# ATTACHMENT 3

# FINAL EPU STEAM DRYER LOAD DEFINITION

# CDI REPORT NO. 12-20NP

# (NON-PROPRIETARY)

Certain information, considered proprietary by Continuum Dynamics, Inc., has been deleted from the report in this Attachment. The deletions are identified by double square brackets ([[ ]]).

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C.D.I. Report No. 12-20NP

# Acoustic and Low Frequency Hydrodynamic Loads at 115% CLTP Target Power Level on Nine Mile Point Unit 2 Steam Dryer to 250 Hz Using ACM Rev. 4.1

Revision 0

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# Executive Summary

Measured strain gage time-history data in the four main steam lines at Nine Mile Point Unit 2 (NMP2), taken during power ascension from Current Licensed Thermal Power (CLTP) to Extended Power Uprate (EPU) power levels, were processed by a dynamic model of the steam delivery system to predict loads on the full-scale steam dryer. These loads were processed by a real-time stress analysis to predict the minimum stress ratio at each examined power level and enable the drawing of limit curves that assisted in the ascension to EPU conditions. That process is nearly complete – NMP2 is now at 115% CLTP target power conditions – and a summary of the uprate dryer loads, focusing on this power load, is desired. This report provides that summary.

At each power level the measured data were first converted to pressures, then positioned on the four main steam lines and used to extract acoustic sources in the system. A validated acoustic circuit methodology (ACM Rev. 4.1) was used to predict the fluctuating pressures anticipated across components of the steam dryer in the reactor vessel. The acoustic circuit methodology included a low frequency hydrodynamic contribution, in addition to an acoustic contribution at all frequencies. This pressure loading was then provided for structural analysis to assess the structural adequacy of the steam dryer in NMP2.

This effort provides the Constellation Energy Group with a dryer dynamic load definition that comes directly from measured NMP2 full-scale data and the application of a validated acoustic circuit methodology, at every power level where data were acquired.

# Table of Contents

# 1. Introduction

In Spring 2005 Exelon installed new steam dryers into Quad Cities Unit 2 (QC2) and Quad Cities Unit 1. This replacement design, developed by General Electric, sought to improve dryer performance and overcome structural inadequacies identified on the original dryers, which had been in place for 30 years. As a means of confirming the adequacy of the steam dryer, the QC2 replacement dryer was instrumented with pressure sensors at 27 locations. These pressures formed the set of data used to validate the predictions of an acoustic circuit methodology under development by Continuum Dynamics, Inc. (C.D.I.) for several years [1]. One of the results of this benchmark exercise [2] confirmed the predictive ability of the acoustic circuit methodology for pressure loading across the dryer, with the inclusion of a low frequency hydrodynamic load. This approach, validated against the Exelon full-scale data and identified as the Acoustic Circuit Model (ACM) Rev. 4.1 [3], is used in the effort discussed herein.

ACM Rev. 4.1 filters the QC2 data in exactly the same way as the Nine Mile Point Unit 2 (NMP2) data, that is, (1) the EMF frequencies of 60, 120, 180, and 240 Hz are filtered; (2) the vane passing frequency and other non-acoustic frequencies identified in the EIC data are also filtered; and (3) the strain gage signals at the upper and lower locations on each main steam line are coherence filtered. The resulting loads are computed for the Nine Mile Point dryer, after applying bias and uncertainty values found when comparing model predictions on the QC2 dryer with pressure data recorded on the outer bank hoods of the QC2 dryer.

This report applies this validated methodology to the NMP2 steam dryer and main steam line geometry. Strain gage data obtained from the four main steam lines were used to predict pressure levels on the NMP2 full-scale dryer at 115% CLTP target power conditions. These data were then used to predict dryer stresses, and to determine the minimum stress ratio on the dryer. The intermediate results from Current Licensed Thermal Power (CLTP) to the current power level were used to develop limit curves, summarized in Appendix A of this report.

# 2. Modeling Considerations

The acoustic circuit analysis of the NMP2 steam supply system is broken into two distinct analyses: a Helmholtz solution within the steam dome and an acoustic circuit analysis in the main steam lines. This section of the report highlights the two approaches taken here. These analyses are then coupled for an integrated solution.

## 2.1 Helmholtz Analysis

A cross-section of the steam dome (and steam dryer) is shown below in Figure 2.1, with NMP2 dimensions as shown [4]. The complex three-dimensional geometry is rendered onto a uniformly-spaced rectangular grid (with mesh spacing of approximately 1.5 inches to accommodate frequency from 0 to 250 Hz in full scale), and a solution, over the frequency range of interest, is obtained for the Helmholtz equation

$$\frac{\partial^2 P}{\partial x^2}+\frac{\partial^2 P}{\partial y^2}+\frac{\partial^2 P}{\partial z^2}+\frac{\omega^2}{a^2}P=\nabla^2 P+\frac{\omega^2}{a^2}P=0$$

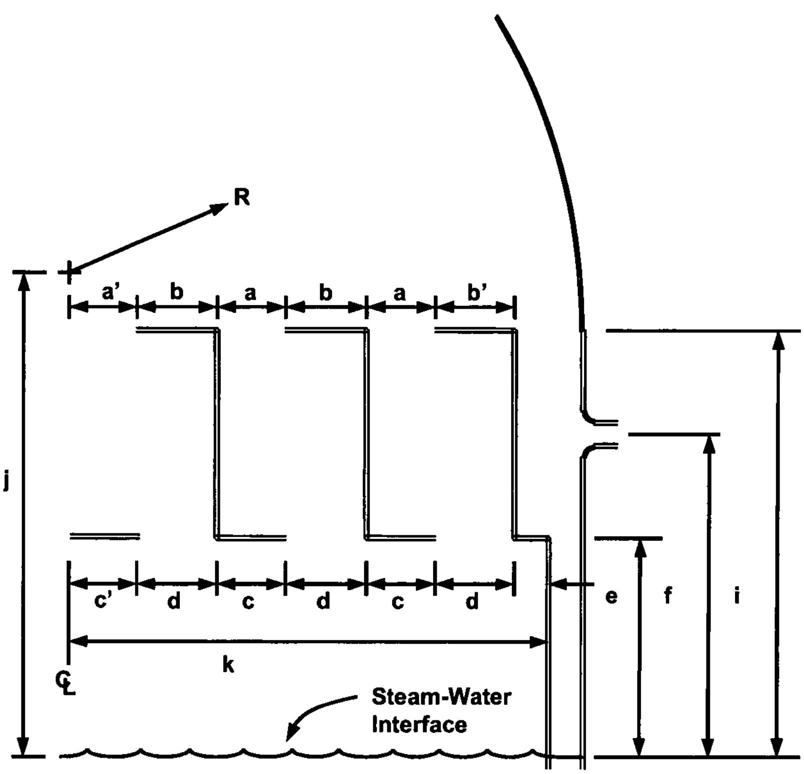


Figure 2.1. Cross-sectional description of the steam dome and dryer at NMP2, with the dimensions of a = 18.25 in, a' = 15.25 in, b = 13.27 in, b' = 13.65 in, c = 15.75 in, c' = 24.0 in, d = 15.75 in, e = 16.25 in, f = 71.5 in, g = 160.625 in, i = 84.5 in, j = 181.5 in, k = 118.75 in, and R = 124.75 in.

where P is the pressure at a grid point, $\omega$ is frequency, and a is complex acoustic speed in steam.

This equation is solved for incremental frequencies from 0 to 250 Hz, subject to the boundary conditions

$$\frac{dP}{dn} = 0$$

normal to all solid surfaces (the steam dome wall and interior and exterior surfaces of the dryer),

$$\frac{dP}{dn} \propto \frac{i\omega}{a} P$$

normal to the nominal water level surface, and unit pressure applied to one inlet to a main steam line and zero applied to the other three.

**2.2 Acoustic Circuit Analysis**

The Helmholtz solution within the steam dome is coupled to an acoustic circuit solution in the main steam lines. Pulsation in a single-phase compressible medium, where acoustic wavelengths are long compared to transverse dimensions (directions perpendicular to the primary flow directions), lend themselves to application of the acoustic circuit methodology. If the analysis is restricted to frequencies below 250 Hz, acoustic wavelengths are approximately six feet in length and wavelengths are therefore long compared to most components of interest, such as branch junctions.

Acoustic circuit analysis divides the main steam lines into elements which are each characterized, as sketched in Figure 2.2, by a length L, a cross-sectional area A, a fluid mean density $\bar{\rho}$, a fluid mean flow velocity $\bar{U}$, and a fluid mean acoustic speed $\bar{a}$.

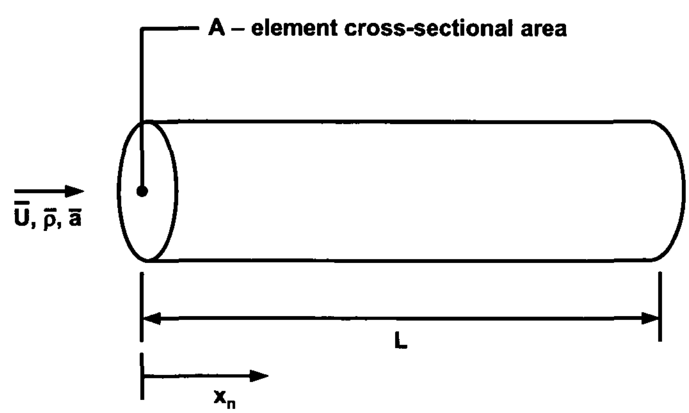


Figure 2.2. Schematic of an element in the acoustic circuit analysis, with length L and cross-sectional area A.

