Exelon Generation
4300 Winfield Road
Warrenville, IL 60555

www.exeloncorp.com

Exelon Nuclear

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U. S. Nuclear Regulatory Commission
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Quad Cities Nuclear Power Station, Units 1 and 2
Renewed Facility Operating License Nos. DPR-29 and DPR-30
NRC Docket Nos. 50-254 and 50-265

Subject: Quad Cities Unit 2 Startup and Power Ascension Testing Following Installation of Acoustic Side Branch Modifications

Reference: Letter from Keith R. Jury (Exelon Generation Company, LLC) to U. S. NRC, "Quad Cities Nuclear Power Station Operational Plan Commitments," dated April 14, 2006

Following completion of the spring 2006 refueling outage for Quad Cities Nuclear Power Station (QCNPS) Unit 2, the unit was returned to service and implemented the start-up test program described during the March 16, 2006, meeting between Exelon Generation Company, LLC (EGC) and the NRC. The start-up test program included collecting data during operation at extended power uprate (EPU) power levels. EGC has reviewed the collected data and compiled results from this review. As described in the reference, EGC is providing the startup and power ascension test data and associated analysis to the NRC in the attachment to this letter.

There are no regulatory commitments contained in this letter. If you have any questions concerning this letter, please contact Mr. Thomas G. Roddey at (630) 657-2811.

Respectfully,

Patrick R. Simpson

Patrick R. Simpson
Manager – Licensing

A098
JE26

Attachment: Exelon Report AM-2006-002, "Quad Cities Unit 2 Main Steam Line Acoustic Source Identification and Recommendations for Load Reduction," Revision 0

cc: Regional Administrator – NRC Region III
NRC Senior Resident Inspector – Quad Cities Nuclear Power Station

ATTACHMENT

Exelon Report AM-2006-002, "Quad Cities Unit 2 Main Steam Line Acoustic Source Identification and Recommendations for Load Reduction," Revision 0

Quad Cities Unit 2 Main Steam Line Acoustic Source Identification and Load Reduction

Document Number AM-2006-002
Revision 0

Nuclear Engineering Department
Exelon Nuclear Generating Co.

Prepared by: Guy DeBoo Date: 5/3/06

Reviewed by: Kevin Ramsden Date: 5/3/06

Approved by: Roman Gesior Date: 5/3/06
(Date Issued)

Abstract

This report documents the results of extensive data collection on the Quad Cities Unit 2 replacement dryer and the Main Steam Lines. This data was taken with the intent of identifying acoustic sources in the steam system. Review of the data confirmed that vortex shedding coupled column resonance in the relief and safety valve stub pipes were the principal sources of large magnitude acoustic loads in the main steam system. Modifications were developed in subscale testing to alter the acoustic properties of the valve standpipes and add acoustic damping to the system. The modifications developed and installed consisted of acoustic side branches that were attached to the Electromatic Relief Valve (ERV) and Main Steam Safety Valve (MSSV) attachment pipes. Subsequent post-modification testing was performed in plant to confirm the effectiveness of the modifications.

Quad Cities Unit 2 MS Line Acoustic Source Identification and Load Reduction Report AM-2006-002 Revision 0

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1. Introduction

The Quad Cities Units 1 and 2 have experienced significant steam system component fatigue, fretting, and wear failures that have been attributed to the increased steam flow velocities. A 17 % extended power uprate, (EPU) increased the steam line flow velocities and caused a significant increase in acoustically generated pressure oscillations. As a result of the increased pressure oscillations, the steam dryer experienced the most significant fatigue failures while the actuators for the Electromatic Relief Valves (ERVs) have experienced the most fretting and wear. Cyclic loads caused by differential pressure oscillations initiated the fatigue cracks that lead to the steam dryer failures. Quad Cities Unit 2 in-vessel pressure measurements on the steam dryer surface and main steam line acceleration measurements taken at the ERV inlet flanges have been used to confirm the sources of the pressure oscillations causing this degradation.

Analysis of the collected power ascension test data led to the conclusion very strong acoustic sources in the 140-160 Hz range accounted for the majority of the loading on the dryer and the remainder of the steam path. Subscale testing performed by Continuum Dynamics, Inc. confirmed the likely acoustic sources as being the ERV and MSSV standpipes. Load mitigation testing was performed in subscale tests and the most promising design concept was shown to be the addition of an acoustic side branch (ASB) to separate the standpipe column resonance frequency from the vortex shedding frequency at EPU conditions. Acoustic damping was also added to the ASB to further suppress potential resonant response at non-EPU flow rates. The damping properties of the ASB modification were tested in full-scale pressurized air tests to demonstrate acoustic response of the modification prior to installation.

Subsequent to the ASB installation during the spring 2006 Quad Cities Unit 2 outage, power ascension testing was performed to validate the effectiveness of the ASB modification in reducing the acoustic loads on the main steam system. The modifications proved to be highly effective in reducing the acoustic loads.

This report provides a summary of the prior testing, the basis of the acoustic source identification, and the results of the post-modification testing.

2. Description of Instrumentation

2.1 In-Vessel Measurements

In-vessel pressure sensors and strain gages were used to collect data during the power ascent following the installation of the Quad Cities Unit 2 replacement dryer in the spring 0f 2005. This data provides valuable insights with respect to the magnitude and frequency of pressure loads on the steam dryer.

References 1 and 2 provide detailed description of the in-vessel pressure and strain measurements taken during power ascension testing on Quad Cities Unit 2. The in-vessel measurement devices were removed prior to installation of the modifications to the ERV and MSSV standpipes in the spring of 2006.

2.2 Steam Line Measurements

Extensive instrumentation of the steam lines has been performed prior to and following the installation of the modifications to the ERV and MSSV standpipes. Accelerometers on the ERV and MSSVs are employed to study vibration of these valves. Strain gages were also applied at two locations on each main steam line to measure the breathing mode of the main steam line and allow determination of fluctuating pressures in the lines.

References 3, 4, 7, and 8 provide detailed descriptions of the instrumentation placement, and the data gathered during power ascension testing following dryer replacement as well as power ascension testing performed subsequent to the ASB modification installation.

3. Results of Power Ascension Testing Following Replacement Dryer Installation

Figures 1 and 2 were obtained from Reference 1 and are representative of the oscillating differential pressure acting on the steam dryer. These measurements were taken from the instrumented steam dryer installed in Quad Cities Unit 2. After installation, measurements were taken during the unit's power ascension to a maximum thermal power of 2885 MWt. Figure 1 presents a power spectral density (PSD) of the pressure measurements from the P3 pressure transducer located on the steam dryer outer surface, opposite the "B" main steam line nozzle. This PSD shows the primary cyclic pressure load occurs at discreet frequencies of approximately 140 Hz and between 150 and 160 Hz. Figure 2 presents similar cyclic pressure measurements from the other side of the steam dryer opposite the "C" main steam line nozzle. The frequency content of these pressure measurements is typical of the pressure loading on the whole dryer.

Figure 1: QC-2 Steam Dryer EPU Measured Pressure Opposite B MS line Nozzle

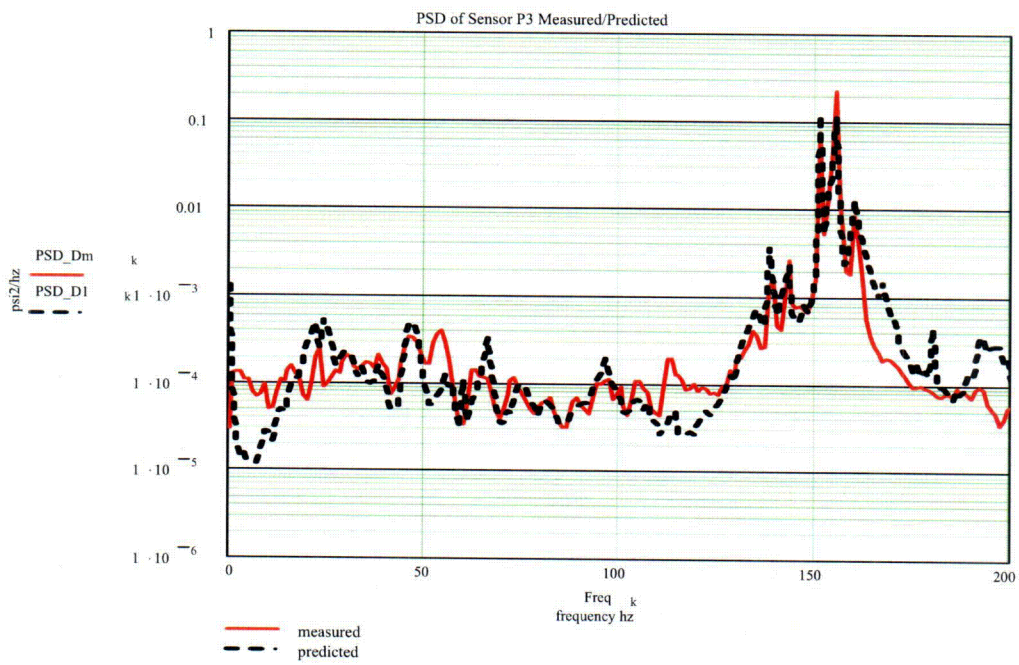

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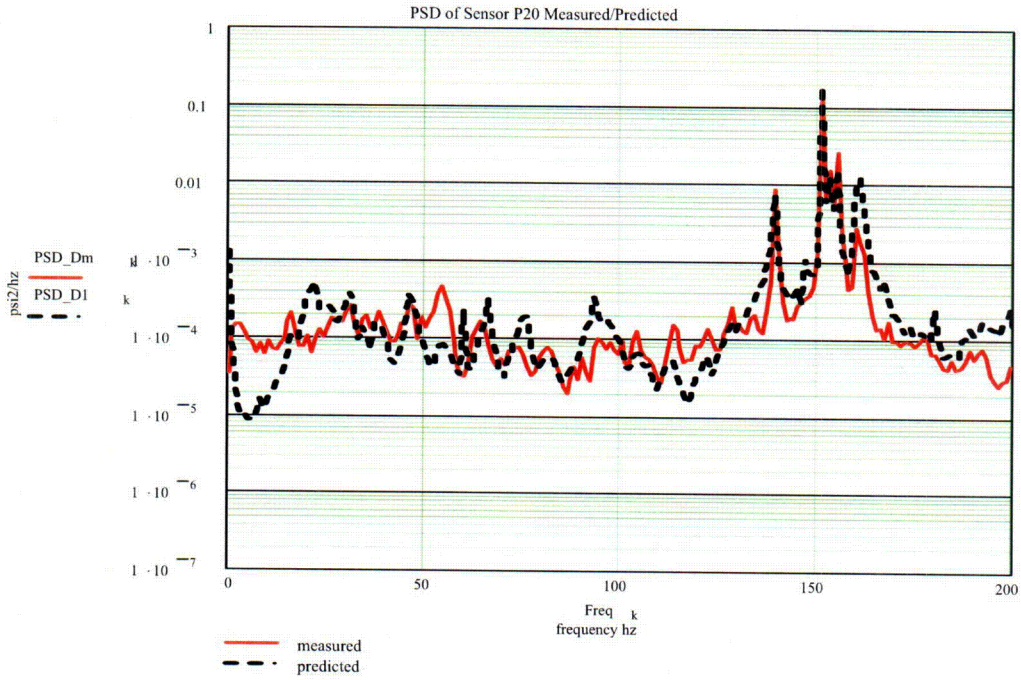
Figure 2: QC-2 Steam Dryer EPU Measured Pressure Opposite C MS line Nozzle



C02

Strain gage measurements of the Quad Cities Unit 2 steam dryer response to the oscillating pressure loads confirm the primary response to be in the frequency range of 150 Hz to 160 Hz. The EPU steam dryer strain gage measurements obtained in the spring of 2005, prior to the steam line modifications are presented in Attachment A. Calculating the cumulative mean squared strain from these measurements reinforces this conclusion. The strain accumulation with respect to the frequency content for typical steam dryer shell components is displayed in Figures 3 through 5. These measured responses demonstrate, with the exception of the dryer skirt flat panel at the 90° and 270° sides, that the significant strain response is generated by the 150 to 160 Hz frequency content of the oscillating pressure loads. It is clear from these physical measurements that the prior original dryer fatigue failures were the result of unsteady pressure loads in the 150 to 160 Hz frequency range.

The pressure oscillations that led to the steam dryer failures are also the source of the increased main steam line vibration levels that have caused the ERV actuator failures. The actuator degradation has been characterized as accelerated fretting, wear, and loss of fasteners. These degradation mechanisms are generally the result of high frequency vibration loads (i.e. greater than 50 Hz). Figures 6 through 8 provide typical vibration levels in three orthogonal directions for the ERVs at Quad Cities Unit 2 from Reference 3. The vibration data are presented in Fast Fourier Transforms (FFTs) to identify the frequency content of the vibration loads. As seen in Figures 6 through 8, the vibratory accelerations are primarily in the same frequency range as the oscillating pressures (i.e. 150 to 160 Hz) with additional contribution at approximately 140 Hz. For both the steam dryer pressure measurements and the steam line vibration measurements, the trend of these peak frequencies from pre-EPU power levels to EPU power levels can be seen in Figure 9. Figure 9 presents waterfall plots of typical steam line vibration measurements for pre-EPU power levels, ~820 MWe, to EPU power levels, 912 MWe. Typically at pre-EPU power levels, the magnitude of the 140 Hz is almost fully developed, but continues to increase slightly at EPU power. At pre-EPU power, the 150 to 160 Hz content is beginning to develop and increases significantly as the reactor power increases to EPU levels. This trend in line vibration is consistent with the steam dryer and ERV actuator operating performance. At pre-EPU power levels, steam dryer fatigue cracking was not observed and ERV actuator degradation was managed through increased preventive maintenance (i.e. actuators experienced little deterioration during each fuel cycle and were rebuilt during each refuel outage).

Based on these in-vessel pressure measurements and the main steam line vibration measurements, the oscillating loads causing the steam dryer fatigue failures and the ERV fretting and wear degradation is attributed to these predominant frequencies of ~140 Hz and the range from 150 and 160 Hz.

