Enclosure 4

MFN 12-043, Revision 1

GE Hitachi Nuclear Energy, “ESBWR Steam Dryer – Plant Based Load Evaluation Methodology, PBLE01 Model Description,” NEDO-333408, Revision 2, Class I (Non-Proprietary), February 2013

Public Version

GE Hitachi Nuclear Energy

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Non-Proprietary Information-Class I (Public)

ESBWR STEAM DRYER - PLANT BASED LOAD EVALUATION METHODOLOGY

PBLE01 Model Description

INFORMATION NOTICE

This is a non-proprietary version of the document NEDC-33408P, Revision 2, which has the proprietary information removed. Portions of the document that have been removed are indicated by an open and closed bracket as shown here [[ ]].

IMPORTANT NOTICE REGARDING THE CONTENTS OF THIS REPORT

Summary of Changes

NEDO-33408, Revision 2

Page / Section	Description of Changes
Changes from –A Revision 1 to Revision 2	
Cover Page	Copyright date updated with 2013
General	Replaced “gage” with “gauge” in multiple places for consistency
S2.1	Removed reference to use of “steam line pressure data” to define acoustic loads
S2.1	Added text from NEDC-33408 Supplement 1P-A, Revision 2 section 2.3 stating that alternate FE programs can be used as described in new Appendix D.
Figure 2	Replaced Quad Cities 2 acoustic mesh figures with acoustic mesh figures used for the Grand Gulf EPU benchmark.
S2.2.2 and Figure 3	Revised description of typical vessel model to reflect expected range of mesh elements (500,000 to 1,000,000) and deleted discussion of Quad Cities 2 drain channel sensitivity along with Figure 3.
S2.3.1	Delete reference to Quad Cities 2 benchmarking using eight pressure sensors in Sections 3.2 and 3.3.
S2.4.3	Added new section to describe vane upstream droplet wetness correlation previously documented in NEDC-33408 Supplement 1P-A, Revision 2.
Figure 9	Delete reference to Quad Cities 2 and specific pressure transducer nomenclature since figure is provided as illustrative purpose only.
S3.0	Replaced references to Quad Cities 2 with Grand Gulf Nuclear Station.
S3.1.1	Corrected section number to 3.1. Section replaced with new text describing GGNS PBLE01 validation procedure.
S3.2	Section replaced with new text describing GGNS PBLE01 validation at CLTP.
S3.3	Section replaced with new text describing GGNS PBLE01 validation at EPU.
S3.4	Delete QC2 Benchmark Conclusions section and replace with GGNS PBLE01 validation conclusions.
S4.2.1	RG 1.20 Section 2.1.(1)(b) PBLE01 conformance revised to reflect use of GGNS end-to-end benchmark.
S4.2.1	RG 1.20 Section 2.1.(3) PBLE01 conformance revised to reflect use of GGNS end-to-end benchmark

Page / Section	Description of Changes
Changes from –A Revision 1 to Revision 2	
S4.4.1	Correct incorrect reference to figure.
S4.4.1	Deleted reference to "if model size allows it the upper frequency limit for the meshing requirements should be 150% of the highest frequency considered in the analysis. This statement should be removed, as it does not apply to PBLE01. The PBLE01 acoustic FRFs are calculated thru 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). The 150 % applies only to the modal superposition, which is not used in PBLE01.
S4.4.1	Delete paragraph preceding Figure 18 which refers to Quad Cities 2 benchmark analysis which have been deleted.
S4.4.2	Delete reference to Quad Cities 2 benchmark.
S4.4.2	Add information on calibration of on-dryer sensors in response to NRC RAI 3.9.274.
S4.4.4	Delete entire section that refers to sensitivity studies performed on the Quad Cities 2 acoustic model and replace with summary of GGNS EPU end-to-end benchmarks.
Figure 20	Figure added to show end-to-end bias and uncertainty for GGNS EPU benchmark for the upper dryer region.
Figure 21	Figure added to show end-to-end bias and uncertainty for GGNS EPU benchmark for the lower dryer region.
S4.5	Delete entire section that refers to Quad Cities 2 benchmarks.
S5.0	Replace references to Quad Cities 2 benchmarks with references to GGNS EPU end-to-end benchmarks.
Appendix A	Delete QC2 benchmark results and replace with GGNS dryer instrumentation descriptions.
Appendix B	Delete QC2 benchmark results and replace with GGNS PBLE01 validation plot comparisons at CLTP.
Appendix C	Delete QC2 uncertainty assessment and replace with GGNS PBLE01 validation plot comparisons at EPU.
Appendix D	Add new Appendix that defines requirements for PBLE01 finite element program (Appendix J from NEDC-33408 Supplement 1P-A).
Appendix E	Add new Appendix that provides comparison of predicted and measured on-dryer sensor response (strain gage and accelerometers).
Appendix F	Add new Appendix that provides a summary table of end to end bias and uncertainties.