Application of acoustic circuit methodology generates solutions for the fluctuating pressure $P_n$ and velocity $u_n$ in the $n^{th}$ element of the form

$$P_n = \left[A_n e^{ik_{1n}x_n} + B_n e^{ik_{2n}x_n}\right] e^{i\omega t}$$

$$u_n = -\frac{1}{\rho \bar{a}^2}\left[\frac{\left(\omega + \bar{U}_n k_{1n}\right)}{k_{1n}} A_n e^{ik_{1n}x_n} + \frac{\left(\omega + \bar{U}_n k_{2n}\right)}{k_{2n}} B_n e^{ik_{2n}x_n}\right] e^{i\omega t}$$

where harmonic time dependence of the form $e^{i\omega t}$ has been assumed. The wave numbers $k_{1n}$ and $k_{2n}$ are the two complex roots of the equation

$$k_n^{\,2} + i\frac{f_n\left|\bar{U}_n\right|}{D_n \bar{a}^2}\left(\omega + \bar{U}_n k_n\right) - \frac{1}{\bar{a}^2}\left(\omega + \bar{U}_n k_n\right)^2 = 0$$

where $f_n$ is the pipe friction factor for element n, $D_n$ is the hydrodynamic diameter for element n, and $i = \sqrt{-1}$. $A_n$ and $B_n$ are complex constants which are a function of frequency and are determined by satisfying continuity of pressure and mass conservation at element junctions.

The solution for pressure and velocity in the main steam lines is coupled to the Helmholtz solution in the steam dome, to predict the pressure loading on the steam dryer.

The main steam line piping geometry is summarized in Table 2.1.

Table 2.1. Main steam line lengths at NMP2, measured from the inside wall of the steam dome down the centerline of the main steam lines. Main steam line diameter is 26 inch Schedule 80 (ID = 23.50 in).

| Main Steam Line | Length to First Strain Gage Measurement (ft) | Length to Second Strain Gage Measurement (ft) |
|---|---|---|
| A | 13.6 | 26.2 |
| B | 14.5 | 19.9 |
| C | 22.1 | 27.5 |
| D | 20.4 | 25.8 |

## 2.3 Low Frequency Contribution

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## 3. Input Pressure Data

Strain gages were mounted on the four main steam lines of NMP2. Two data sets were examined in the analysis. The first data set recorded the strain at Low Power (25% CLTP target power), while the second data set recorded the strain at 115% CLTP target power. The data were provided in the following files:

| Data File Name | Target Power Level (% CLTP) |
|---|---|
| 20120609134630 | 25% |
| 20120721142636 | 115% |

The strain gage signals were converted to pressures by the use of the conversion factors provided in [5] and summarized in Table 3.1. The raw data signals are shown in Figure 3.1. Exclusion frequencies were used to remove extraneous signals, as also identified in [5], summarized in Table 3.2 and shown in Figure 3.2. These signals were further processed by coherence filtering as described in [3].

All pressure signals result from either hydrodynamic fluctuations or random noise. To be conservative, these signals will be assumed to have a load that is hydrodynamic in nature. Therefore, a load is imposed on the dryer at all frequencies, and the bias and uncertainty are determined by benchmarking against QC2 data, as described in [3].

The coherence filtered main steam line pressure signals may be represented in two ways, by their minimum and maximum pressure levels, and by their PSDs. Table 3.3 provides the pressure level information, while Figure 3.3 compares the frequency content at the eight strain gage locations. In addition, Figure 3.4 compares the raw data signals to the coherence filtered signals used in ACM Rev. 4.1.

NMP2 testing determined that the MSL B loads were affected by the RCIC steam line configuration. Further testing and analyses were undertaken at the 115% CLTP target power data to define the loads for the RCIC steam line isolated condition and the RCIC steam line drain configuration that promote the 92.5 Hz content, as described in Appendix C. These two RCIC conditions are considered off-normal conditions associated with a short-duration technical specification limiting condition of operation duration or with transient loading associated with an unusual steam line drain configuration. The final stress report will address these loading conditions and the impact of these alternate RCIC lineup conditions on the top stress locations on the dryer.

Table 3.1. Conversion factors from strain to pressure at 115% CLTP target power conditions [5]. Channels are averaged to give the average strain.

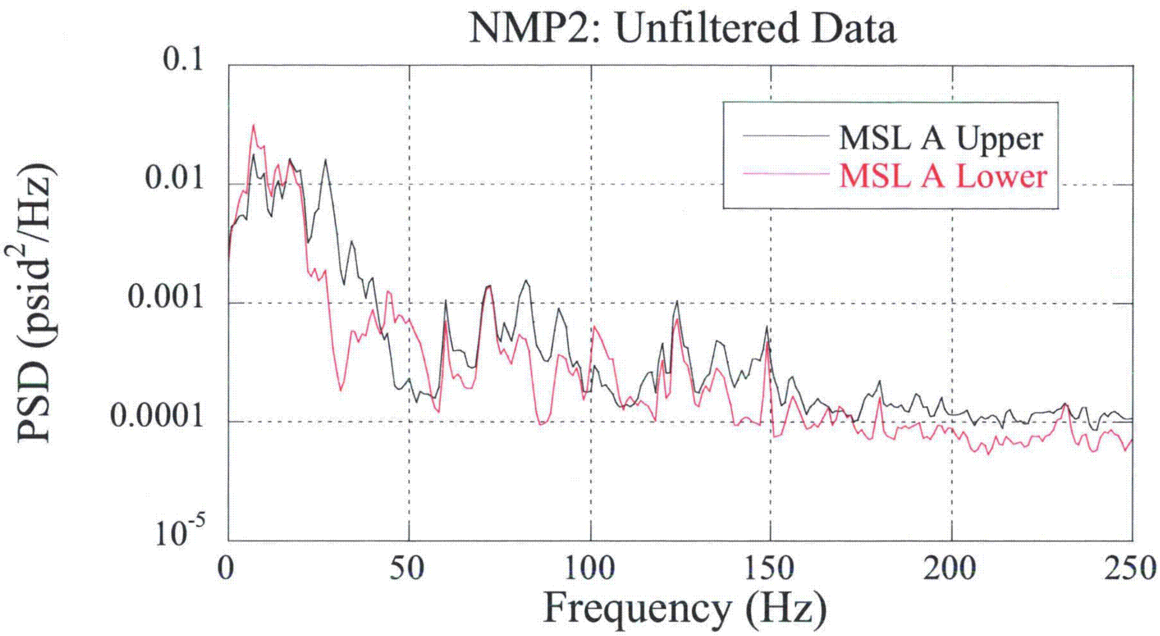
| **Location** | **Strain to Pressure (psid/µstrain)** | **Channel Number** | **Channel Number** | **Channel Number** | **Channel Number** |
|---|---|---|---|---|---|
| MSL A Upper | 3.82 | 1 | 2 | 3 | 4 |
| MSL A Lower | 3.84 | 5 | 6 | 7 | 8 |
| MSL B Upper | 3.84 | 9 | 10 | 11 | 12 |
| MSL B Lower | 3.81 | 13 | 14 | 15 | 16 |
| MSL C Upper | 3.85 | 17 | 18 | 19 | 20 |
| MSL C Lower | 3.81 | 21 | 22 | 23 | 24 |
| MSL D Upper | 3.92 | 25 | 26 | 27 | 28 |
| MSL D Lower | 3.94 | 29 | 30 | 31 | |

Table 3.2. Exclusion frequencies for NMP2 strain gage data at 115% CLTP target power conditions, as suggested in [5]. The frequency range is applied with a second-order, stop-band Butterworth filter in MatLab.

| **Frequency Range (Hz)** | **Exclusion Cause** |
|---|---|
| 0.0 – 2.0 | Mean |
| 59.9 – 60.1 | EMF Frequency |
| 119.6 – 120.3 | EMF Frequency |
| 179.8 – 180.2 | EMF Frequency |
| 148.9 – 149.3 | Recirculation Vane Passing Frequency |

Table 3.3. Main steam line (MSL) pressure levels in NMP2 at 115% CLTP target power conditions, after coherence filtering.

| | **Minimum Pressure (psid)** | **Maximum Pressure (psid)** | **RMS Pressure (psid)** |
|---|---|---|---|
| MSL A Upper | -2.59 | 2.37 | 0.56 |
| MSL A Lower | -2.32 | 2.36 | 0.54 |
| MSL B Upper | -1.97 | 1.48 | 0.40 |
| MSL B Lower | -1.30 | 1.31 | 0.34 |
| MSL C Upper | -2.09 | 1.62 | 0.42 |
| MSL C Lower | -3.17 | 2.54 | 0.63 |
| MSL D Upper | -2.07 | 2.00 | 0.49 |
| MSL D Lower | -1.56 | 1.72 | 0.35 |