Figure 3: QC-2 Steam Dryer Measured Strain Accumulation at 2885 MWt – S1 Skirt Curved Panel

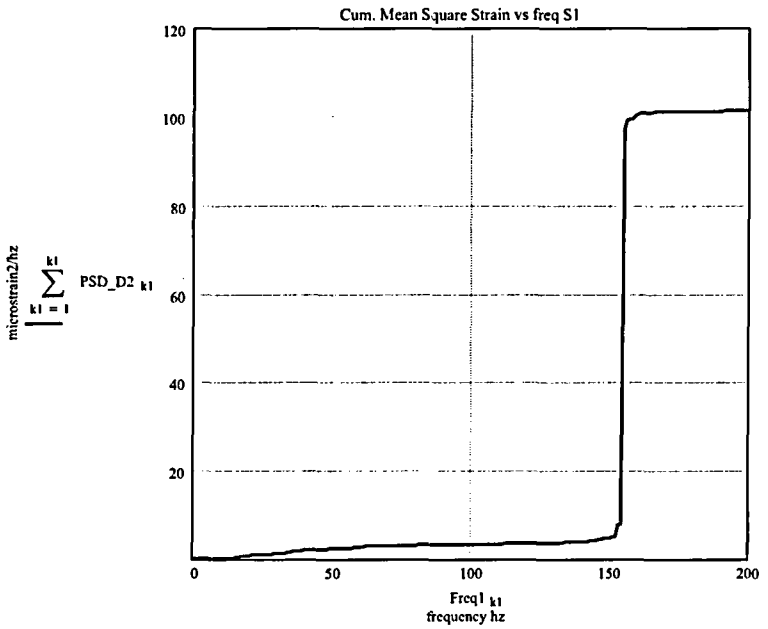


Figure 4: QC-2 Steam Dryer Measured Strain Accumulation at 2885 MWt – S5 Dryer Hood Closure Plate

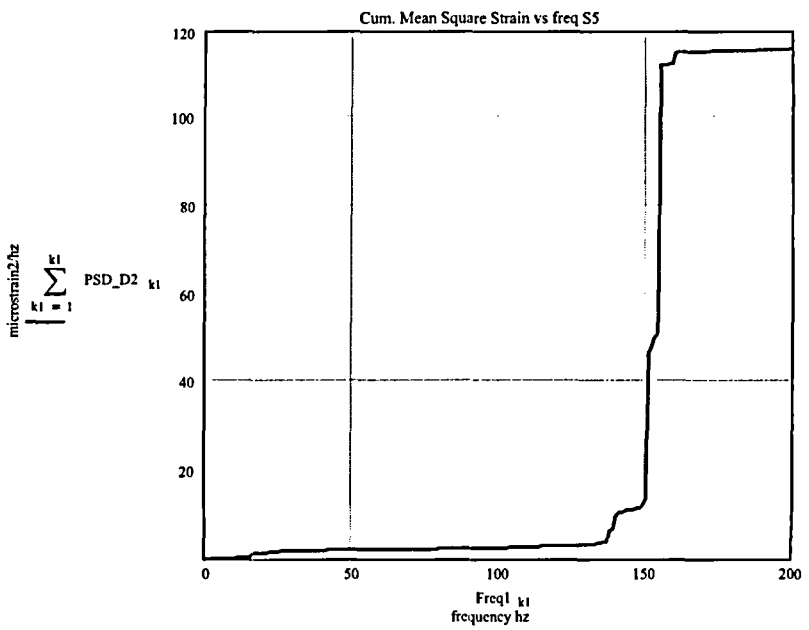


Figure 5: QC-2 Steam Dryer Measured Strain Accumulation at 2885 MWt – S9 Outer Hood Panel Opposite A MS Nozzle

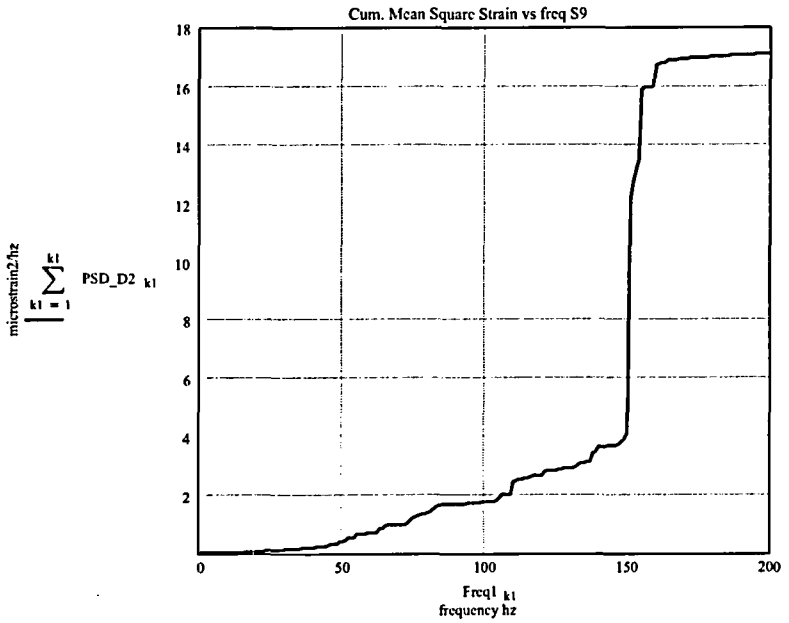


Figure 6: QC-2 3D ERV Inlet Flange X Direction

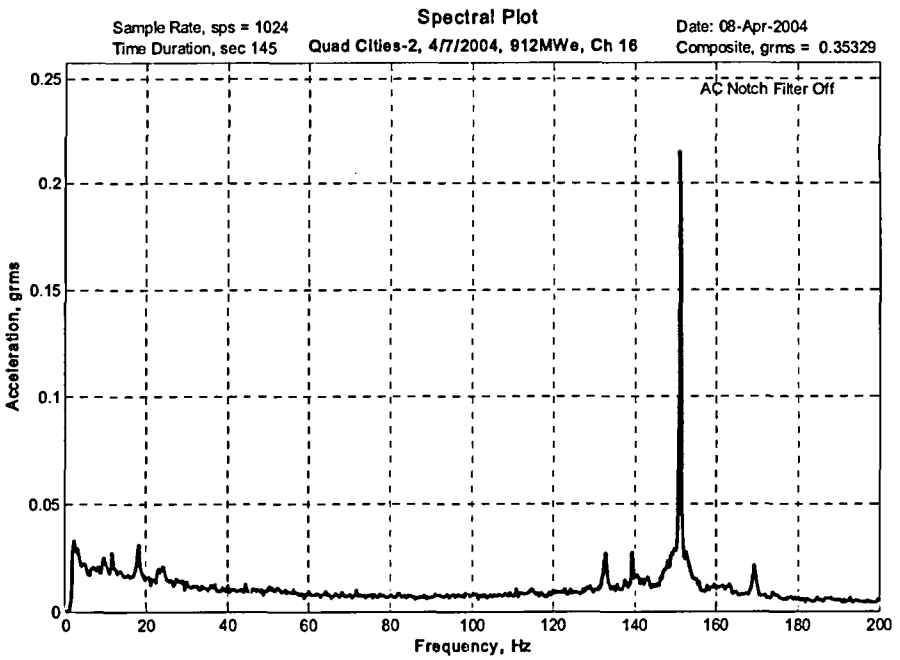


Figure 7: QC-2 3D ERV Inlet Flange Y Direction

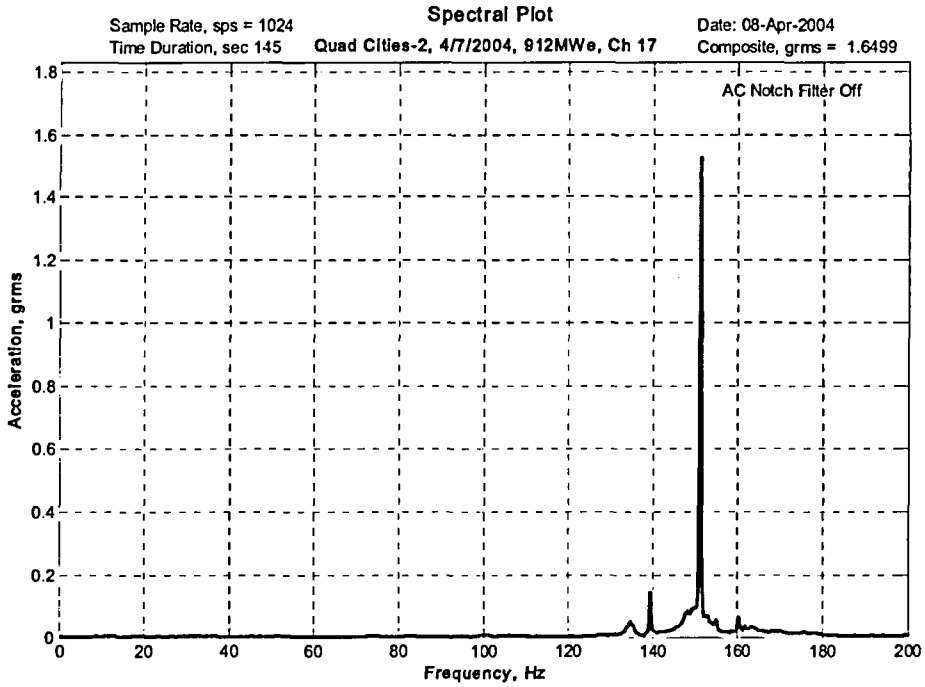


Figure 8: QC-2 3D ERV Inlet Flange Z Direction

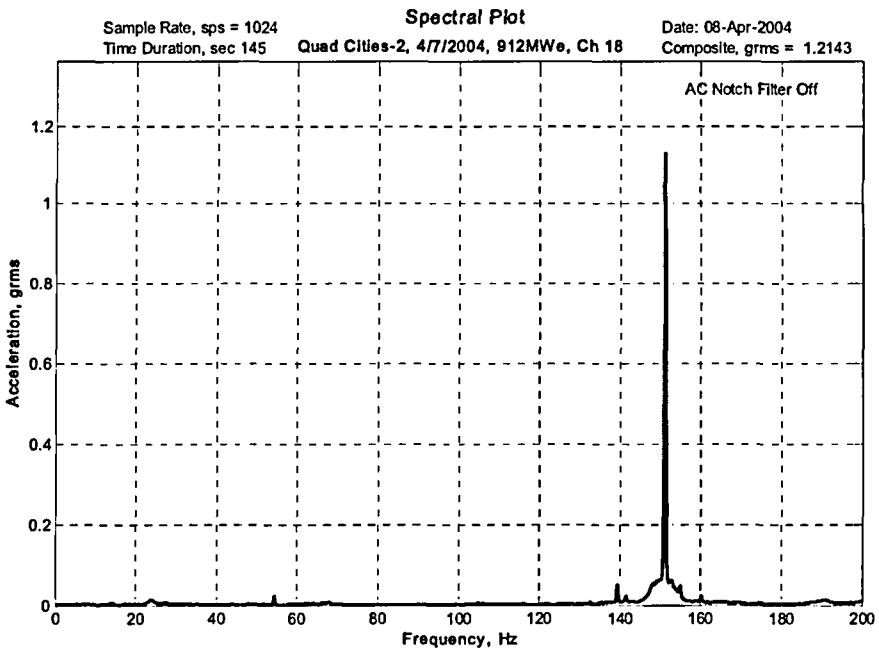


Figure 9a: QC-2 3D ERV Inlet Flange Y Direction Power Ascension Waterfall Plot

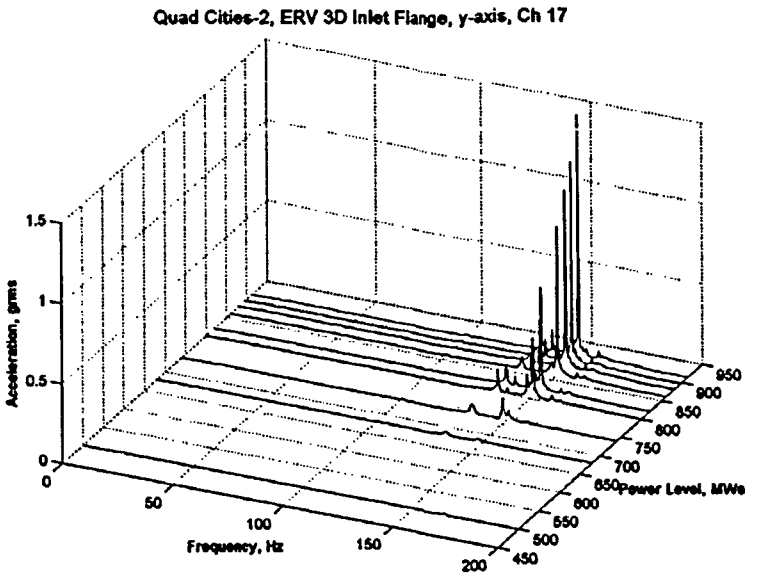
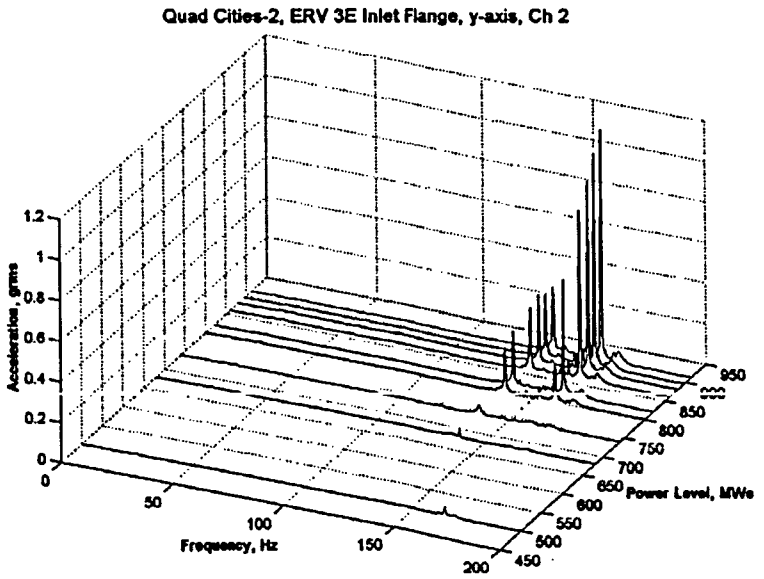


Figure 9b: QC-2 3B ERV Inlet Flange Y Direction Power Ascension Waterfall Plot



4. Acoustic Source Identification

4.1 Steam System Acoustic Characteristics

The acoustic characteristics of the Quad Cities steam system, including the reactor and steam piping to the turbine have been investigated to identify acoustic sources. Based on these investigations, the sources of the discreet frequency pressure oscillations have been attributed the branch lines for relieving steam pressure. The pressure relief branch lines are all the same size (i.e. height and diameter) with different types of relief valves, which change the acoustic characteristics of each branch. In Reference 5, Continuum Dynamics, Inc. calculated the first mode acoustic frequencies for each of the branch line configurations installed in the Quad Cities steam system. The pressure relief valves installed on the Quad Cities main steam lines include Dresser 6x8 safety valves, ERVs, and a single Target Rock safety relief valve on the A steam line. The calculated frequencies are summarized in Table 1 for each type of pressure relief valve.