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Acronyms and Abbreviations

BWR	Boiling Water Reactor
CAD	Computer-Aided Design
CLTP	Current Licensed Thermal Power
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
EPU	Extended Power Uprate
ESBWR	Economic Simplified Boiling Water Reactor
FE / FEM	Finite Elements / Finite Element Method / Finite Element Model
FRF	Frequency Response Function
GDC	General Design Criteria
GEH	GE Hitachi Nuclear Energy
GGNS	Grand Gulf Nuclear Station
Hz	Hertz
MSL	Main Steam Line
NRC	Nuclear Regulatory Commission
PBLE	Plant Based Load Evaluation
PSD	Power Spectral Density
PT	Pressure Transducer
PWR	Pressurized Water Reactor
RG	Regulatory Guide
RPV	Reactor Pressure Vessel
SF	Singularity Factor
SRV	Safety / Relief Valve
3D	Three Dimensional

Abstract

A methodology, termed Plant Based Load Evaluation (PBLE01), is presented for defining the fluctuating loads that are imposed upon the Economic Simplified Boiling Water Reactor (ESBWR) reactor 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.

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 [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:

(1) Predict the fluctuating pressure loads on the dryer,

(2) Use these fluctuating pressure load in a structural analysis to qualify the steam dryer design

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

The PBLE01 (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 the PBLE01 method that will be applied for determining the fluctuating loads on the ESBWR 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 ESBWR steam dryer.

2.0 MODEL DESCRIPTION

2.1 Overview

[[

]]

Figure 1. PBLE01 Process Flow

The PBLE01 can be [[

]]

This is the methodology to be used in the ESBWR evaluation and is described in this report. [[

]]

The PBLE01 is built on the commercial software packages Matlab [2] and Sysnoise [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 Sysnoise. 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, 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 FE programs as described in Appendix D can also be used.

2.2 Dome Acoustic Model

2.2.1 Sysnoise Modeling Principles

Sysnoise [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. [5] and [10]). [[

]]

The following system of equations is solved:

$$(1) \quad \left[K + i\omega C - \omega^2 M\right]\{p\} = \{F_A\}$$

Where F_A 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.

2.2.2 Geometry Modeling

The dome FE mesh (Figure 2) 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. Modeled steam region (left) and details of typical vessel meshes (right)

Figure 3. (Figure Deleted)

[[

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[[

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Figure 4. [[

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[[ ]]

Table 1 First Ten RPV modes

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

2.2.3 Finite Element Model

[[

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[[

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Figure 5. [[ ]]

[[

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[[

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Figure 6. [[ ]]

[[

]]