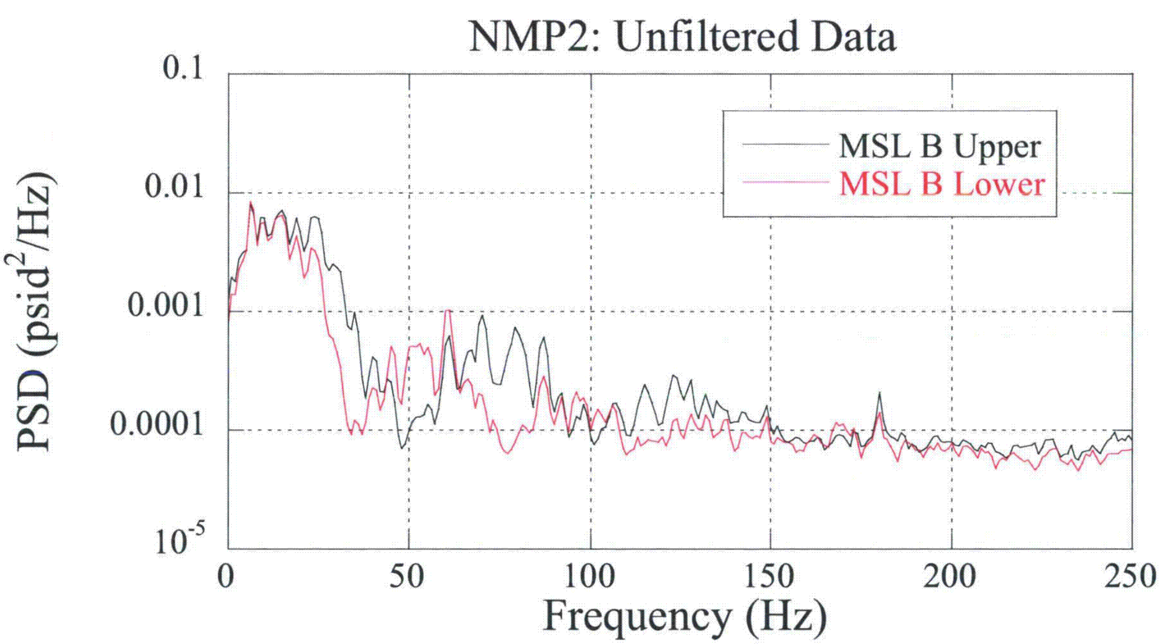
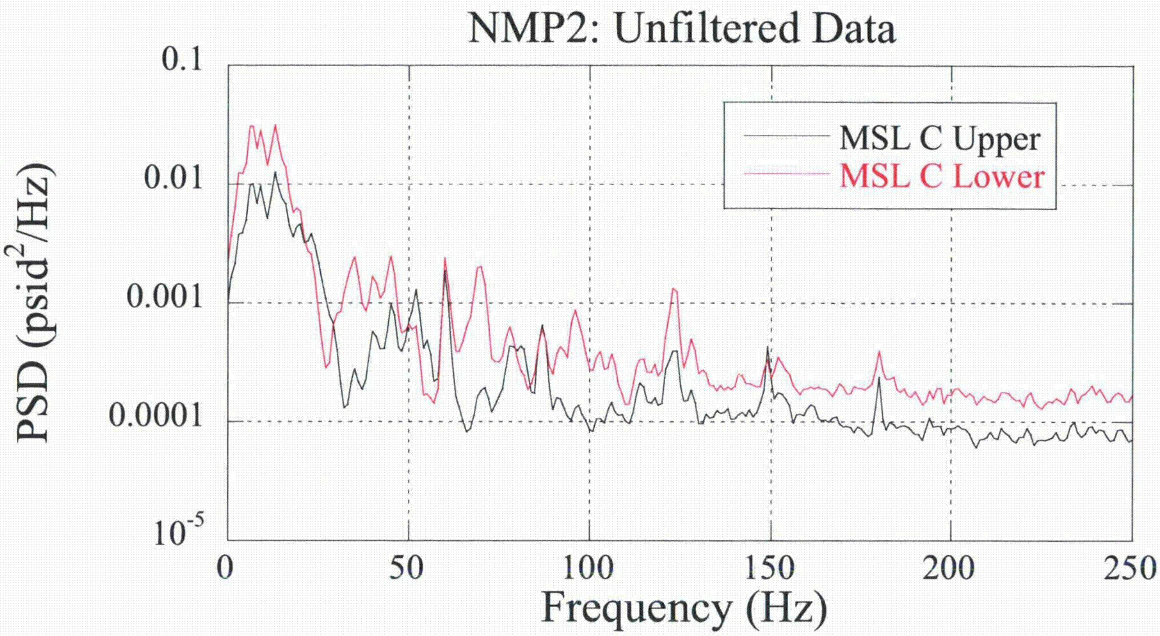




Figure 3.1a: Unfiltered data measured on the NMP2 main steam lines at 115% CLTP target power conditions for main steam lines A (top) and B (bottom).



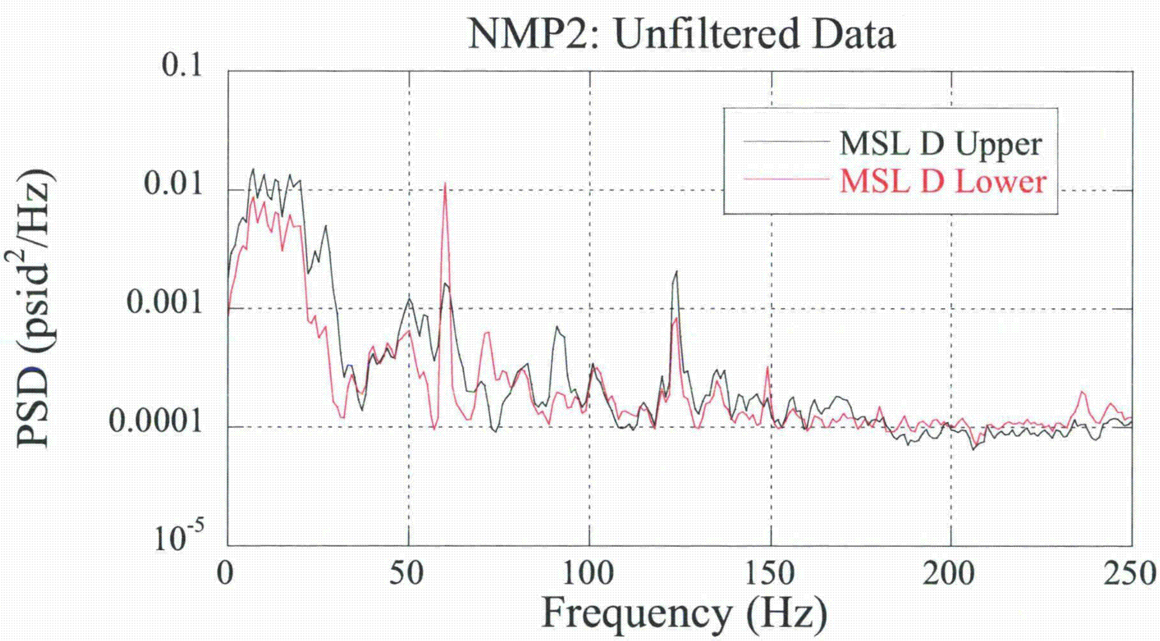
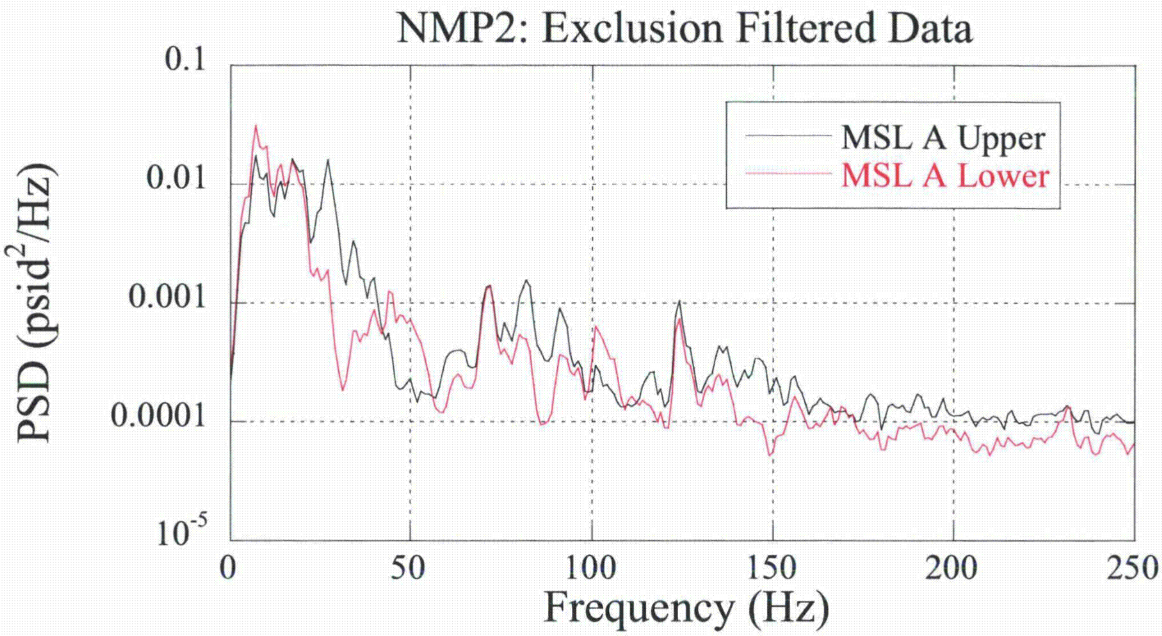




Figure 3.1b: Unfiltered data measured on the NMP2 main steam lines at 115% CLTP target power conditions for main steam lines C (top) and D (bottom).