Table 1: Pressure Relief Branch Line Acoustic Frequencies

Relief Valve Type	¼ Wave Acoustic Frequency
Dresser 6x8 Safety Valve	158 Hz
Electromatic Relief Valve	133 Hz
Target Rock Safety Relief Valve	117 Hz

4.2 Quad Cities Station Steam Line Frequencies

Steam line vibration data was collected at Quad Cities Unit 2 during the EPU start-up tests in the spring of 2002 to assess the steam line response to EPU flow conditions. The B main steam line acceleration response for pre-EPU (820 MWe) and EPU (912 MWe) is presented in Figures 10 through 13. When these vibration measurements were obtained, the Quad Cities Unit 2 steam line relief valve configuration was different than currently exists in the plant. Power operated relief valves (PORVs) were installed instead of ERVs. The current ERVs were not installed on the Quad Cities Unit 2 steam lines until spring 2004. Consequently, acoustic characteristics of the steam lines were different in the spring of 2002 from the characteristics that existed after the ERVs were installed. By examining the frequency content of the FFTs in Figures 10 through 13, a predominant 160 Hz frequency with second and third multiples can be seen at both the pre-EPU and EPU power levels. The amplitude of the signal at this frequency is also observed to increase significantly (approximately a factor of

1.75) from pre-EPU to EPU power levels. Based on the prior calculations, this predominant frequency is attributed to the Dresser 6x8 safety valves installed on this steam line.

Quad Cities Unit 2 B main steam line vibration data was taken at the same steam line location after the PORVs were replaced with ERVs. The FFTs of these EPU power level measurements are presented in Figures 14 and 15. With two ERVs installed on the B main steam line, the predominant frequency of the steam line vibration measurements has changed to approximately 138 Hz. The 160 Hz frequency content is still present, although at a lower amplitude.

These steam line vibration measurements provide confirmation that the acoustic source of the approximately 140 Hz frequency is the ERVs standpipes. It also confirms the source of the 150 to 160 Hz frequency content can be attributed to the Dresser 6x8 safety valve stand pipes since this valve and this frequency were consistent in the measurements from both steam line configurations.

Figure 10: QC-2 B Main Steam Line Between PORV and Dresser Safety Valve - Vertical Direction, pre-EPU Power Level

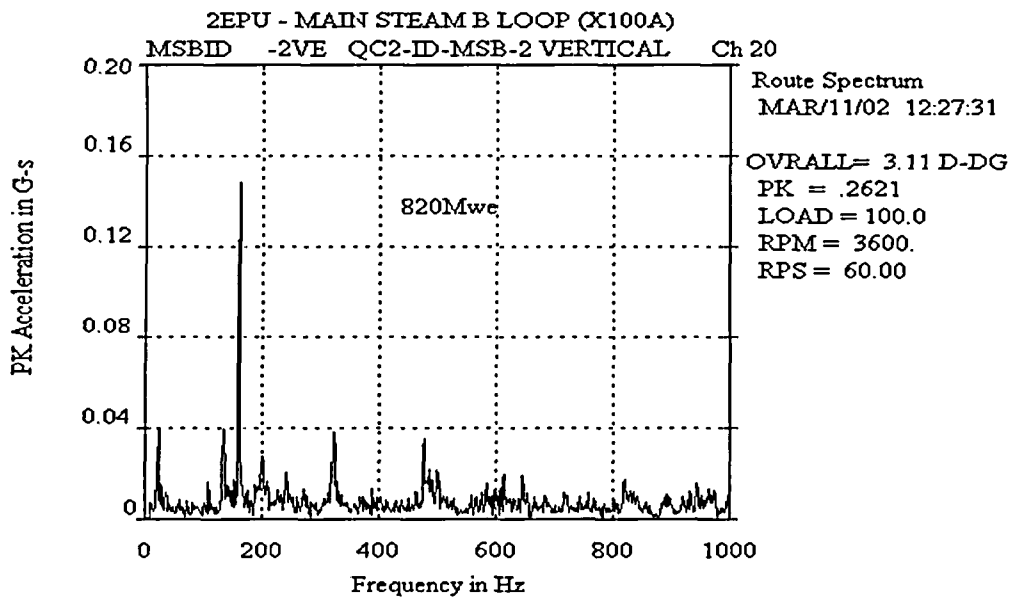


Figure 11: QC-2 B Main Steam Line Between PORV and Dresser Safety Valve – Horizontal Direction, pre-EPU Power Level

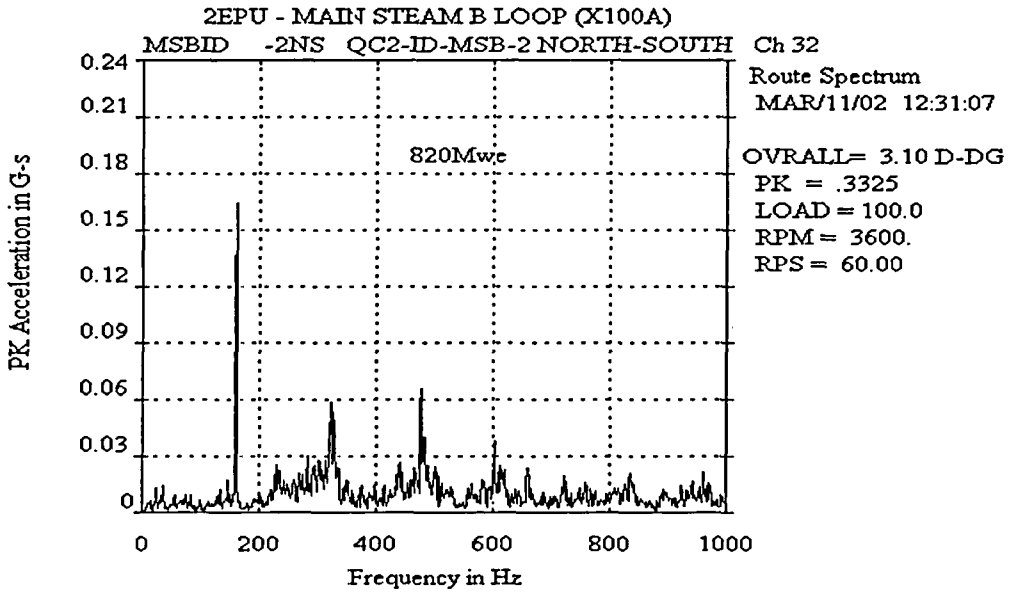


Figure 12: QC-2 B Main Steam Line Between PORV and Dresser Safety Valve – Vertical Direction, EPU Power Level

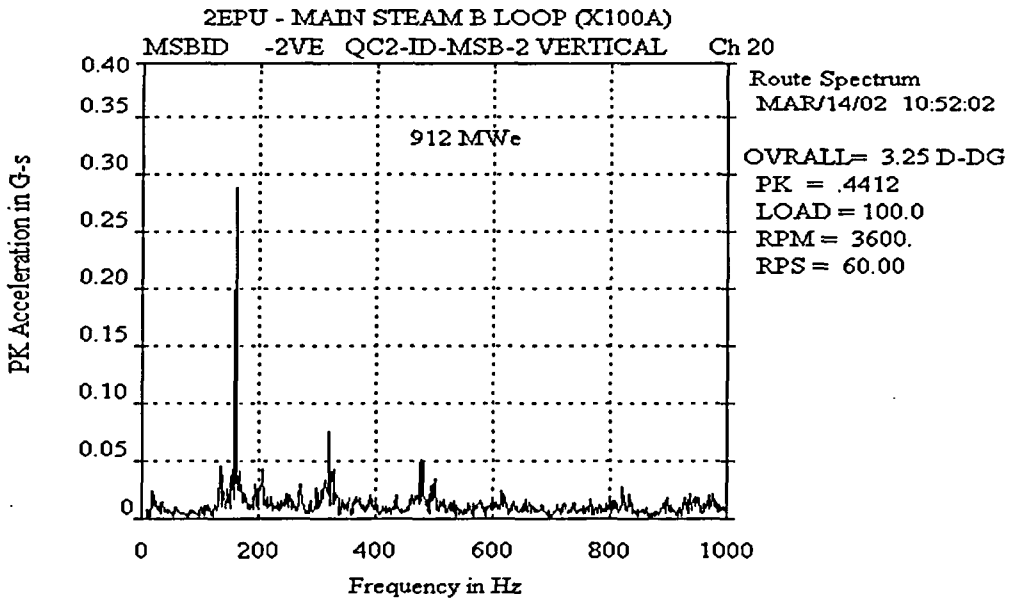


Figure 13: QC-2 B Main Steam Line Between PORV and Dresser Safety Valve – Horizontal Direction, EPU Power Level

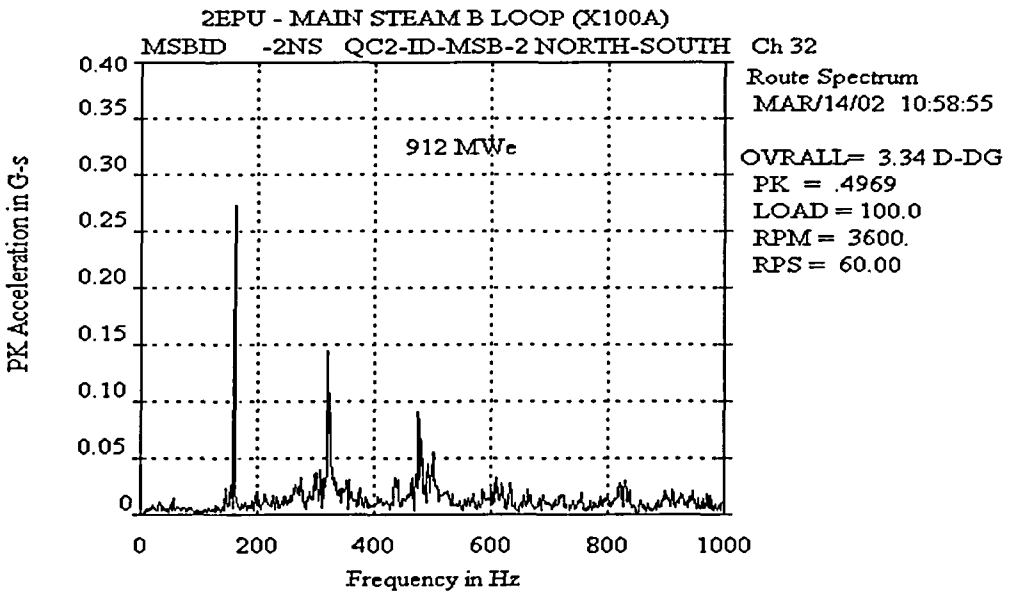


Figure 14: QC-2 B Main Steam Line Between ERV and Dresser Safety Valve – Vertical Direction, EPU Power Level

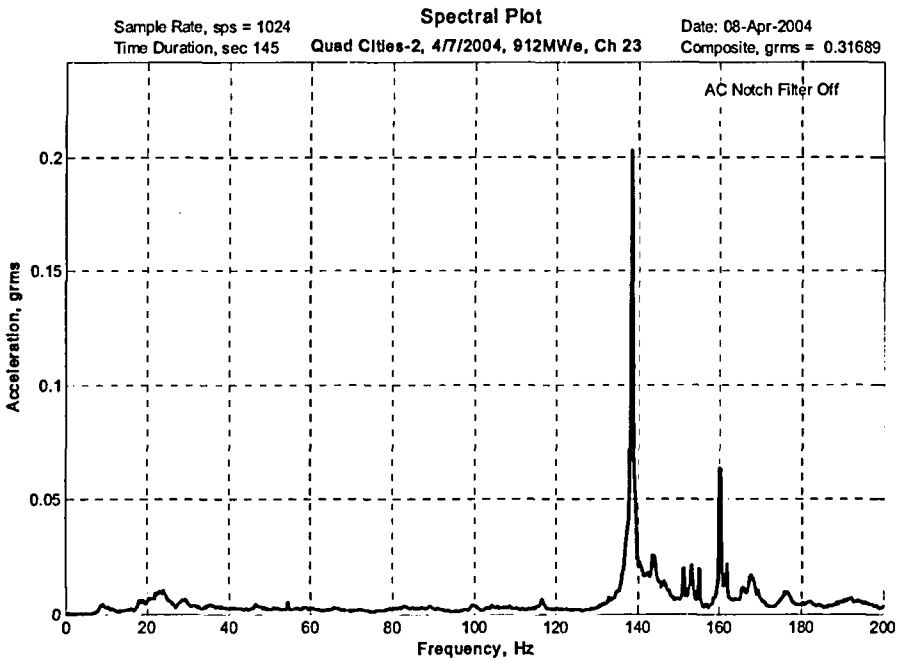
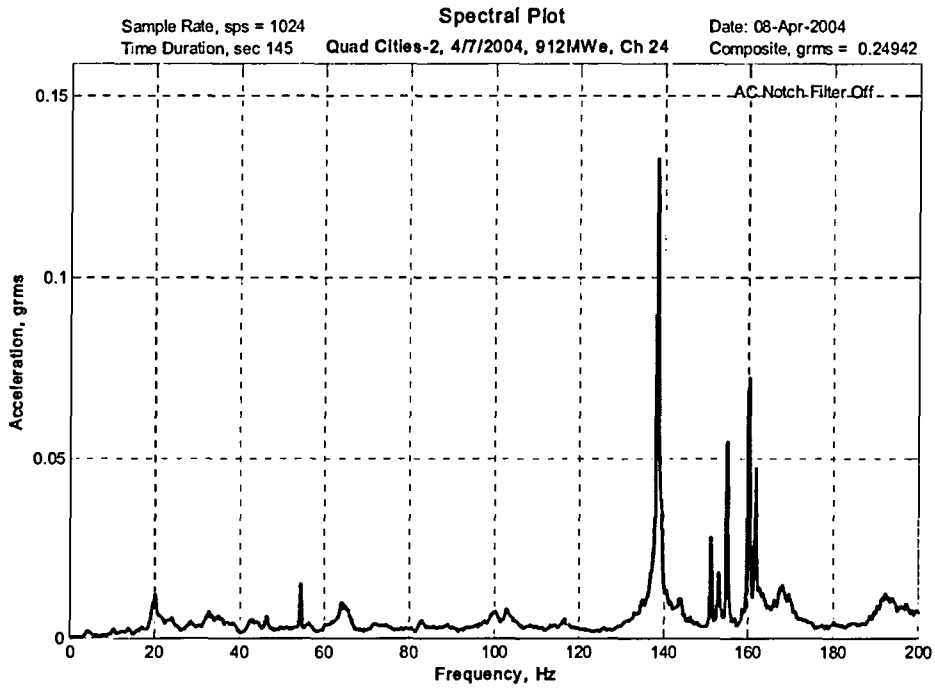