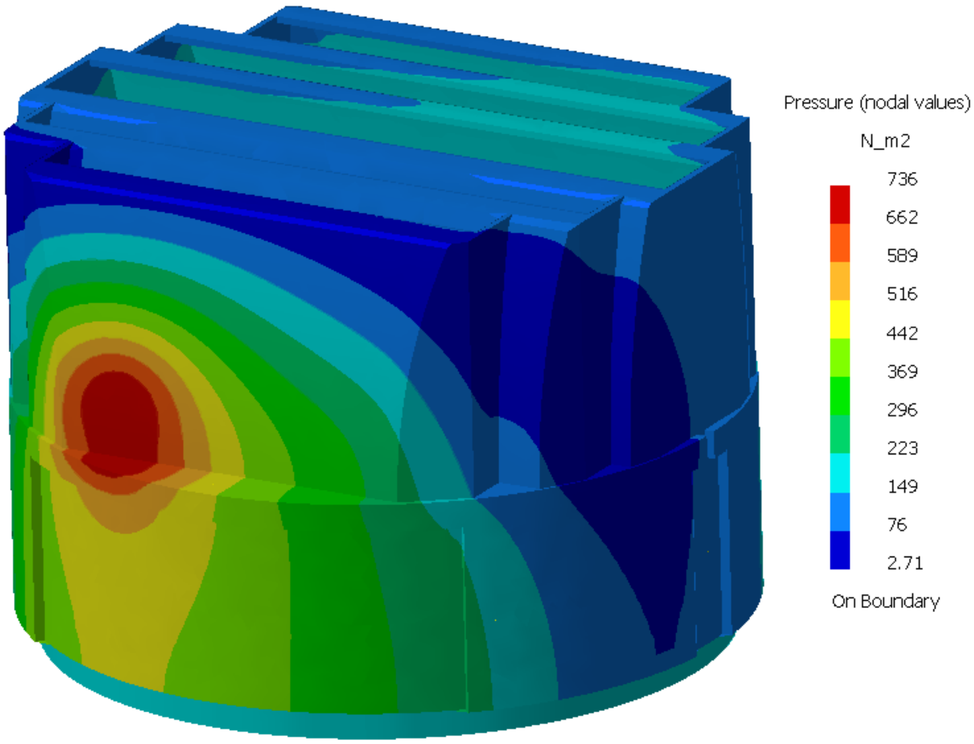

**Figure 7. Pressure amplitudes on dryer at 15 Hz (Forced Response)
View of CD side**

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 8. Vessel passive boundary conditions

2.3 PBLE01 from [[ ]]

2.3.1 Solution Formulation

The pressure at any dryer point P [[

]]

These considerations make the PBLE01 from in-vessel pressures 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 9. [[ ]]

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 [6]. Petr [7] developed the [[

]] by Karplus [8].

2.4.1 [[ ]]

The following summary follows the description given in [7], Section 2. The variable nomenclature for this section is in Table 2.

[[

]]

Table 2 [[ ]]

[[	
	]]

[[

]]

[[

]]

Figure 10. [[ ]]

2.4.2 Steam-water interface

[[

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[[

]]

Figure 11. Steam-Water Interfaces

Table 3 Impedances in a Typical BWR RPV Environment

[[				
				]]

