pressure Based on PT Sensor [[

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[[

]] are identified in Figure 48.

[[

]]

Figure 48 depicts the results for Case 1. This includes both the [[

]]

If all frequency bands are combined, the resulting error for all frequency and time intervals the error results for are:

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 48 Test Case 1: Error in Peak Pressure Response from SG Versus PT.

Figure 49 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 49 Test Case 1: Error in RMS as a Function of Frequency Band Pressure Response

[[ ]]

Figure 50 and Figure 51 compare the RMS response of pressure from the [[

]] Figure 52 through Figure 55 provide these same plots for test Cases 2 and 3. For all frequency intervals of Cases 1, 2, and 3 (Figure 50, Figure 52, and Figure 54), the [[

]]

[[

]]

Figure 50 Case 1: Error in RMS as a Function of Frequency Band Pressure Response from
[[ ]]

[[

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Figure 51 Test Case 1: Average RMS as a Function of Frequency Band Pressure Response
[[ ]]

[[

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Figure 52 Test Case 2: Error in RMS as a Function of Frequency Band Pressure Response

[[ ]]

[[

]]

Figure 53 Test Case 2: Average RMS as a Function of Frequency Band Pressure Response

[[ ]]

[[

]]

Figure 54 Test Case 3: Error in RMS as a Function of Frequency Band Pressure Response

[[ ]]

[[

]]

Figure 55 Test Case 3: Average RMS as a Function of Frequency Band Pressure Response

[[ ]]

I.7. PBLE DRYER LOADS BIAS USING SG SIGNALS FOR UNSTEADY MSL PRESSURE

[[

]]

I.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 gages at location SG1 and SG2. [[

]]

There were 19 combinations of [[ ]]used in this investigation. These are summarized in Table 22:

Table 22 Strain Gages Combinations used in Strain Gage 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 56 summarize the error in peak response in [[

]]

[[

]]

Figure 56 Error in Peak Response as a Function of SG [[ ]] (All Frequency and Time Intervals)

Table 23 [[ ]]

[[						
						]]

Note: [[ ]]

Figure 57 through Figure 59 provide PSD comparisons of pressure calculated using [[ ]] This is also reflected in Figure 60 through Figure 62 that provide the [[ ]]

[[

]]

Figure 57 8 Strain Gage [[ ]]

[[

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Figure 58 4 Strain Gage [[ ]]

[[

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Figure 59: 2 Strain Gage [[ ]]

[[

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Figure 60: Frequency Band [[

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[[

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**Figure 61: Frequency Band [[
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[[

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Figure 62: Frequency [[ ]]

I.9. STAIN GAGE ARRANGEMENT AND THE IMPACT TO PBLE LOADS

In calculating acoustic pressure [[ ]] provides pressure predictions commensurate [[ ]] There is a substantial increase in error [[ ]]

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APPENDIX J ACOUSTIC FINITE ELEMENT PROGRAM REQUIREMENTS FOR PBLE

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