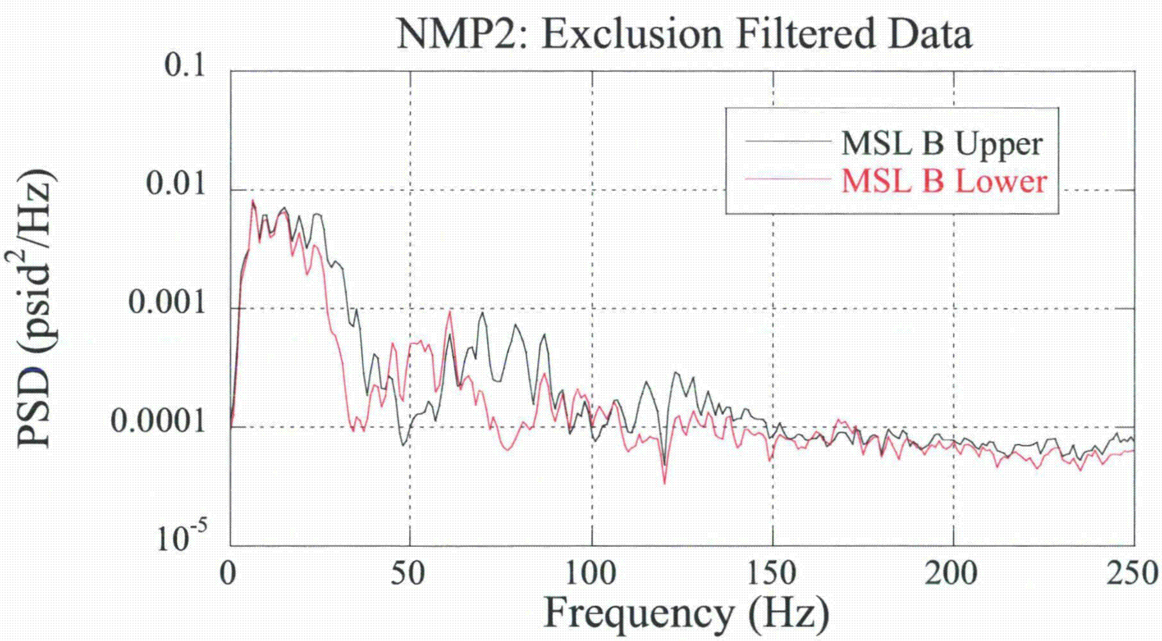




Figure 3.2a: Exclusion filtered data measured on the NMP2 main steam lines at 115% CLTP target power conditions for main steam lines A (top) and B (bottom).

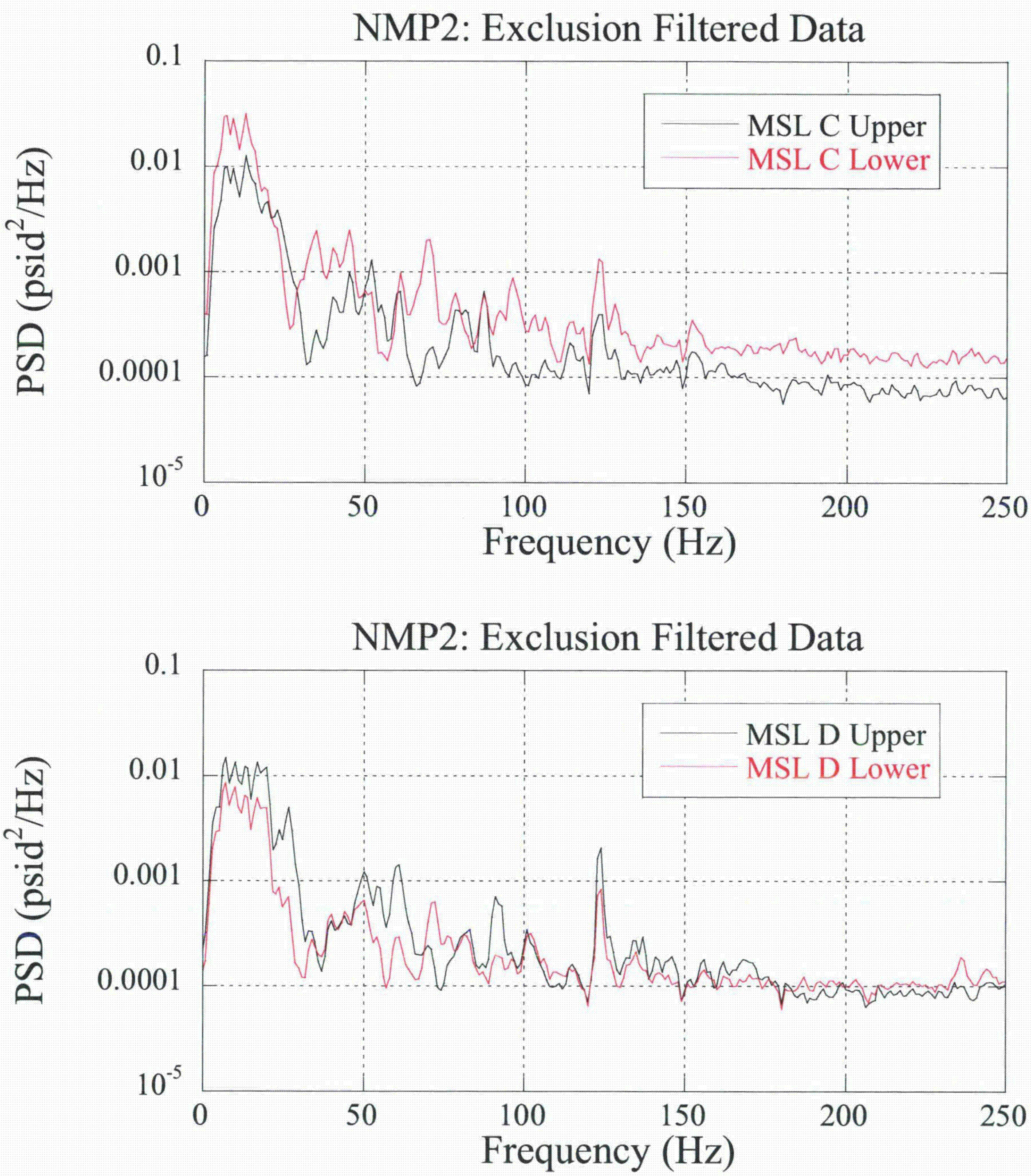



Figure 3.2b: Exclusion filtered data measured on the NMP2 main steam lines at 115% CLTP target power conditions for main steam lines C (top) and D (bottom).

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Figure 3.3a: Coherence filtered data measured on the NMP2 main steam lines at 115% CLTP target power conditions for main steam lines A (top) and B (bottom).

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Figure 3.3b: Coherence filtered data measured on the NMP2 main steam lines at 115% CLTP target power conditions for main steam lines C (top) and D (bottom).

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Figure 3.4a: Unfiltered and coherence filtered data comparisons on NMP2 main steam line A at 115% CLTP target power conditions for upper (top) and lower (bottom) locations.

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Figure 3.4b: Unfiltered and coherence filtered data comparisons on NMP2 main steam line B at 115% CLTP target power conditions for upper (top) and lower (bottom) locations.

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Figure 3.4c: Unfiltered and coherence filtered data comparisons on NMP2 main steam line C at 115% CLTP target power conditions for upper (top) and lower (bottom) locations.

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Figure 3.4d: Unfiltered and coherence filtered data comparisons on NMP2 main steam line D at 115% CLTP target power conditions for upper (top) and lower (bottom) locations.

# 4. Results

The measured main steam line pressure data were used to drive the validated acoustic circuit methodology for the NMP2 steam dome coupled to the main steam lines to make a pressure load prediction on the NMP2 dryer at 115% CLTP target power conditions. A low resolution load, developed at the nodal locations identified in Figures 4.1 to 4.4, produces the maximum differential pressure RMS pressure levels across the dryer as shown in Figure 4.5. PSDs of the peak loads on either side of the dryer are shown in Figure 4.6.

Note that these loads include the bias and uncertainty corrections discussed in Section 5 of this report.