Figure 15: QC-2 B Main Steam Line Between ERV and Dresser Safety Valve – Horizontal Direction, EPU Power Level



5. Main Steam System Acoustic Load Reduction

Identifying that the Dresser 6x8 safety valves and the ERV standpipes are the sources of the oscillating pressure loads causing damage to the steam dryer and the ERVs provided the focus of the steam system acoustic load reduction effort. To reduce these acoustic loads, the main steam relief and safety valve branch lines were modified with acoustic side branches (ASBs). The ASB primary functions were to increase the acoustic length of the assembly and to absorb the acoustic pressure waves emanating from the relief branch lines. The increased effective length of the relief branch lines would shift the acoustic frequency downward and cause the acoustic excitation from the branch opening shear layer instability to occur at lower steam line velocities (i.e. lower thermal power levels). The acoustic side branch was filled with a fine screen material to absorb the acoustic pressure waves reflecting from the ERV and safety valve disk seats. The ASB acoustic performance was demonstrated with a series of sub-scale model and full-scale model tests. These tests results are documented in References 5 and 6. The ASBs were designed and installed on the ERV and safety valve branch lines. Based on the Reference 6 test results, the ASBs installed on the safety valves branch lines were expected to shift the ¼ wave acoustic frequency from 158 Hz down to approximately 128 Hz. The ASBs installed on the ERV branch lines were longer than the ASBs on the safety valves and were expected to reduce the ¼ wave acoustic frequency even lower. The magnitudes of the acoustic pressure waves were anticipated to drop by approximately 85% for the acoustic resonant frequencies.

The Target Rock safety relief valve is the one branch line without an ASB. The sub-scale test results indicated the acoustic response from the Target Rock safety relief valve branch line had the potential to increase due to the addition of the ASBs on the upstream safety valves. As a precaution, the lengths of the ASBs installed on the 4A and 4E safety valves upstream of the Target Rock safety relief valve were reduced to avoid the potential coupling between them and the Target Rock safety relief valve.

6. Main Steam System Performance with ASBs Installed

After installing the ASBs on the safety valve and ERV branch lines, steam line pressure and acceleration measurements were taken during the Quad Cities Unit 2 start-up test, Reference 9. This start-up test collected steam line oscillating pressures using strain gages located on each steam line in two locations separated by approximately 30 feet. The steam line vibration measurements were obtained from the ERV valve inlet flanges, pilots and actuators; from a safety valve ASB on each steam line, and from the Target Rock safety relief valve. These steam line measurements were taken at several different power levels during the unit power ascension to determine the effect of ASBs on the steam line acoustic loads. Table 2 provides a listing of the test conditions and the power levels at which steam line measurements were taken for this startup test.

Acceptance criteria were established for the test based on long-term acceptance, as Level 2 criteria, and short term acceptance (for the duration of the power ascension test) as Level 1 criteria. The acceptance criteria for the strain gage measurements were defined as the envelope of the strain gage measurements obtained from both Quad Cities Units 1 and 2 prior to installing the ASBs. With Level 1 being the envelope of the EPU measurements and Level 2 being the envelope of the original licensed thermal power data (OLTP) measurements. The ERV inlet flange acceleration measurements used similar criteria, enveloping prior measurements from both units. The acceptance criteria for the ERV pilot valve and the ASB measurements were based on vibration tests that determined the long and short-term limits. For this assessment of the main steam acoustic and vibration performance, a more limiting comparison is made to the prior Unit 2 strain gage and ERV acceleration measurements at EPU and OLTP power levels. Using just these measurements, instead of the enveloped measures, demonstrates the actual reduction in oscillating steam line pressures and vibration levels.

Table 2. Test Condition Summary

Test Condition	Generator Power (MWe)	Core Thermal Power (MWth)
2	156	665
3	238	864
4	309	1061
5	500	1619
6	546	1752
7	606	1922
8	649	2055
9	700	2201
10	748	2338
11	805	2505
12/19 [1]	821	2562
13	850	2652
14	872	2714
15	900	2770
16	909	2810
17	919	2849
18	929	2874

Note: 1. Test Condition 12 was retaken so the results presented are from Test Condition 19 but referred to as TC12.

6.1 Steam Line Strain Gage Measurements

FFTs of the steam line measurements obtained during the start-up test are presented in Attachment B and were compared to the steam line measurements taken at the same steam line location prior to the installation of the ASBs. The steam line data for the comparison were obtained during the unit restart after installing the replacement steam dryer in May 2005. The May 2005 startup test details are provided in Reference 7. The current steam line data presented were obtained at TC18, with the unit operating at 2874 MWt. These measurements were compared to the prior EPU data, obtained during TC41 with the unit operating at 2887 MWt and the OLTP obtained during TC32 with the unit operating at 2489 MWt. All data sets were identically processed to develop these spectra. Details of the data processing for these comparisons are provided in Reference 8.

Reviewing the steam line strain gage FFTs, the only substantial change in strain magnitudes occurs from 140 to 160 Hz. The reduction in strain magnitudes between 140 and 160 Hz is readily seen to be below the prior EPU levels. In fact, at almost all steam line locations, the magnitude in this frequency range is reduced to measurement threshold levels and is well below the OLTP values. At the MSL A upper location, there is a small peak at approximately 158 Hz, which is slightly greater than the OLTP value. However, the contribution of this small peak is insignificant when compared to the magnitude of the reduction at the 155 Hz peak. A similar argument can be made for the other steam line locations: MSL B upper, MSL B lower, MSL C upper, and MSL D upper with very small, single frequency peaks that exceed the OLTP values. The result of this comparison is that the acoustic resonance at EPU power levels is reduced to measurement threshold levels and oscillating pressures are now less than at the prior OLTP power levels.

For the remaining frequency content presented in the strain gage FFTs, the current spectral values generally follow those of the prior EPU and OLTP values. In the frequency range of 0 to 40 Hz, the magnitudes of the spectral values are generally the same or less than the EPU values with one exception at the MSL C upper location. At this location, the magnitude of the spectral values between 22 and 25 Hz are greater than the prior EPU values. This is the only location with this change in response. At this location, two of the eight strain gages had failed and this may affect the results of the strain averaging. At this lower frequency, the possible sources would be attributed to the vortex shedding over the dryer surfaces or at the entrance to the steam nozzles. The position of the upper strain gages on each steam line is almost identical and only this location is responding in this manner. The changes to the steam lines were to add the ASBs to the relief branch lines and this change would not modify the low frequency content of the pressure oscillations. Based on these arguments, it is not likely that this

frequency content is real. Regardless, the affect of this anomaly is insignificant with respect to the pressure loads on the steam dryer as it is seen at only this location and its magnitude is significantly less the prior peak at the higher acoustic frequencies. Additional information to follow will also show that this frequency content did not affect the C main steam line vibration levels.

Further confirmation of the magnitude of the steam line oscillating pressures relative to prior steam line operating conditions can be seen in Table 3. The main steam line strain gage rms and maximum-minimum measurements for each test condition are summarized in Table 3. The maximum value for any test condition is compared to the OLTP value measured prior to installing the ASBs. This comparison provides additional confirmation that the current steam line strain measurements and therefore the oscillating pressure rms and maximum-minimum values are less than the OLTP values. Charts trending the strain gage maximum-minimum values are presented in Attachment C. On these charts the Quad Cities Unit 2 prior EPU and OLTP maximum-minimum values are plotted with the current data trends. These trends demonstrate the oscillating pressures are generally increasing with the square of the power. This indicates the acoustic resonance has been eliminated, and the steam system unsteady pressure functional dependence is now related to the steam flow dynamic pressure only. At some intermediate power levels there are small oscillations in the maximum-minimum strain values that are attributed to the altered branch line acoustic sources. As the steam line flow velocities increase with thermal power these sources are excited, but with the ASBs the acoustic resonance is damped and the magnitude of the pressure waves remain below the prior OLTP levels. The measurement trend for MSL C upper approaches the prior OLTP level, however it becomes flat and turns down with increasing thermal power. Most of the steam line measurements are well below the prior OLTP levels. Only the MSL A upper and MSL C upper locations are close to the prior OLTP limit. A second order polynomial fits these trends very well and when extrapolated to 2957 MWt, only the MSL C upper location produces maximum-minimum values that are slightly greater than the prior OLTP limit. Based on these trends and significant reduction of the acoustic resonance pressure oscillations, it is concluded that the full thermal power (i.e.2957 MWt) pressure loads will not exceed prior OLTP levels.

With this conclusion, the affect on the steam dryer pressure loads can be deduced by examining the cumulative strain plots in Figures 3 through 5. The elimination of the 150 to 160 Hz pressure loads will effectively reduce the dryer strains to those at frequencies below 150 Hz. As seen from these figures, the strain levels would substantially reduced and levels below the prior OLTP levels would be expected.

Table 3: Summary of Main Steam Line Strain Measurements from Q2R18 Startup Test

	RMS Values (microstrain)																				
Description	EPU	OLTP	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	TC 12	TC 13	TC 14	TC 15	TC 16	TC 17	TC 18	Max TC	% of OLTP
MSL A Upper	0.30	0.18	0.01	0.02	0.03	0.06	0.07	0.09	0.10	0.11	0.12	0.14	0.14	0.15	0.15	0.16	0.16	0.16	0.16	0.16	93.4%
MSL A Lower	0.43	0.26	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.10	0.11	0.13	0.13	0.13	0.14	0.14	0.15	0.15	0.15	0.15	58.3%
MSL B Upper	0.30	0.20	0.01	0.02	0.03	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.14	0.15	0.15	0.15	0.15	0.15	77.0%
MSL B Lower	0.25	0.18	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.12	0.14	0.14	0.14	0.14	0.15	0.15	0.15	82.8%
MSL C Upper	0.33	0.25	0.02	0.02	0.03	0.07	0.07	0.09	0.11	0.13	0.14	0.16	0.19	0.20	0.20	0.21	0.21	0.21	0.21	0.21	85.8%
MSL C Lower	0.22	0.17	0.02	0.03	0.03	0.06	0.05	0.06	0.07	0.08	0.08	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.12	0.12	65.9%
MSL D Upper	0.34	0.22	0.02	0.02	0.03	0.06	0.07	0.08	0.09	0.10	0.11	0.13	0.13	0.14	0.19	0.16	0.16	0.16	0.16	0.19	84.6%
MSL D Lower	0.38	0.30	0.01	0.02	0.03	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.13	0.14	0.14	0.15	0.15	0.15	0.16	0.16	52.0%

	Max-Min Values (microstrain)																				
Description	EPU	OLTP	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	TC 12	TC 13	TC 14	TC 15	TC 16	TC 17	TC 18	Max TC	% of OLTP
MSL A Upper	2.40	1.55	0.15	0.18	0.25	0.55	0.57	0.70	0.90	0.90	0.97	1.11	1.13	1.22	1.33	1.30	1.36	1.32	1.49	1.49	95.9%
MSL A Lower	3.34	2.13	0.17	0.25	0.30	0.56	0.60	0.72	0.79	0.88	1.03	1.06	1.17	1.17	1.25	1.20	1.33	1.28	1.34	1.34	62.8%
MSL B Upper	2.45	1.68	0.12	0.17	0.23	0.49	0.57	0.67	0.79	0.93	0.98	1.11	1.18	1.14	1.23	1.30	1.23	1.34	1.45	1.45	85.8%
MSL B Lower	2.27	1.60	0.21	0.26	0.30	0.58	0.65	0.69	0.80	0.92	0.98	1.04	1.02	1.18	1.30	1.22	1.22	1.33	1.30	1.33	83.2%
MSL C Upper	2.53	1.92	0.14	0.20	0.28	0.64	0.60	0.72	0.84	1.06	1.15	1.43	1.52	1.90	1.88	1.72	1.81	1.78	1.72	1.90	99.0%
MSL C Lower	1.96	1.54	0.20	0.24	0.28	0.53	0.46	0.51	0.60	0.69	0.71	0.78	0.80	0.84	1.07	0.98	1.04	0.94	1.03	1.07	69.7%
MSL D Upper	2.92	1.78	0.17	0.19	0.25	0.54	0.58	0.65	0.78	0.87	1.09	1.16	1.06	1.28	1.46	1.44	1.42	1.40	1.42	1.46	81.9%
MSL D Lower	2.73	2.23	0.20	0.23	0.32	0.58	0.63	0.78	0.83	0.88	1.06	1.17	1.08	1.19	1.45	1.30	1.25	1.32	1.35	1.45	65.1%