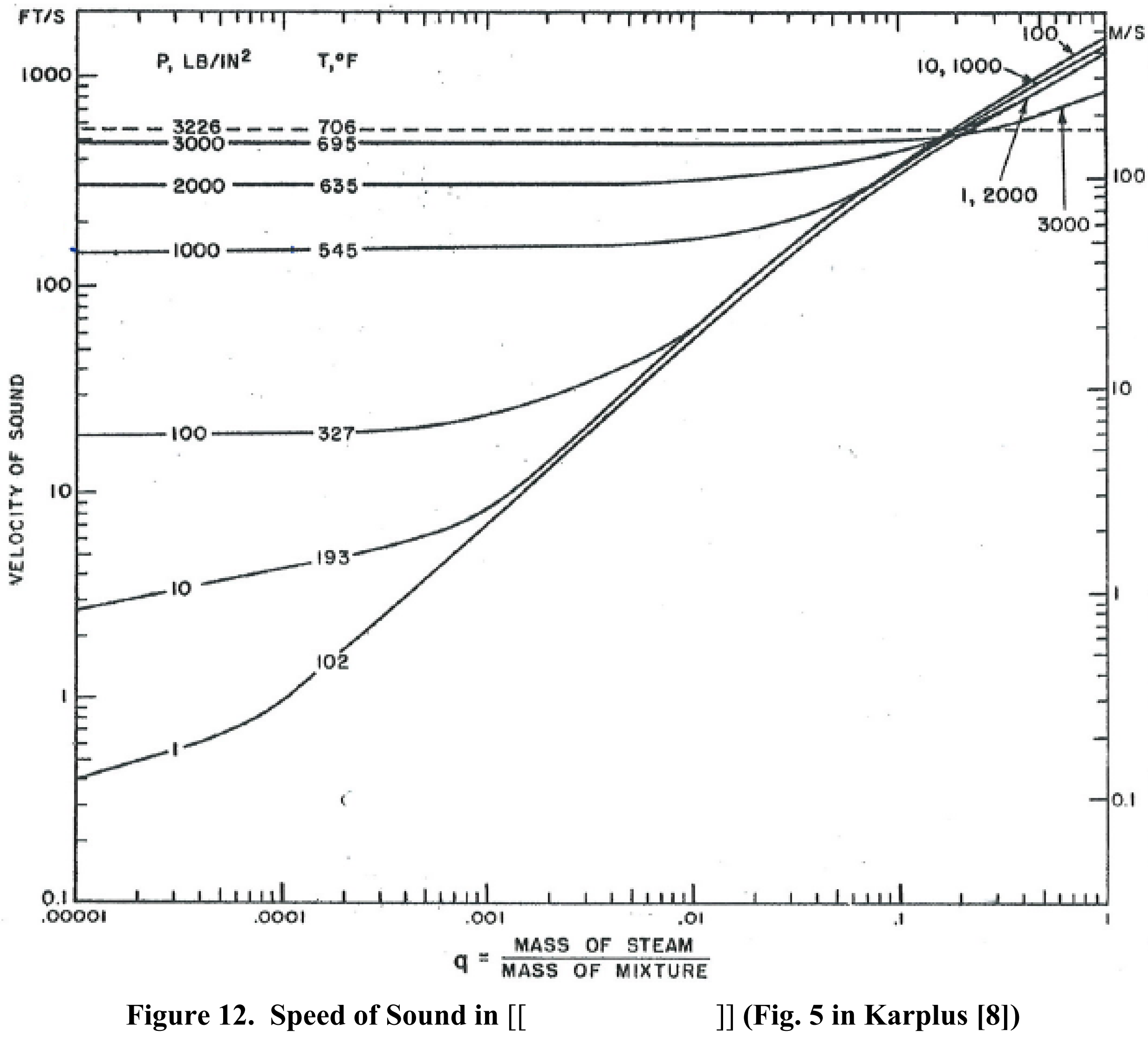

Figure 12. Speed of Sound in [[ ]] **(Fig. 5 in Karplus [8])**

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

]]

2.4.3 [[ ]]

[[

]]

[[

]]

Figure 13. [[ ]]

3.0 MODEL QUALIFICATION: BWR PLANT VALIDATION

The Grand Gulf Nuclear Station (GGNS) replacement steam dryer, installed in 2012, was instrumented with a significant number of on-dryer pressure sensors. This section presents the steam dryer fluctuating load definitions obtained with the PBLE01 at GGNS for two power levels, one at the GGNS Current Licensed Thermal Power (CLTP) level and at Extended Power Uprate (EPU) conditions.