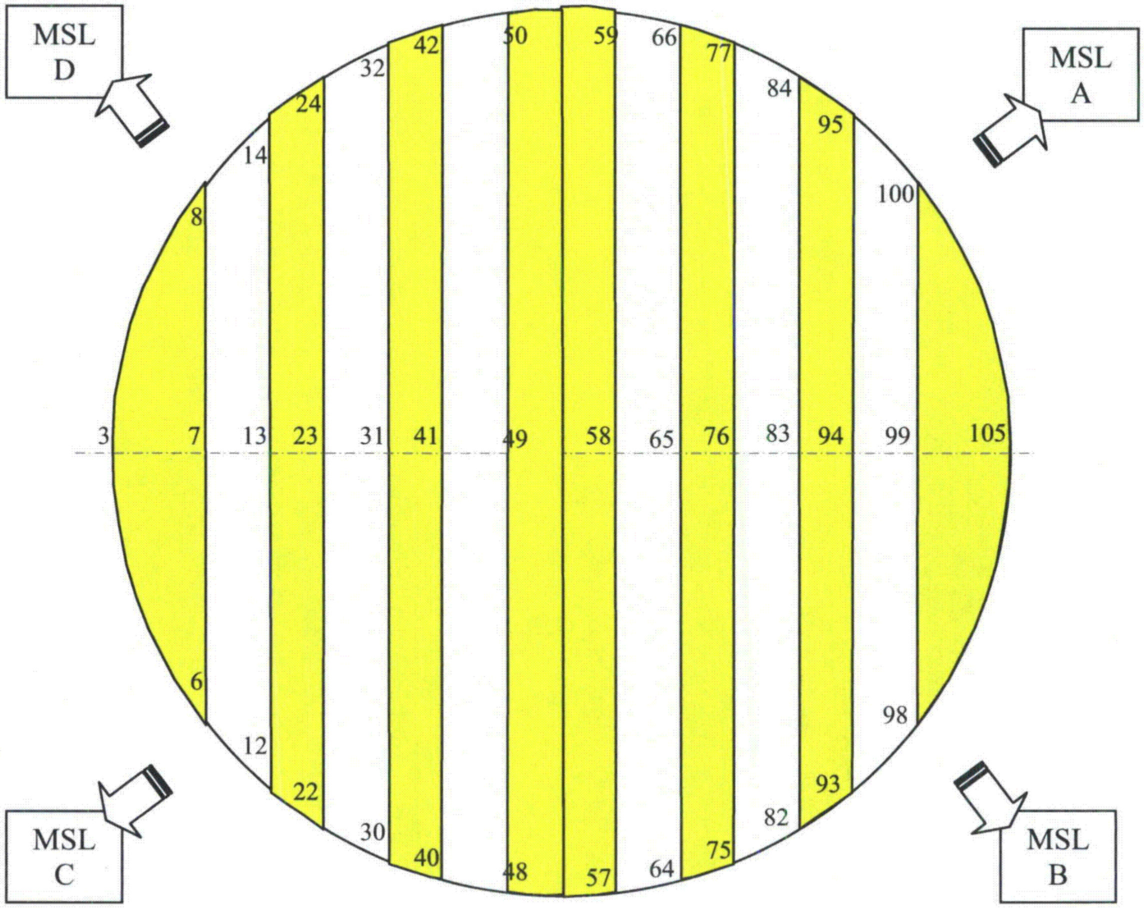


Figure 4.1. Cover and base plate low resolution load pressure node locations on the NMP2 dryer, with pressures acting downward in the notation defined here. Main steam line A is off the upper right corner of the figure; main steam line B off the lower right corner of the figure; main steam line C off the lower left corner of the figure; and main steam line D off the upper left corner of the figure. The cover plate on the A/B side of the dryer is identified by the nodes 98-99-100-105; the cover plate on the C/D side of the dryer is identified by the nodes 3-8-7-6. Base plates are identified by the nodes 64-65-66-77-76-75 and 82-83-84-95-94-93 (A/B side), 48-49-50-59-58-57 (center), and 12-13-14-24-23-22 and 30-31-32-42-41-40 (C/D side). The high resolution grid mesh (for subsequent finite element analysis) is spaced 3 inches on the cover plates, 6 inches on the first base plates, and 12 inches on the rest of the base plates.

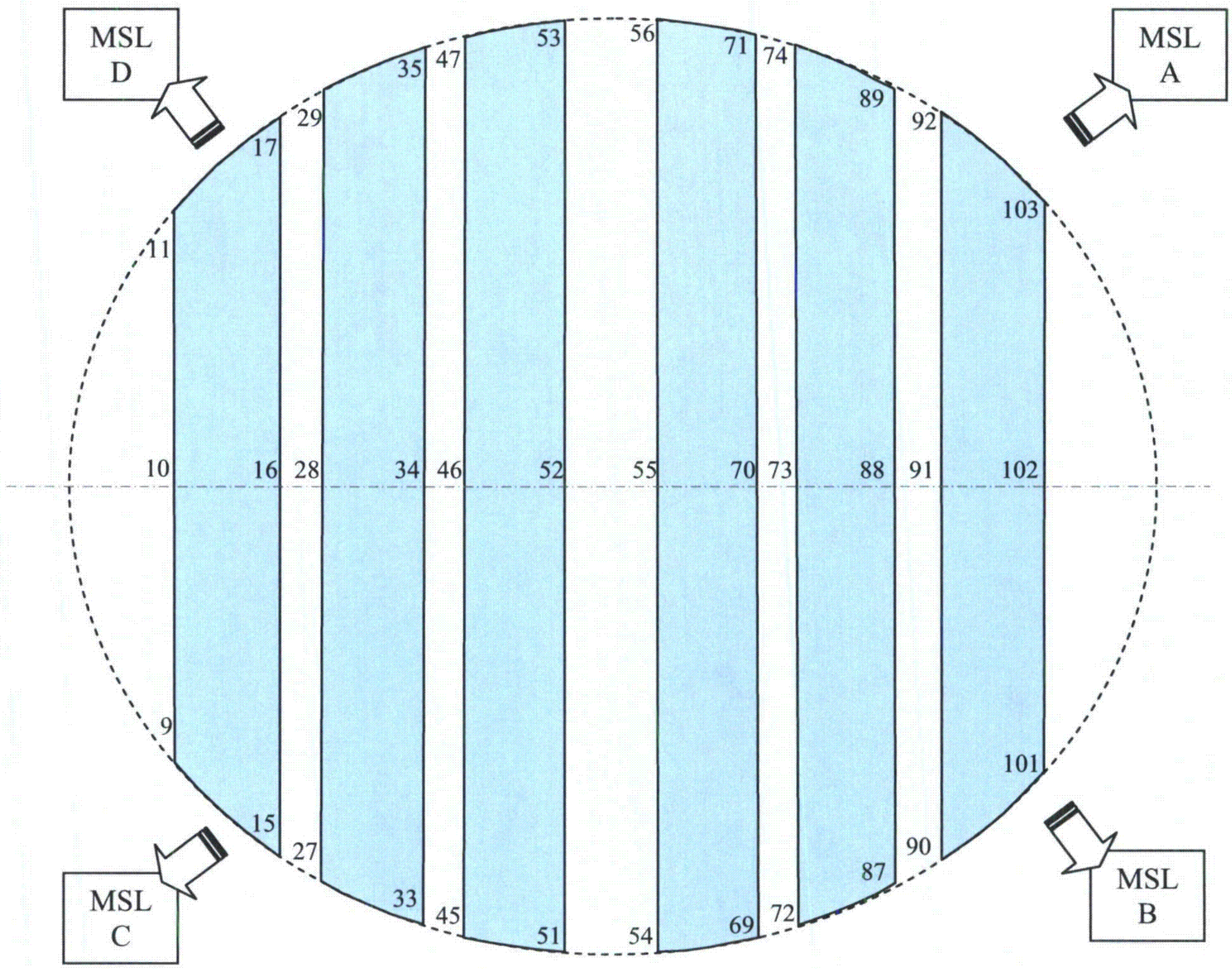


Figure 4.2. Top plate low resolution load pressure node locations on the NMP2 dryer, with pressures acting downward in the notation defined here. Main steam line A is off the upper right corner of the figure; main steam line B off the lower right corner of the figure; main steam line C off the lower left corner of the figure; and main steam line D off the upper left corner of the figure. Top plates on the A/B side of the dryer are identified by the nodes 90-91-92-103-102-101, 72-73-74-89-88-87, and 54-55-56-71-70-69. Top plates on the C/D side of the dryer are identified by the nodes 9-10-11-17-16-15, 27-28-29-35-34-33, and 45-46-47-53-52-51. The high resolution grid mesh (for subsequent finite element analysis) is spaced 3 inches on the outer top plates, 6 inches on the first inner top plates, and 12 inches on the rest of the inner top plates.

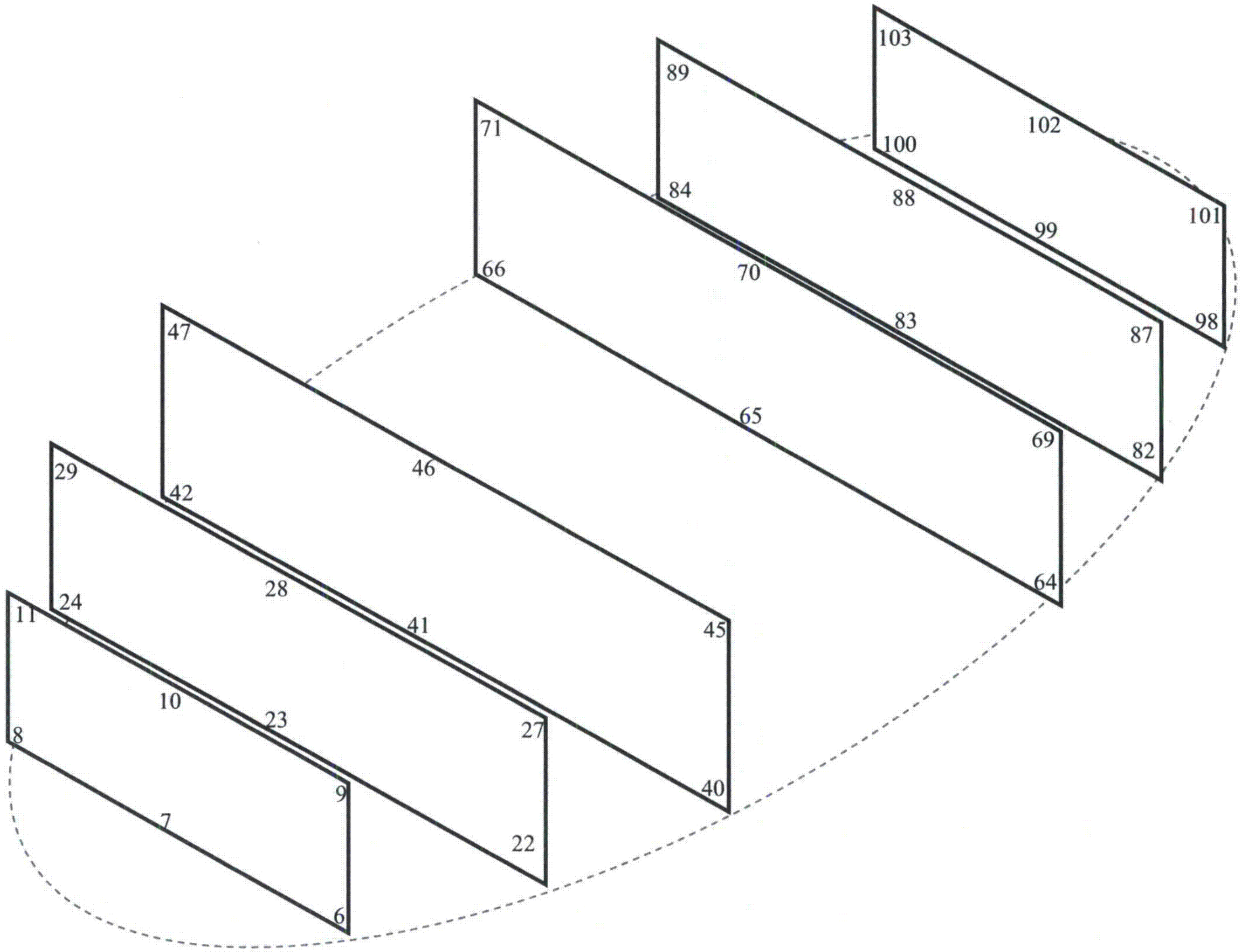


Figure 4.3. Outer and inner hood low resolution load pressure nodes on the NMP2 dryer. Main steam lines A and B are off the upper right corner of the figure; main steam lines C and D are off the lower left corner of the figure. Pressures act lower left to upper right on the outer hood identified by the nodes 6-7-8-11-10-9 (opposite C/D) and on the inner hoods identified by the nodes 22-23-24-29-28-27 and 40-41-42-47-46-45. Pressures act upper right to lower left on the outer hood identified by the nodes 98-99-100-103-102-101 (opposite A/B) and on the inner hoods identified by the nodes 82-83-84-89-88-87 and 64-65-66-71-70-69. The high resolution grid mesh (for subsequent finite element analysis) is spaced 3 inches on the outer hoods, 6 inches on the first inner hoods, and 12 inches on the inside hoods.

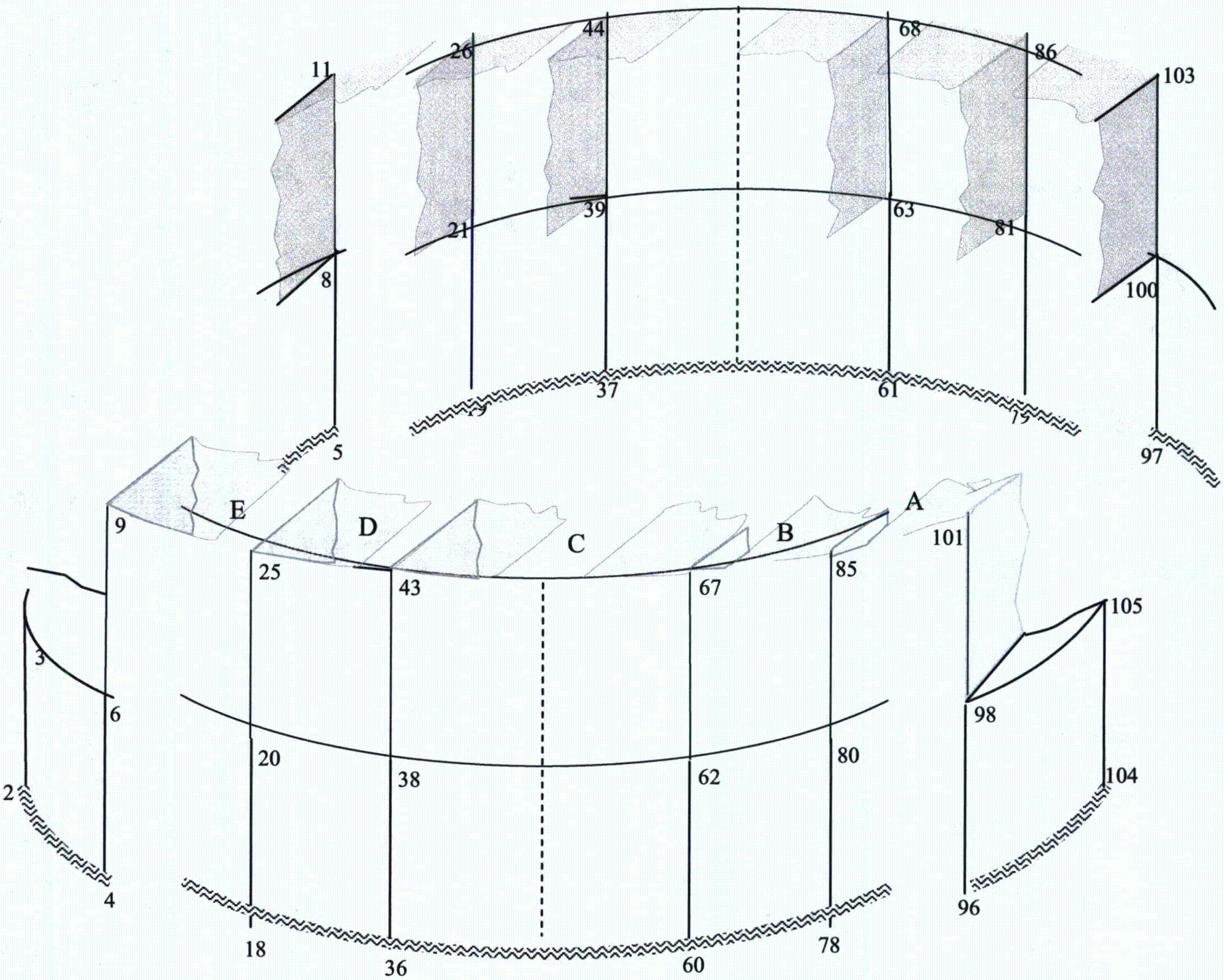


Figure 4.4. Skirt and end plate low resolution load pressure nodes on the NMP2 dryer, with pressures acting from the outside of the dryer to the inside. Main steam lines A and B are off the right side of the figure; main steam lines C and D are off the left side of the figure. Skirt nodes are 2-4-18-36-60-78-96-104 and 2-5-19-37-61-79-97-104. End plate nodes are 20-25 and 21-26, 38-43 and 39-44, 62-67 and 63-68, and 80-85 and 81-86. The high-resolution grid mesh (for subsequent finite element analysis) is spaced 3 inches on the outer portion of the skirt and end plates closest to the main steam lines, 6 inches on the sections nearer the center of the dryer, and 12 inches on the center of the dryer.

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Figure 4.5. Predicted loads on the low resolution grid identified in Figures 4.1 to 4.4, as developed by the ACM Rev. 4.1 model, to 250 Hz. Low-numbered nodes are on the C-D side of the dryer, while high-numbered nodes are on the A-B side of the dryer. Bias and uncertainty are included in these results.

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Figure 4.6. PSD of the maximum pressure loads predicted on the outer bank hood on the C-D side of the NMP2 dryer (top) and on the A-B side of the NMP2 dryer (bottom). Maximum loads occur at the bottom center of the outer bank hoods opposite the main steam lines. Bias and uncertainty are included in these results.

# 5. Uncertainty Analysis

The analysis of potential uncertainty occurring at NMP2 consists of several contributions, including the uncertainty from collecting data on the main steam lines at locations other than the locations on Quad Cities Unit 2 (QC2) and the uncertainty in the ACM Rev. 4.1 model [3]. QC2 dryer data at Original Licensed Thermal Power (OLTP) conditions were used to generate an uncertainty analysis for NMP2.