3.1 Procedure for GGNS PBLE01 Validation

A three-dimensional GGNS acoustic FEM, shown in Figure 2, representing the steam dryer and the steam dome region of the reactor pressure vessel (RPV) above the reactor steam separator tubes and the liquid water interfaces was used to generate acoustic loads. The model was developed with the mesh requirement of [[ ]]

[[

]]

To monitor the steam dryer pressure loads, the GGNS steam dryer was instrumented with 15 pressure transducers (PTs). The location of the pressure transducers is described in Appendix A. [[

]] The regional layout of the GGNS PT sensors is also shown in Appendix A. The layout was selected to be well distributed to capture the pressure response over the entire dryer. The regional locations were also selected to avoid pressure nodes in the acoustic harmonic response for frequencies that contribute most heavily to loading in the dryer components with the highest stress. [[

]]

During the GGNS startup, test data was obtained at various power levels during approximately steady state conditions. The data samples taken were at least [[ ]] seconds long. The [[ ]] data was then used with the acoustic model described above and the methodology defined in Section 2.3.1 to predict loads on the steam dryer.

3.2 GGNS PBLE01 Validation at CLTP

Steady state data was obtained at CLTP conditions during the GGNS startup. The [[ ]] data was then used to define acoustic loads on the steam dryer. Appendix B shows the comparison between the PBLE01 predicted pressure loads and the measured pressures for each of the on-dryer pressure sensors at CLTP condition. It should be noted that the [[ ]]

3.3 GGNS PBLE01 Validation at EPU

Steady state data was obtained at EPU conditions during the GGNS startup. The [[ ]] data was then used to define acoustic loads on the steam dryer. Appendix C shows the comparison between the PBLE01 predicted pressure loads and the measured pressures for each of the on-dryer pressure sensors at EPU condition. During the power ascension from CLTP to EPU conditions, [[ ]]

3.4 GGNS PBLE01 Validation Conclusions

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

Appendix B shows comparison plots for the predicted versus measured pressures at the PT sensor locations for the GGNS CLTP conditions. These predicted values were based on [[ ]] as the input to the PBLE01 methodology. [[ ]] In general, the comparison plots in Appendix B demonstrate that the PBLE01 methodology is capable of adequately capturing the frequency content across the dryer face. In general, at CLTP conditions [[ ]], the predicted loads are [[ ]].

During the power ascension testing, [[

]] The comparison plots in Appendix C demonstrate that the PBLE01 methodology is capable of adequately capturing the frequency content across the dryer face at EPU conditions. [[

]]

Overall the PBLE01 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.

Table 4 (Table Deleted)

Figure 14. (Figure Deleted)

Figure 15. (Figure Deleted)

Figure 16. (Figure Deleted)

Figure 17. (Figure Deleted)

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 Plant Based Load Evaluation Engineering Report is to provide a methodology for determining 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.

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 [12], 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. 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 [12] and [13] contain specific acceptance criteria related to formulating forcing functions for vibration prediction. Reference 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 ESBWR steam dryer is in conformance with the guidance contained in Regulatory Guide 1.20 Revision 3.

4.2.1 Conformance with Regulatory Guide 1.20 Rev 3

The following table provides the conformance of the PBLE01 to the requirements contained in Section 2.1 of Regulatory Guide 1.20 Revision 3 [1].

RG 1.20 Section	Criteria	PBLE01 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 PBLE01 method is applicable up to the full power level of the plant. Since the PBLE01 approach in this Engineering Report uses [[ ]], all pressure fluctuation, either hydrodynamic or acoustic are captured.
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 of the PBLE01 method is acceptable based on the end to end benchmarking shown in Section 4.4.4 of this report. CFD modeling is not applicable to the PBLE01
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 PBLE01 is capable of determining acoustic resonances that may be detrimental to the steam dryer. Modifications for reducing acoustic resonances is beyond the scope of this Engineering Report
2.1.(1)	Scale Model Testing	Not applicable - Scale model Testing is not used in the PBLE01 for determination of the steam dryer loads
2.1.(1)	Computational Fluid Dynamic (CFD) modeling	Not applicable - CFD modeling is not used in the PBLE01 for determination of the steam dryer loads

RG 1.20 Section	Criteria	PBLE01 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 PBLE01 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 – FRF are determined by the PBLE01. Bias errors and uncertainties have been addressed.
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 PBLE01 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 PBLE01 loads [[ ]]

RG 1.20 Section	Criteria	PBLE01 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 PBLE01 uses in plant data for the determination of the steam dryer load definition.
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 PBLE01 methodology in this report uses [[ ]] for determination of the load definition. The PBLE01 methodology in this report demonstrates the methodology to determine end to end bias errors and uncertainties associated with the PBLE01 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.	Not applicable – the PBLE01 methodology in this report [[ ]].