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Bias is computed by taking the difference between the measured and predicted RMS pressure values for the sixteen pressures, and dividing the mean of this difference by the mean of the predicted RMS. RMS is computed by integrating the PSD across the frequency range of interest and taking the square root

$$\mathrm{BIAS} = \frac{\frac{1}{N}\sum(\mathrm{RMS}_{\mathrm{measured}} - \mathrm{RMS}_{\mathrm{predicted}})}{\frac{1}{N}\sum \mathrm{RMS}_{\mathrm{predicted}}}$$

where $\mathrm{RMS}_{\mathrm{measured}}$ is the RMS of the measured data and $\mathrm{RMS}_{\mathrm{predicted}}$ is the RMS of the predicted data. Summations are over the number of pressures examined.

Uncertainty is defined as the fraction computed by the standard deviation

$$\mathrm{UNCERTAINTY} = \frac{\sqrt{\frac{1}{N}\sum(\mathrm{RMS}_{\mathrm{measured}} - \mathrm{RMS}_{\mathrm{predicted}})^2}}{\frac{1}{N}\sum \mathrm{RMS}_{\mathrm{predicted}}}$$

ACM Rev. 4.1 bias and uncertainty results are compiled for specified frequency ranges of interest [7], and summarized in Table 5.1. Other random uncertainties, specific to NMP2, are summarized in Table 5.2 and are combined with the ACM results by SRSS methods to determine an overall uncertainty for NMP2, which is shown in Table 5.3.

Table 5.1. NMP2 bias and uncertainty for specified frequency intervals. A negative bias indicates that the ACM overpredicts the QC2 data in that interval.

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Table 5.2. Bias and uncertainty contributions to total uncertainty for NMP2 plant data.

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Table 5.3. NMP2 total uncertainty for specified frequency intervals.

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# 6. Conclusions

The C.D.I. acoustic circuit analysis, using full-scale measured data for NMP2:

a) [[

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b) Predicts that the loads on dryer components are largest for components nearest the main steam line inlets and decrease inward into the reactor vessel.

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17. Continuum Dynamics, Inc. 2012. Nine Mile Point Unit 2 Real Time Nodal Analysis Results at 107.5% Power (Rev. 0). C.D.I. Technical Memorandum No. 12-21.

18. Continuum Dynamics, Inc. 2012. Limit Curves with ACM Rev. 4.1 for the 107.5% Power Level Basis at Nine Mile Point Unit 2 (Rev. 0). C.D.I. Technical Note No. 12-22 (Proprietary).

19. Continuum Dynamics, Inc. 2012. Limit Curves with ACM Rev. 4.1 for the 110% Power Level Basis at Nine Mile Point Unit 2 (Rev. 0). C.D.I. Technical Note No. 12-15 (Proprietary).

20. Continuum Dynamics, Inc. 2012. Limit Curves with ACM Rev. 4.1 for the 105% Power Level Basis at Nine Mile Point Unit 2 with the Inboard RCIC Valve Closed (Rev. 0). C.D.I. Technical Note No. 12-23 (Proprietary).

21. Continuum Dynamics, Inc. 2012. Limit Curves with ACM Rev. 4.1 for the 112.5% Power Level Basis at Nine Mile Point Unit 2 (Rev. 0). C.D.I. Technical Note No. 12-24 (Proprietary).

22. Continuum Dynamics, Inc. 2012. Limit Curves with ACM Rev. 4.1 for the 115% Power Level Basis at Nine Mile Point Unit 2 (Rev. 0). C.D.I. Technical Note No. 12-16 (Proprietary).

23. Continuum Dynamics, Inc. 2012. Limit Curves with ACM Rev. 4.1 for the 110% Power Level Basis at Nine Mile Point Unit 2 with the Inboard RCIC Valve Closed (Rev. 0). C.D.I. Technical Note No. 12-26 (Proprietary).

24. Continuum Dynamics, Inc. 2012. Limit Curves with ACM Rev. 4.1 for the 115% Power Level Basis with 92.5 Hz Peak at Nine Mile Point Unit 2 (Rev. 0). C.D.I. Technical Note No. 12-28 (Proprietary).

25. Continuum Dynamics, Inc. 2012. Limit Curves with ACM Rev. 4.1 for the 115% Power Level Basis at Nine Mile Point Unit 2 with the Inboard RCIC Valve Closed (Rev. 0). C.D.I. Technical Note No. 12-30 (Proprietary).

26. Continuum Dynamics, Inc. 2012. Stress Evaluation of Nine Mile Point Unit 2 Steam Dryer at 115% CLTP. C.D.I. Report No. 12-18 (Proprietary).

# Appendix A: Power Ascension Data Comparison

This appendix summarizes the results of the power ascension from CLTP to 115% CLTP target power conditions at NMP2. Table A.1 summarizes the results, referencing the target power level (in % CLTP), the Structural Integrity data file number (date and time), the minimum stress ratio computed by the real-time stress analysis, the measured steam flow (in % CLTP), and the C.D.I. document number detailing the limit curve analysis and summarizing the real-time stress analysis results.

Figures A.1 compare the MSL exclusion filtered signals for the target power levels of 100.0, 102.5, 105.0, 107.5, 110.0, 112.5, and 115.0% CLTP. Figures A.2 compare the MSL exclusion filtered signals for the target power levels of 105.0, 110.0, and 115.0% CLTP with the inboard RCIC valve closed. Figure A.3 plots the minimum stress ratios computed by the real-time stress analysis as a function of measured steam flow.

Table A.1. Tabulation of NMP2 power ascension data. C.D.I. document numbers are preceded by N for technical note, M for technical memorandum, and R for report.

| **Target Power Level (% CLTP)** | **Structural Integrity Data File Name** | **Minimum Stress Ratio** | **Measured Steam Flow (% CLTP)** | **C.D.I. Document Number** |
|---|---|---|---|---|
| 100.0 | 20120625022309 | 2.912 | 100.5 | N: 12-13 [14] |
| 102.5 | 20120628154002 | 2.749 | 101.62 | M: 12-18 [15] |
| 105.0 | 20120630165003 | 2.654 | 103.84 | N: 12-14 [16] |
| 105.0 RCIC Valve Closed | 20120703013557 | 2.452 | 104.47 | N: 12-23 [20] |
| 107.5 | 20120708005230 | 2.493 | 107.13 | M: 12-21 [17]<br>N: 12-22 [18] |
| 110.0 [Note 1] | 20120710180627 | 2.398 | 110.0 | N: 12-15 [19] |
| 110.0 RCIC Valve Closed [Note 1] | 20120728161342 | 2.222 | 110.22 | N: 12-26 [23] |
| 112.5 [Note 1] | 20120719032244 | 2.373 | 112.53 | N: 12-24 [21] |
| 115.0 [Note 1] | 20120721142636 | 2.196 | 115.5 | N: 12-16 [22] |
| 115.0 [Note 2] | 20120721142636 | 2.388 | 115.5 | N: 12-28 [24] |
| 115.0 RCIC Valve Closed [Note 3] | 20120904092600 | 2.050 | 115.79 | N: 12-30 [25] |
| 115.0 | 20120721142636 | 2.492 | 115.5 | R: 12-18 [26] |

Note 1. Only strain gage channels 2 and 4 were used when computing the MSL A Upper signal (see Appendix B for details).

Note 2. All four strain gage channels were used when computing the MSL A Upper signal. A peak was inserted in the MSL B data at 92.5 Hz (see Appendix C for details).

Note 3. All four strain gage channels were used when computing the MSL A Upper signal.

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Figure A.1a. Base curves for main steam line A upper (top) and lower (bottom) for target power levels 100.0% CLTP (black curves), 102.5% CLTP (red curves), 105.0% CLTP (blue curves), 107.5% CLTP (green curves), 110.0% CLTP (magenta curves), 112.5% CLTP (cyan curves), and 115.0% CLTP (gray curves).

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Figure A.1b. Base curves for main steam line B upper (top) and lower (bottom) for target power levels 100.0% CLTP (black curves), 102.5% CLTP (red curves), 105.0% CLTP (blue curves), 107.5% CLTP (green curves), 110.0% CLTP (magenta curves), 112.5% CLTP (cyan curves), and 115.0% CLTP (gray curves).

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Figure A.1c. Base curves for main steam line C upper (top) and lower (bottom) for target power levels 100.0% CLTP (black curves), 102.5% CLTP (red curves), 105.0% CLTP (blue curves), 107.5% CLTP (green curves), 110.0% CLTP (magenta curves), 112.5% CLTP (cyan curves), and 115.0% CLTP (gray curves).

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Figure A.1d. Base curves for main steam line D upper (top) and lower (bottom) for target power levels 100.0% CLTP (black curves), 102.5% CLTP (red curves), 105.0% CLTP (blue curves), 107.5% CLTP (green curves), 110.0% CLTP (magenta curves), 112.5% CLTP (cyan curves), and 115.0% CLTP (gray curves).

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Figure A.2a. Curves for main steam line A upper (top) and lower (bottom) with the inboard RCIC valve closed, for target power levels 105.0% CLTP (black curves), 110.0% CLTP (red curves), and 115.0% CLTP (blue curves).

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Figure A.2b. Curves for main steam line B upper (top) and lower (bottom) with the inboard RCIC valve closed, for target power levels 105.0% CLTP (black curves), 110.0% CLTP (red curves), and 115.0% CLTP (blue curves).

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Figure A.2c. Curves for main steam line C upper (top) and lower (bottom) with the inboard RCIC valve closed, for target power levels 105.0% CLTP (black curves), 110.0% CLTP (red curves), and 115.0% CLTP (blue curves).

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Figure A.2d. Curves for main steam line D upper (top) and lower (bottom) with the inboard RCIC valve closed, for target power levels 105.0% CLTP (black curves), 110.0% CLTP (red curves), and 115.0% CLTP (blue curves).

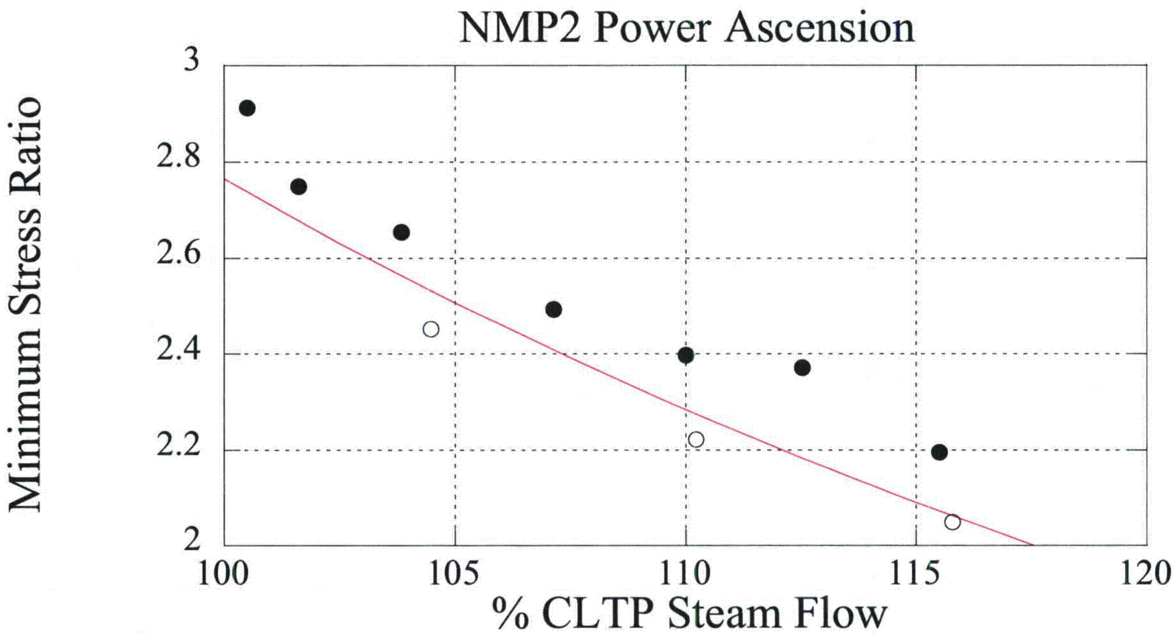


Figure A.3. Minimum stress ratio behavior for power levels examined by limit curves, plotted as a function of % CLTP measured steam flow, as identified in Table A.1. The red curve would be the data trend assuming a velocity squared increase in load to a minimum stress ratio of 2.0 at EPU conditions, where EPU equals 117.56% CLTP measured steam flow. Predicted dryer stresses with the inboard RCIC valve open are shown by solid black circles, while the stresses with the inboard RCIC valve closed are shown by the open black circles.

# Appendix B: MSL A Upper Strain Gage Signals

The first time that data were taken at 110% CLTP target power (on 10 July 2012), one of the strain gage pairs (identified as channels in Table 3.1) on MSL A upper gave elevated noise levels. It was determined that the signals from that strain gage pair and its opposite pair would be disregarded when converting to pressure. While this approach normally increases the baseline noise level, in this case it reduced the baseline noise because of the bad strain gage reading. Subsequent to the collection of these data, the plant underwent a scram. The plant recovered 110% CLTP target power on 18 July 2012 and acquired data at 115% CLTP target power on 21 July 2012. These data were converted to pressures assuming the same strain gage channel pairs as for the 10 July data. The initial limit curve report [22] was prepared using pairs 2 and 4 for MSL A upper. Further review of the data at 115% CLTP target power (taken on 21 July 2012) concluded that the noise level in the MSL A upper strain gage was in fact normal during this dataset, and that the conversion to pressure should apply all four strain gage pairs. Thus, the 115% dataset used for the load definition report included the four strain gage pairs at MSL A upper. Table B.1 summarizes the status of the four pairs during power ascension. It may be seen that the minimum stress ratio increased from 2.196 to 2.492 with the inclusion of the two pairs previously disregarded. Figure B.1 compares the two pressure signals at MSL A upper.

Table B.1. Tabulation of active strain gage pairs on MSL A upper during power ascension data.

| Target Power Level (% CLTP) | Structural Integrity Data File Name | Minimum Stress Ratio | Active Pairs | Active Pairs | Active Pairs | Active Pairs |
|---|---|---|---|---|---|---|
| 100.0 | 20120625022309 | 2.912 | 1 | 2 | 3 | 4 |
| 102.5 | 20120628154002 | 2.749 | 1 | 2 | 3 | 4 |
| 105.0 | 20120630165003 | 2.654 | 1 | 2 | 3 | 4 |
| 105.0 RCIC Valve Closed | 20120703013557 | 2.452 | 1 | 2 | 3 | 4 |
| 107.5 | 20120708005230 | 2.493 | 1 | 2 | 3 | 4 |
| 110.0 [Note 1] | 20120710180627 | 2.398 | | 2 | | 4 |
| 112.5 [Note 1] | 20120719032244 | 2.373 | | 2 | | 4 |
| 115.0 [Note 1] | 20120721142636 | 2.196 | | 2 | | 4 |
| 115.0 [Note 2] | 20120721142636 | 2.388 | 1 | 2 | 3 | 4 |
| 115.0 [Note 3] | 20120721142636 | 2.492 | 1 | 2 | 3 | 4 |
| 110.0 RCIC Valve Closed | 20120728161342 | 2.222 | 1 | 2 | 3 | 4 |
| 115.0 RCIC Valve Closed | 20120904092600 | 2.050 | 1 | 2 | 3 | 4 |

Note 1. Strain gage pair 3 was giving elevated noise level, so this pair and its opposite pair (1) were not included when computing the pressure at MSL A Upper.

Note 2. A peak was inserted in the MSL B data at 92.5 Hz.

Note 3. Data used for the final stress analysis [26].

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Figure B.1. Exclusion filtered pressure measured on the NMP2 main steam lines at 115% CLTP target power conditions for main steam line A, comparing the use of strain gage pairs 2 and 4 with the use of all four strain gage pairs.

# Appendix C: 115% CLTP Target Power Load Definitions

Two datasets were collected at 115% CLTP target power. From these data, four load definitions were developed, encompassing two additional load cases applicable to alternate RCIC system lineups. The four load definitions are identified in Table C.1 in their chronological order, and include the following:

1. The first load definition used only channels 2 and 4 on MSL A upper [22], generating an interim base case with a minimum stress ratio of 2.196 as plotted in Figure A.3.

2. The second load definition used all four channels on MSL A upper, and added a peak at 92.5 Hz, generated from the 110% CLTP target power, to MSL B upper and lower, in an effort to carry to 115% CLTP target power a peak evident in the 110% data but not reproducible after the post scram recovery. The procedure for adding this peak was discussed in [24]. The impact of this configuration is a narrow peak only on MSL B, as seen in Figure C.1, and generated a minimum stress ratio of 2.388.

3. The third load definition used all four channels on MSL A upper, and closed the inboard RCIC valve. The narrow peak only on MSL B moved to 89.3 Hz [25]; its impact is seen in Figure C.2, and generated a minimum stress ratio of 2.050.

4. The fourth load definition used all four channels on MSL A upper, and generated the normal operating base case with a minimum stress ratio of 2.492. This load definition was used for the final stress analysis discussed in [26].

Table C.1. Data sets analyzed at 115% CLTP target power.

| Load Definition Identification Number | Target Power Level (% CLTP) | Structural Integrity Data File Name | Minimum Stress Ratio |
|---|---|---|---|
| 1 | 115.0 | 20120721142636 | 2.196 |
| 2 | 115.0 | 20120721142636 | 2.388 |
| 3 | 115.0 RCIC Valve Closed | 20120904092600 | 2.050 |
| 4 | 115.0 | 20120721142636 | 2.492 |

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Figure C.1. Exclusion filtered data measured on the NMP2 main steam lines at 115% CLTP target power conditions for the addition of a 92.5 Hz peak. The two curves are identical except at the narrow band around the added peak.

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Figure C.2. Exclusion filtered data measured on the NMP2 main steam lines at 115% CLTP target power conditions with closure of the inboard RCIC valve. The two curves are nearly identical except at the narrow band around the added peak.