RG 1.20 Section	Criteria	PBLE01 Conformance
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.	Not applicable – the PBLE01 uses [[ ]] The effects of flow turbulence on the pressure measurement is included in the PBLE01 uncertainty assessment.
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 PBLE01 is a function of the steam fluid conditions within the RPV.
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 conditions of the steam water interface and the associated uncertainty is developed for the PBLE01 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 PBLE01 formulation uses the steam quality in the reactor steam dome and dryer for the sound attenuation coefficients.
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 speed of sound is based on the thermodynamic properties of steam in the RPV
Other	Model Benchmarking	PBLE01 is benchmarked against previously instrumented dryer data
Other	Determination of Biases and Uncertainty	Biases and Uncertainty have been calculated

Note that other sections of Reference 1 refer to structural analysis of the steam dryer or preoperational/startup testing that is outside of the scope of this Engineering Report.

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 ESBWR steam dryer.

4.4 Plant-Specific Application Methodology

4.4.1 [[ ]] Model Inputs

The vessel [[

]]

Acoustic Finite Element Model Mesh

A FE model of the [[

]]

[[

]]

Figure 18. [[ ]]

[[

]]

Table 5 Parameters in the [[ ]]

Phenomena	**Parameter**
[[	
	]]

4.4.2 Plant Input Measurements

Sensor Type and Location

For the PBLE01 [[

]]

Error in Measured Dryer Pressures

This error, [[

]]

In addition, for the ESBWR on-dryer instrumentation, the strain gauge manufacturer will be involved to ensure proper installation and calibration of the strain gauges used in the ESBWR 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 ESBWR on-dryer instrumentation will follow the procedures used at GGNS, 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 ESBWR 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 the PBLE01:

- [[

]]

4.4.4 End to End Uncertainties and Biases

To demonstrate the application of the PBLE01 load definition, a structural evaluation was performed for the GGNS EPU conditions based on the load definition discussed in Section 3.3. At a high level, the analysis process 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 (Section 3.3); (3) a dynamic structural evaluation of the dryer, driven from the acoustic loads (i.e., the "global model" analysis using a large ANSYS model, comprised of mostly shell type elements); and (4) post-processing of stress results. In the post processing step, [[

]] These results are referred to as the projected data at each sensor location.

To monitor the dryer dynamic response six (6) accelerometers and seven (7) strain gauges were installed. The accelerometer and strain gauge locations were selected to monitor the global response of the hoods and the dryer stress in high stress regions. The strain and acceleration instruments are well distributed over different dryer regions. Where possible, locations were selected where the sensor would see higher amplitudes and be in areas with low gradients at the frequencies that most significantly contribute to high stress. The regional layout of the GGNS accelerometers and strain gauge sensors is summarized in Appendix A. The installed locations were selected to provide good correlation with dryer high stress areas and redundancy such that multiple instruments will have good correlation with the high stress regions. For the same time segment selected for the generation of the steam dryer loads (step one and two above) 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 [[ ]] are compared with the ANSYS-predicted strain and acceleration PSD results based on the EPU analysis [[

]]

Figures 20 and 21 show plots of the mean bias and uncertainty [[ ]] GGNS EPU conditions. PSD comparisons of the ANSYS predictions from the GGNS EPU conditions and the measured data for the analysis time interval are included in Appendix E for each sensor. Tabular values of the [[ ]] end to end bias and uncertainty are provided in Appendix F as a function of frequency.

Figure 19. (Figure Deleted)

[[

]]

Figure 20. [[ ]]

[[

]]

Figure 21. [[ ]]

Table 6 (Table Deleted)

5.0 CONCLUSIONS

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

A built-in [[ ]]

The PBLE01 technique is validated by the Grand Gulf Nuclear Station application cases. From comparison between measurements and projections, the PBLE01 predicts good frequency content and spatial distribution. The SRV valve 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 the PBLE01 from [[ ]] is adequate to predict fluctuating dryer loads at any ESBWR plant.

6.0 REFERENCES

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

[2] MATLAB ®, Copyright 1984-2011, The MathWorks, Inc.

[3] Sysnoise® Revision 5.6, LMS International, Users Manual Revision 1.0, March 2003.

[4] S.H. Jang and J.G. Ih, On the multiple microphone method for measuring in-duct acoustic properties in the presence of mean flow, J. Acous. Soc. Am., Vol. 103, No. 3, March 1998.

[5] P.M. Morse and K.U. Ingard, *Theoretical Acoustics*, McGraw-Hill, New York, 1968, p.519.

[6] W. Wagner et al., The IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam, ASME J. Eng. Gas Turbines and Power, 122, 150-182 (2000)

[7] V. Petr, *Wave propagation in wet steam*, Proc. Instn. Mech. Engrs Vol 218 Part C 2004, p 871-882.

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[9] Not used

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APPENDIX A
GGNS DRYER INSTRUMENTATION LOCATIONS

Table A-1 Instrument/Sensor Locations

Sensor ID	Location
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Figure A-1. [[ ]]

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Figure A-2. [[ ]]

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Figure A-3. [[ ]]

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Figure A-4. [[ ]]

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Figure A-5. [[ ]]

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Figure A-6. [[ ]]

APPENDIX B
GGNS PBLE01 VALIDATION AT CLTP

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Figure B-1. [[ ]]

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Figure B-2. [[ ]]

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Figure B-3. [[ ]]

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Figure B-4. [[ ]]

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Figure B-5. [[ ]]

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Figure B-6. [[ ]]

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Figure B-7. [[ ]]

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Figure B-8. [[ ]]

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Figure B-9. [[ ]]

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Figure B-10. [[ ]]

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Figure B-11. [[ ]]

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Figure B-12. [[ ]]

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Figure B-13. [[ ]]

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Figure B-14. [[ ]]

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Figure B-15. [[ ]]

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Figure B-16. [[ ]]

APPENDIX C
GGNS PBLE01 VALIDATION AT EPU

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Figure C-1 [[ ]]

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Figure C-2 [[ ]]

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Figure C-3 [[ ]]

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Figure C-4 [[ ]]

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Figure C-5 [[ ]]

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Figure C-6 [[ ]]

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Figure C-7 [[ ]]

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Figure C-8 [[ ]]

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Figure C-9 [[ ]]

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Figure C-10 [[ ]]

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Figure C-11 [[ ]]

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Figure C-12 [[ ]]

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Figure C-13 [[ ]]

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Figure C-14 [[ ]]

APPENDIX D
ACOUSTIC FINITE ELEMENT PROGRAM REQUIREMENTS FOR PBLE01

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APPENDIX E

COMPARISON OF PROJECTED VERSUS MEASURED PSD ACCELERATIONS (A) AND STRAIN (S) AT GGNS EPU CONDITIONS

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Figure E-1 [[ ]]

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Figure E-2 [[ ]]

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Figure E-3 [[ ]]

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Figure E-4 [[ ]]

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Figure E-5 [[ ]]

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Figure E-6 [[ ]]

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Figure E-7 [[ ]]

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Figure E-8 [[ ]]

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Figure E-9 [[ ]]

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Figure E-10 [[ ]]

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Figure E-11 [[ ]]

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Figure E-12 [[ ]]

APPENDIX F

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Table F-1 [[ ]]

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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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