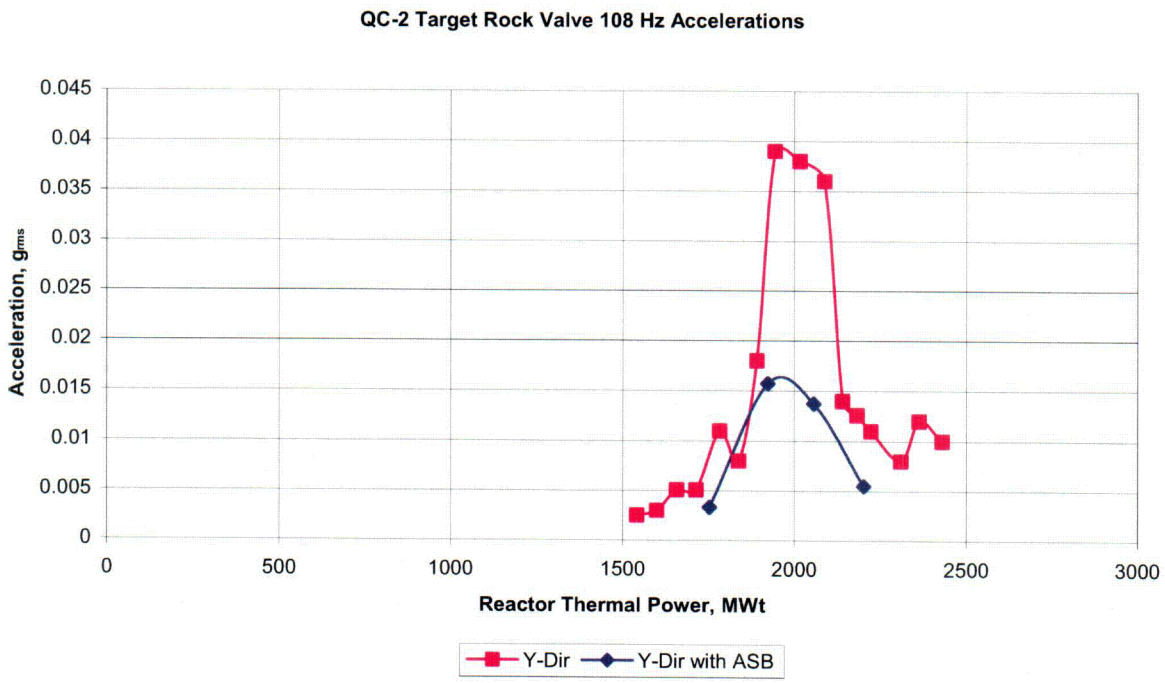
6.2 Steam Line Acceleration Measurements

FFT spectral comparisons for the ERV inlet flange vertical acceleration measurements at TC18, 2874 MWt, are also presented in Attachment B. These comparisons to the prior EPU and OLTP measurements were chosen because they best represent the accelerations that lead to the prior ERV actuator degradation. The current acceleration measurements show very similar frequency response as seen from the strain gage measurements. The acoustic resonance behavior seen in the prior EPU and OLTP data is no longer evident. In the acoustic frequency range from 140 to 160 Hz, very little acceleration response can be seen and it is well below the significant acoustic peaks seen in the prior OLTP data. In the low frequency range, 0 to 40 Hz, the acceleration response continues to be insignificant.

Charts trending the acceleration g_{rms} with respect to thermal power for the ERV inlet flanges, ERV pilot valves, Target Rock safety relief valve, and the ASBs are also provided in Attachment C. These trend plots clearly show the significant reduction of the acceleration levels in the steam lines. For most locations, the maximum g_{rms} is less than 50% of the prior OLTP measurement. For the few locations where the current acceleration is approaching the OLTP limit, the actual magnitude of the acceleration is very small and has an insignificant impact on the steam line and its components. The Y direction acceleration trend plot for the Target Rock safety relief valve shows a steady increase in the g_{rms} value with thermal power. This demonstrates the magnitude of the acoustic resonance of this branch line is very small and has an insignificant impact on the overall g_{rms} value. Figure 16 compares the current g_{rms} for the Y direction accelerations of the Target Rock safety relief valve to those obtained prior to the installation of the ASBs. This figure trends the g_{rms} for the 108 Hz acoustic frequency of the Target Rock safety relief valve branch line for the two data sets. As seen in this figure, the Target Rock safety relief valve acoustic resonance peaks at the same thermal power levels as expected, and the current acceleration levels are less than the accelerations before the ASBs were installed.

The current acceleration levels for the ERV pilot valves and the ASBs are compared to the acceptance criteria determined by component vibration tests. From these comparison plots, it is clear that the current EPU vibration levels, as well as vibration levels extrapolated to full thermal power (i.e.2957 MWt) would remain well below the long-term endurance limits.

Figure 16: QC-2 Target Rock Safety Relief Valve – 108 Hz Vertical Direction Acceleration Trend with Power Level



C03

7. Conclusions and Recommendations

Based on the plant measurement data presented, the following conclusions can be drawn:

1) The acoustic resonant behavior of the main steam line safety and relief valve branches has been essentially eliminated at EPU power levels based on strain gage comparisons. The EPU unsteady pressure loads have been reduced to levels that are less than the prior loads at OLTP power levels. The maximum and minimum pressures are less than the prior OLTP maximum and minimum measurements. The EPU unsteady pressures and accelerations are below those at the OLTP levels, where the plant operated at for more than 25 years. The replacement steam dryer stress levels are effectively reduced to less than OLTP levels.

2) The steam line vibration g_{rms} measurements have been reduced to approximately 50% of the prior OLTP measurements without the ASBs. The acceleration (g) levels in the 140 to 160 Hz frequency range have been reduced to background levels.

3) The acoustic pressure oscillations from Target Rock safety relief valve are seen at lower thermal power levels as expected and have been reduced compared to measurements obtained prior to installation of the ASBs.

4) Extrapolation of the these measurements from 2874 MWt to full thermal power of 2957 MWt show that the acceleration levels will remain below the prior OLTP levels and the unsteady pressures in the steam lines will be at or below the prior OLTP levels.

Based on these conclusions, the unrestricted operation of the QC2 steam system at flows up to the full licensed thermal power of 2957 MWt is justified.

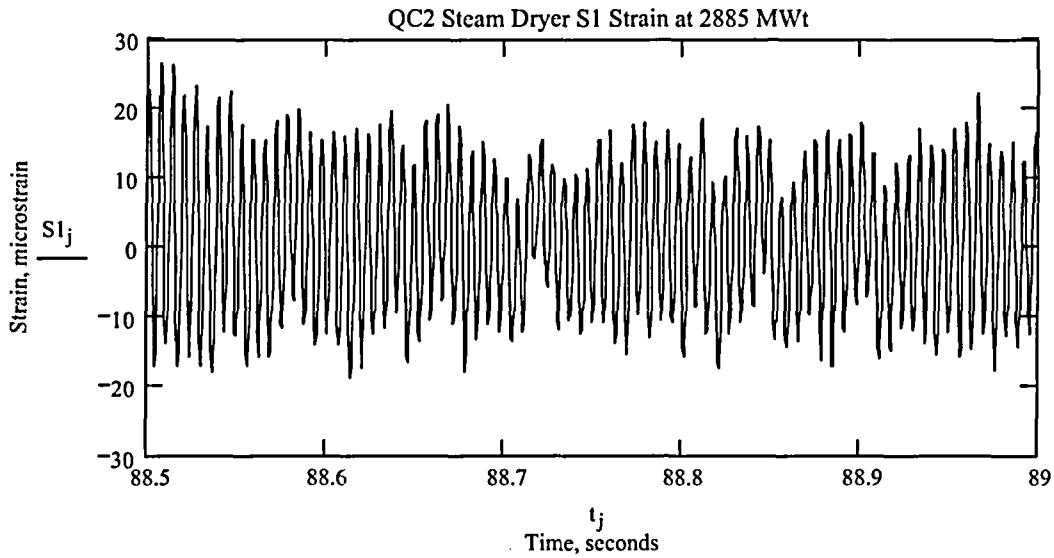
8. References

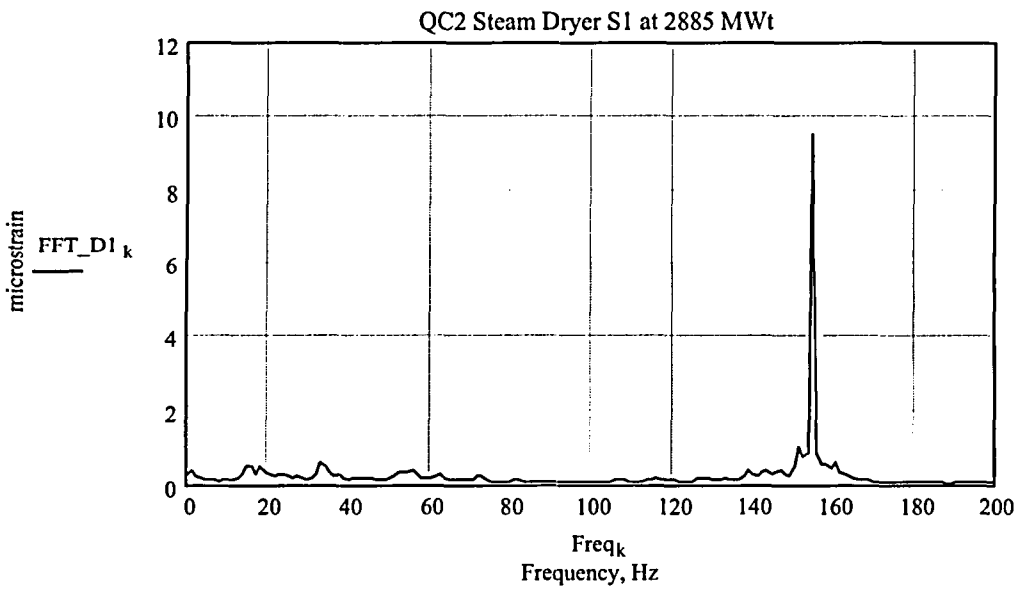
1. Exelon Report AM-2005-004, "Acoustic Circuit Validation Quad Cities Unit 2 Instrumented Steam Path Final Model Revision 930 MWe/2884 MWt Power Level," July 27, 2005.
2. Exelon Report AM-2005-015, "A Comparison of the Cumulative Mean Square Strain in the Application of the Modified 930 MWe Acoustic Circuit Model and FEA to the QC2 TC41 In-Vessel Test Condition," Revision 0, November 14, 2005.
3. SIA Calculation, QC-16Q-303, "Quad Cities Unit 2 ERV Vibration Testing," Revision 0, April 12, 2004.
4. SIA Report No. SIR-06-005, "Quad Cities ERV Accelerometer Data Reduction New Dryer Design," January 2006.
5. C.D.I. Report No. 06-08, "Mitigation of Pressure Oscillations in the Quad Cities Unit 2_Steam Delivery System: A Subscale Four Main Steam Line Investigation of Standpipe Behavior," Revision 2, March 2006. Proprietary
6. Fauske & Associates, LLC Report FAI/06-20, "Test Report for Exelon Full Scale Acoustic Damping Experiments," Revision 0, March 2006.
7. Exelon Report AM-2005-014, "Quad Cities Unit 2 New Steam Dryer Outage Startup Test Report," Revision 0, July 20, 2005.
8. SIA Calculation, SIR-06-199, "Quad Cities Unit 2 Strain Gage and Accelerometer Data Reduction Summary, Revision 1, May 2006.
9. Exelon Procedure, TIC-1463, "Quad Cities Unit 2 Power Ascension Test Procedure for the Acoustic Side Branch (ASB) Installation," Revision 0.

Attachment A

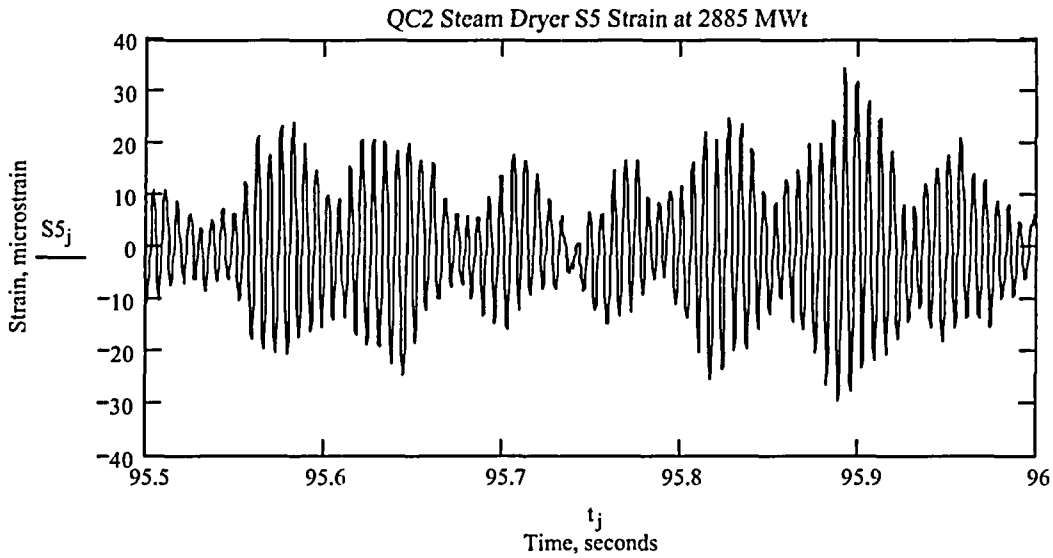
QC2 Replacement Steam Dryer Strain Gage Measurements from 2005 Startup Test

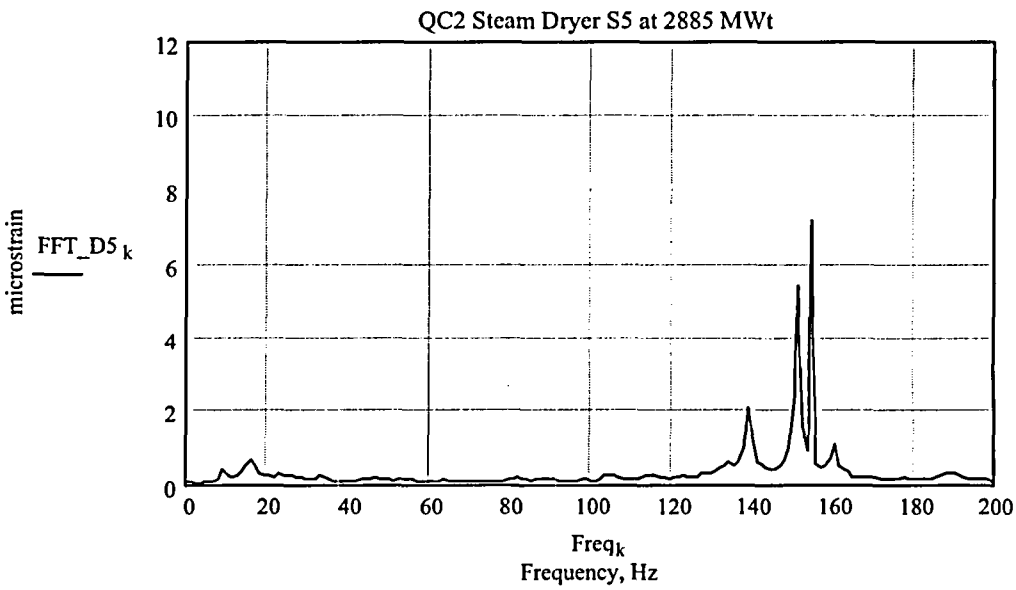
S1 Strain Gage on Skirt Curved Panel:



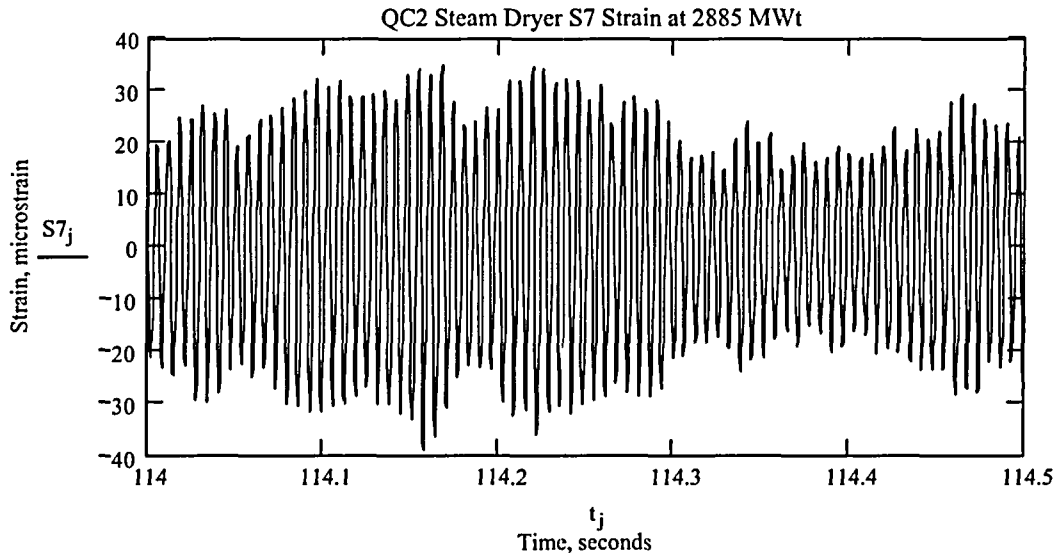


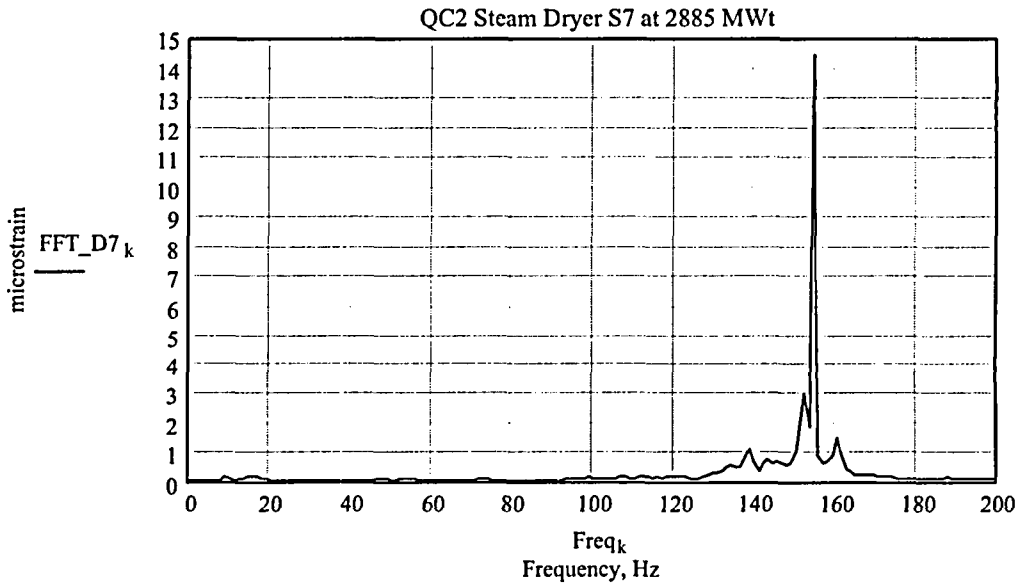
S5 Strain Gage on Dryer Hood Closure Panel:



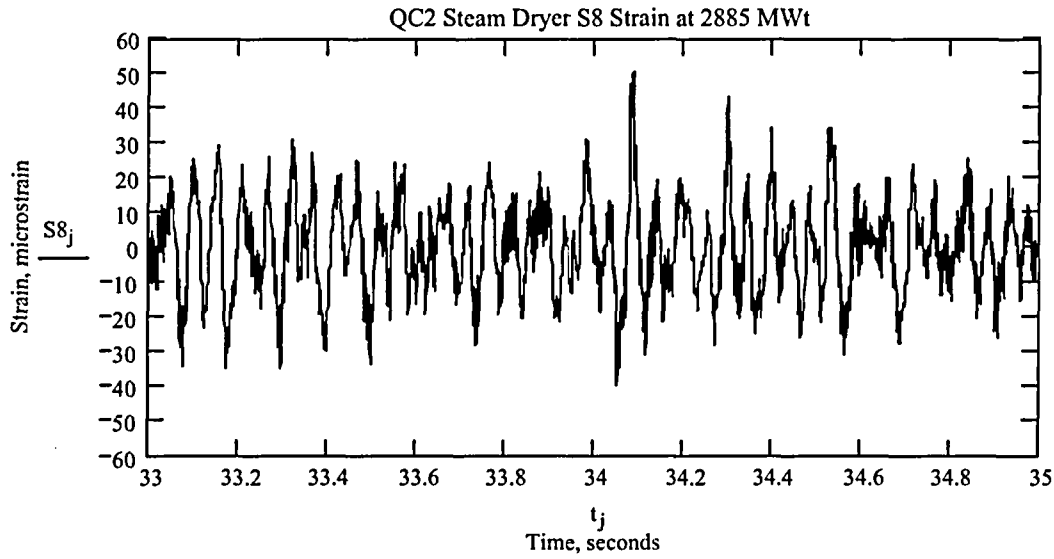


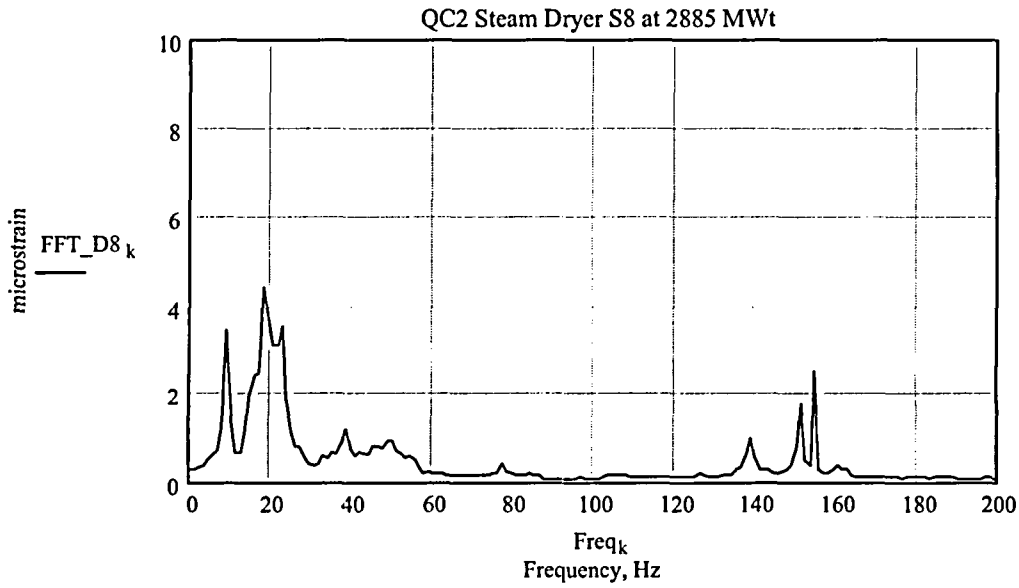
S7 Strain Gage on Outer Hood Top Panel Curved Section:



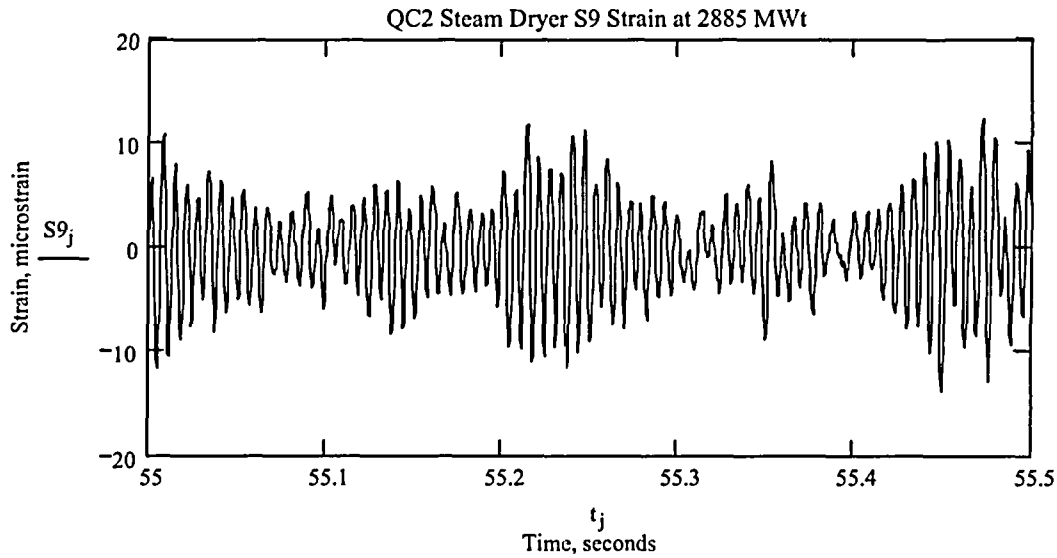


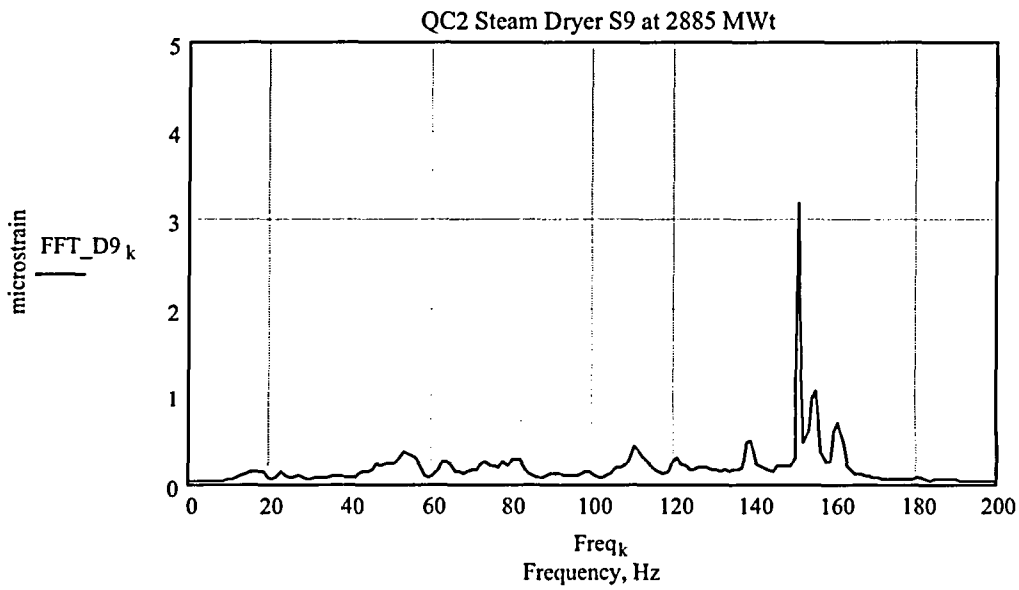
S8 Strain Gage on Skirt Flat Panel:





S9 Strain Gage on Outer Hood Opposite A MS Nozzle:

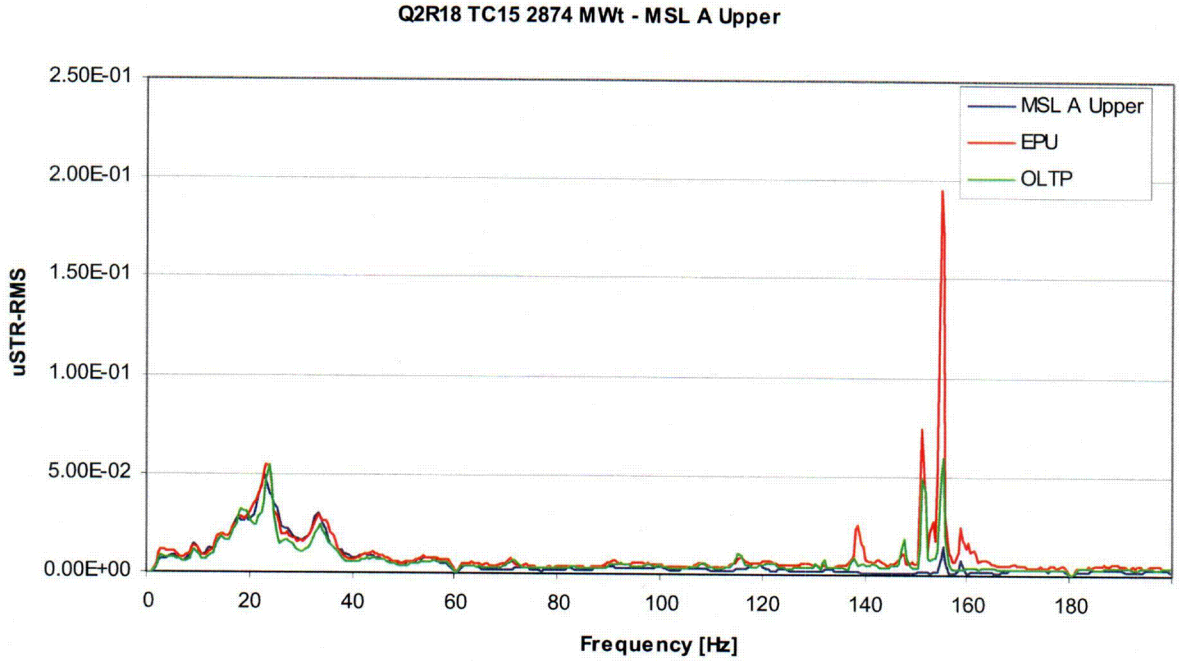


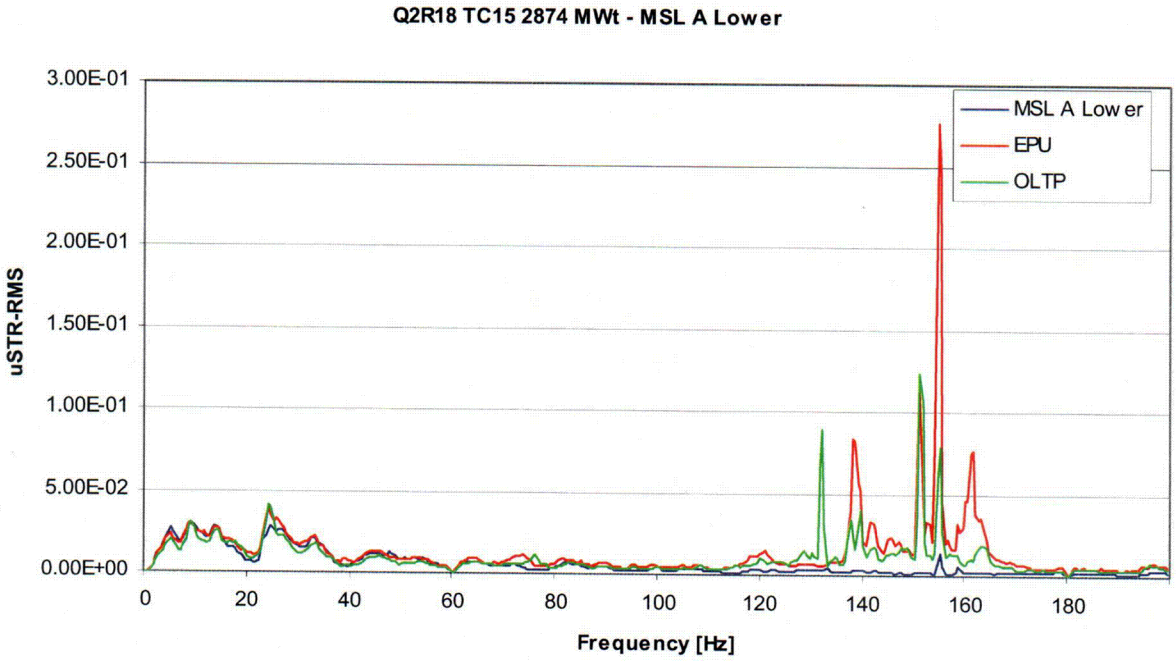


Attachment B

QC2 ASB Modification Startup Test Results for TC18, 2874 MWt

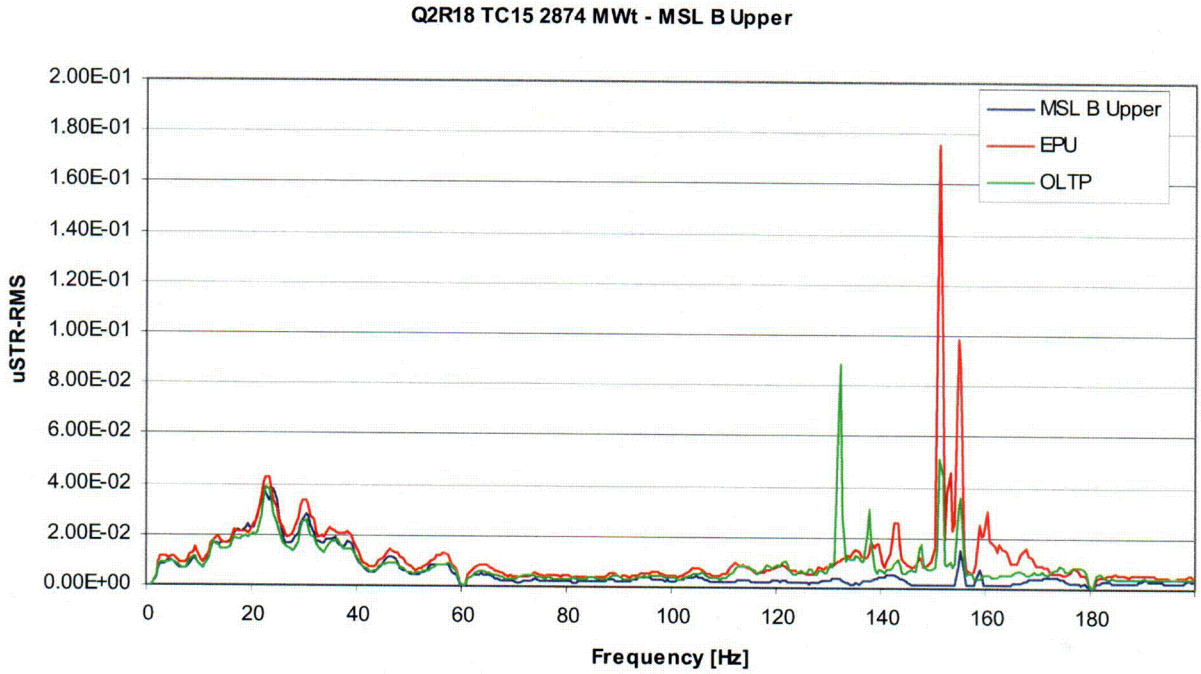
A Steam Line Strain Gage Spectra at 2874 MWt:

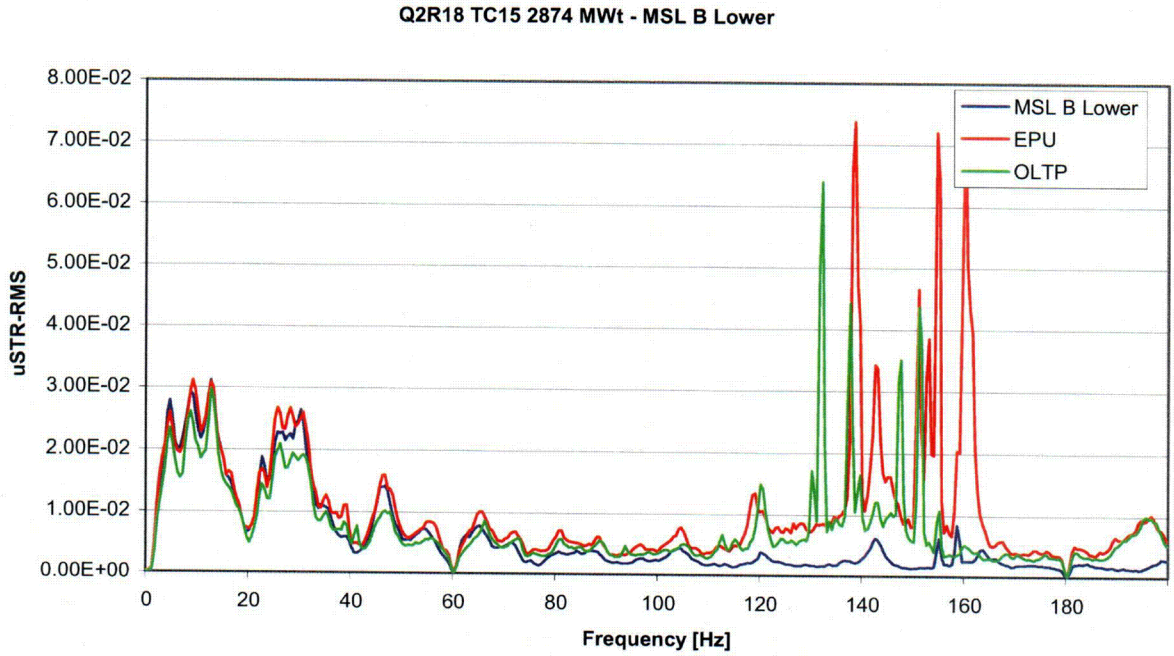




C04

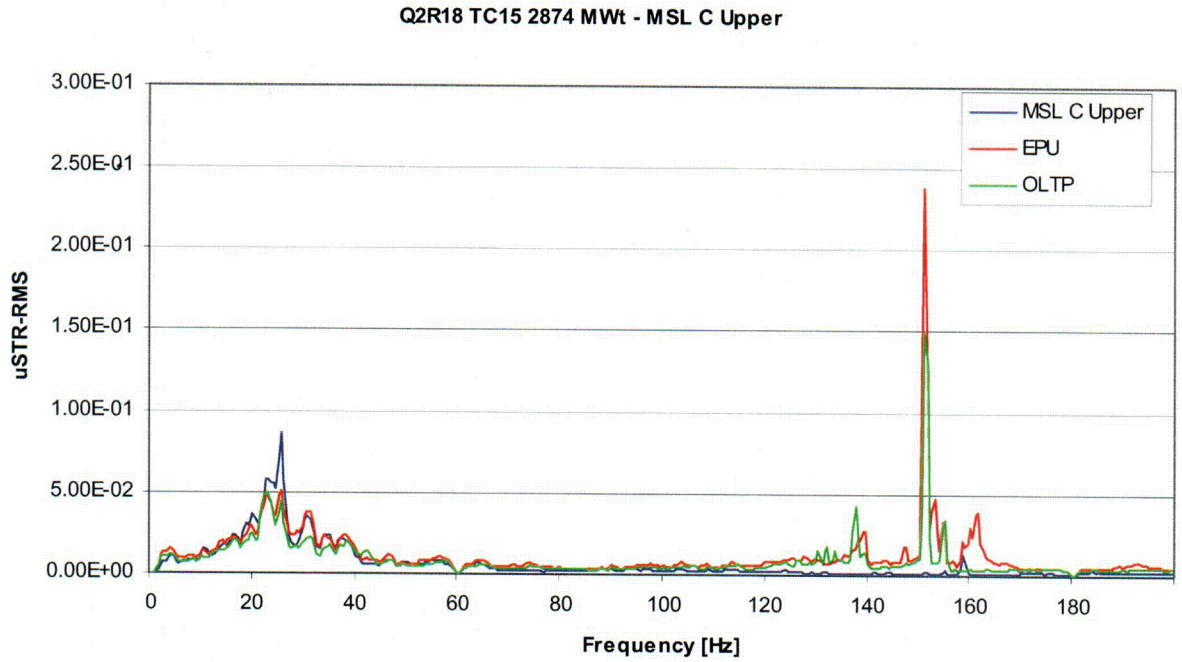
B Steam Line Strain Gage Spectra at 2874 MWt:

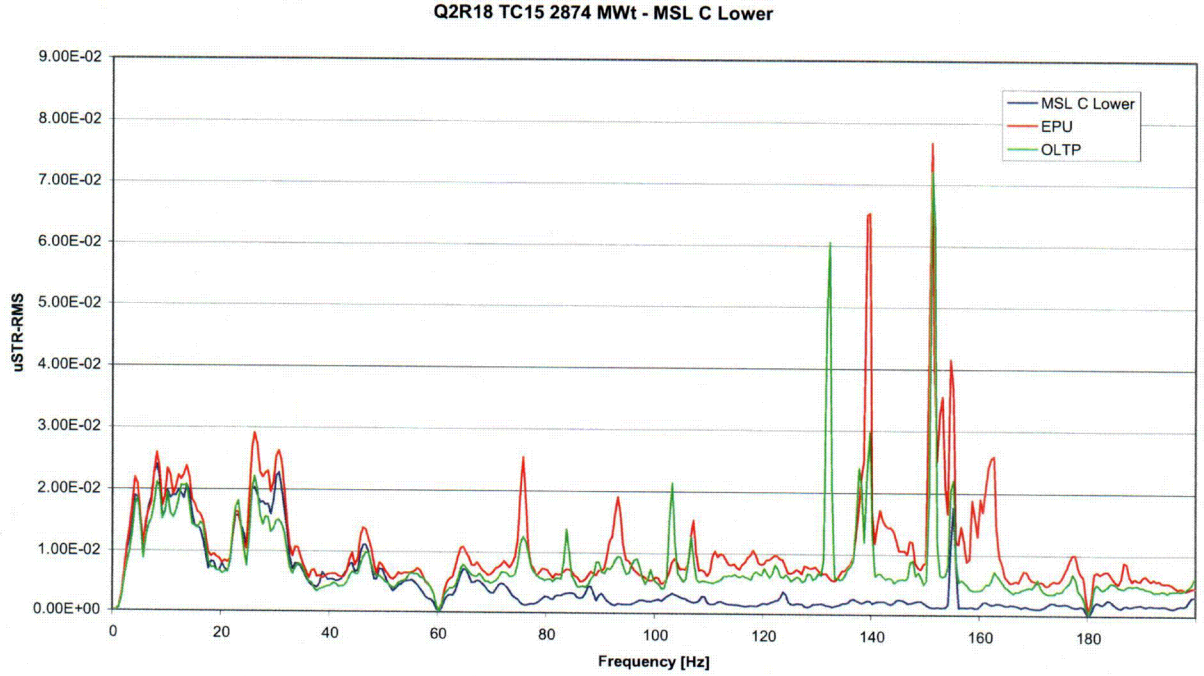




C05

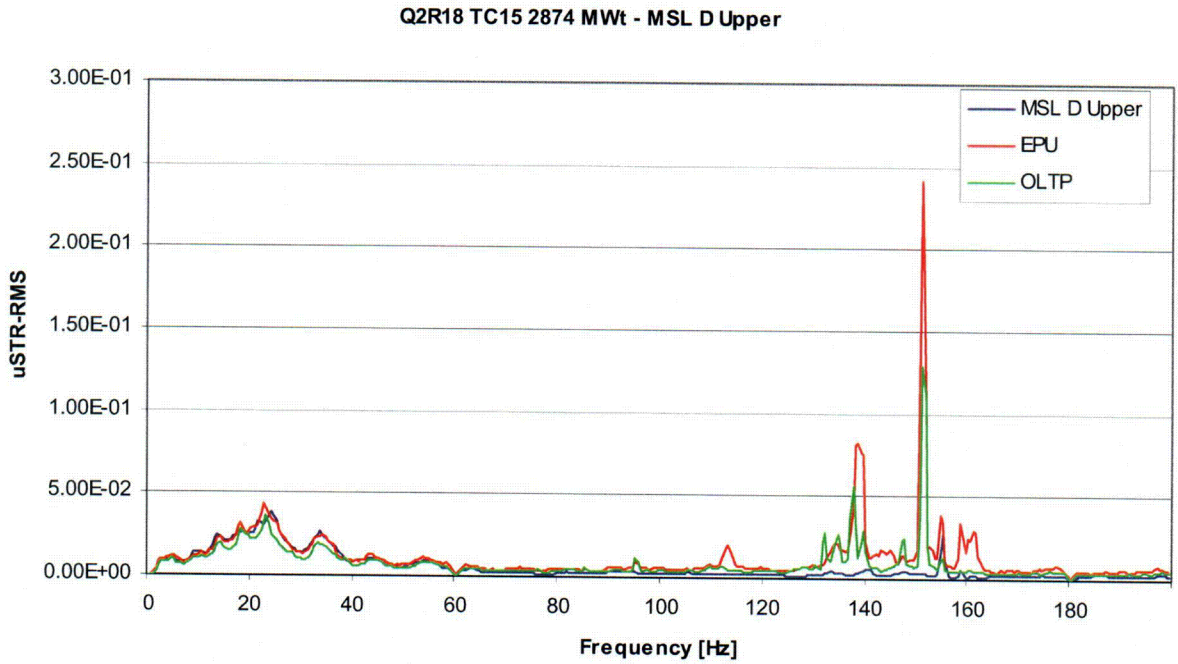
C Steam Line Strain Gage Spectra at 2874 MWt:

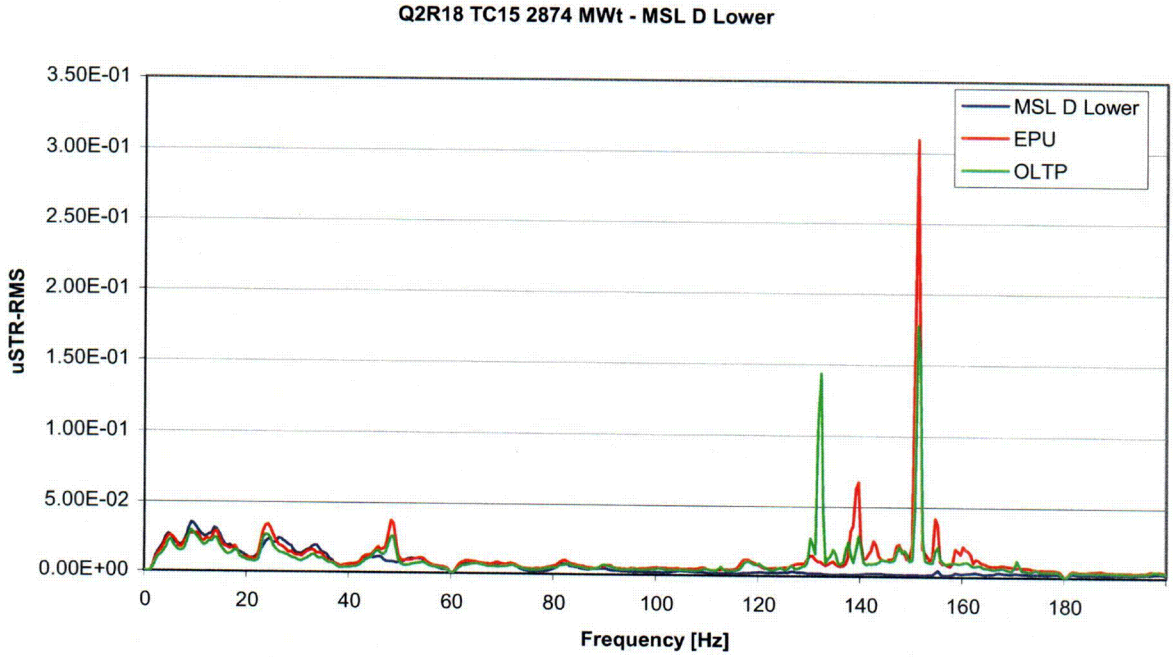




C06

D Steam Line Strain Gage Spectra at 2874 MWt:

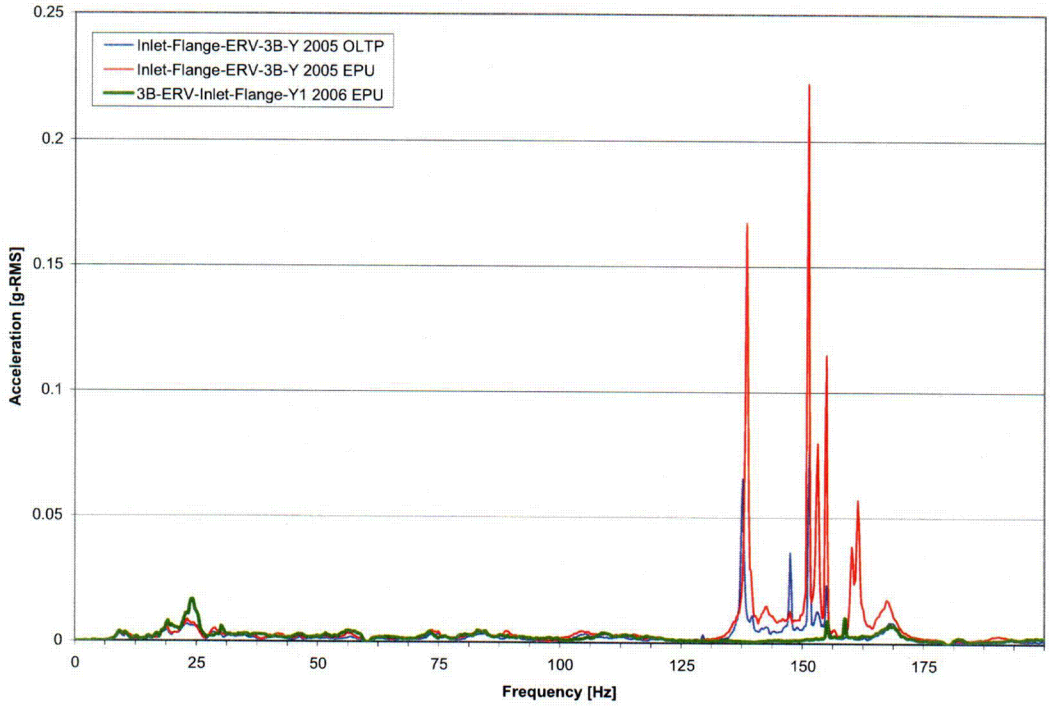




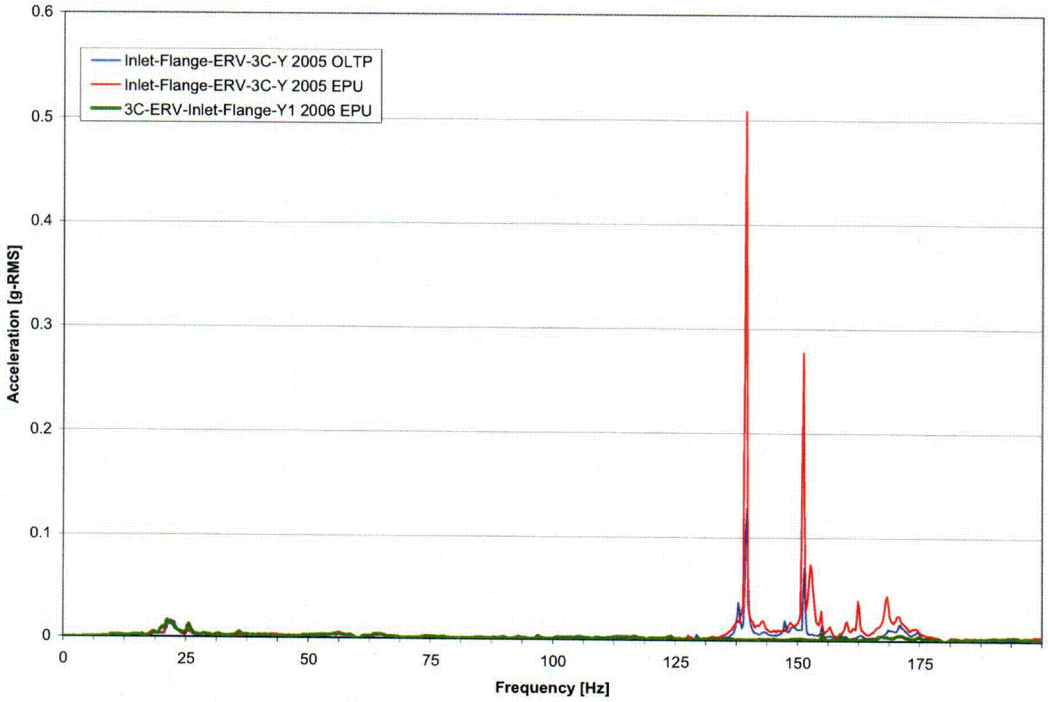
C07

ERV Inlet Flange Vertical Acceleration Spectra at 2874 MWt:

ERV 3B Y-Direction Acceleration Spectra



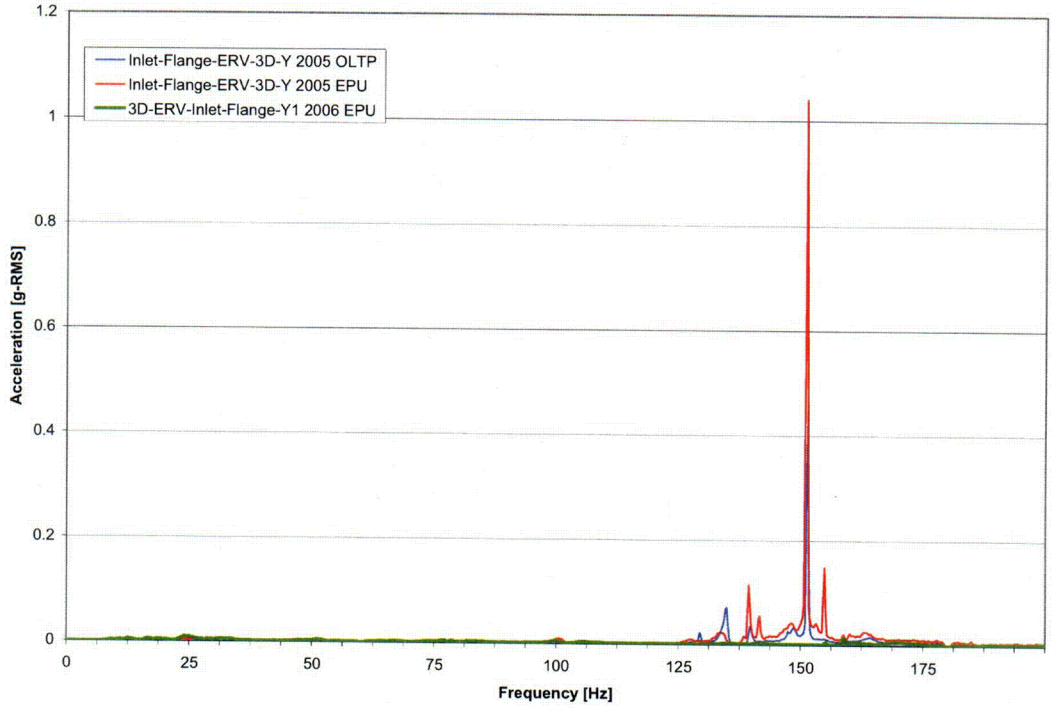
ERV 3C Y-Direction Acceleration Spectra



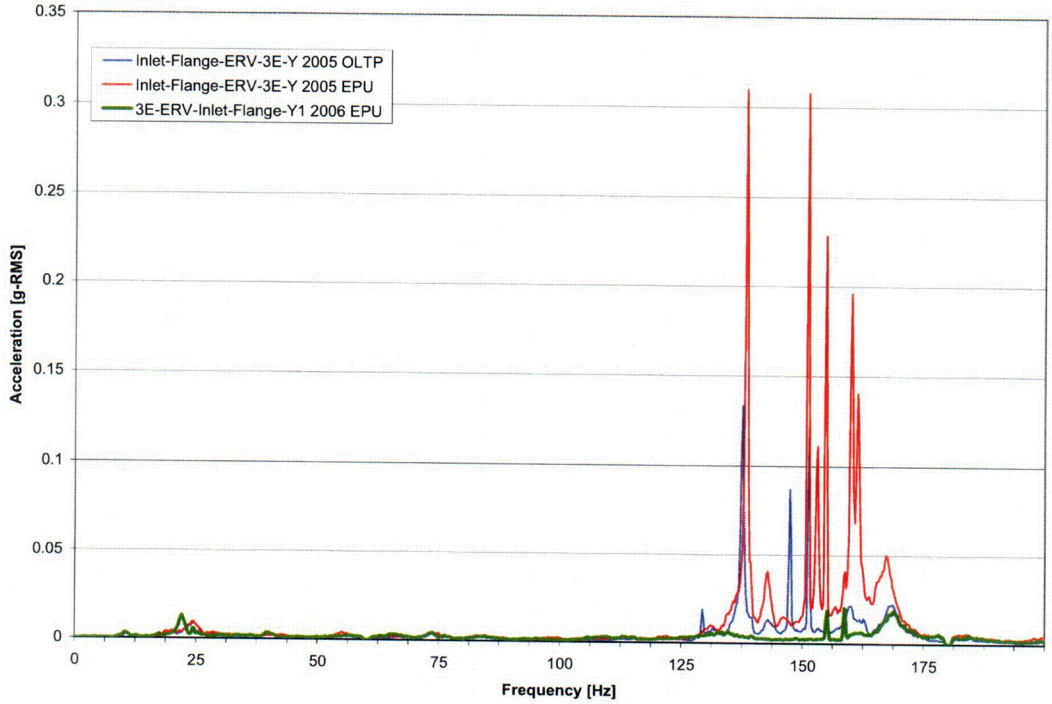
C08

ERV Inlet Flange Vertical Acceleration Spectra at 2874 MWt:

ERV 3D Y-Direction Acceleration Spectra



ERV 3E Y-Direction Acceleration Spectra

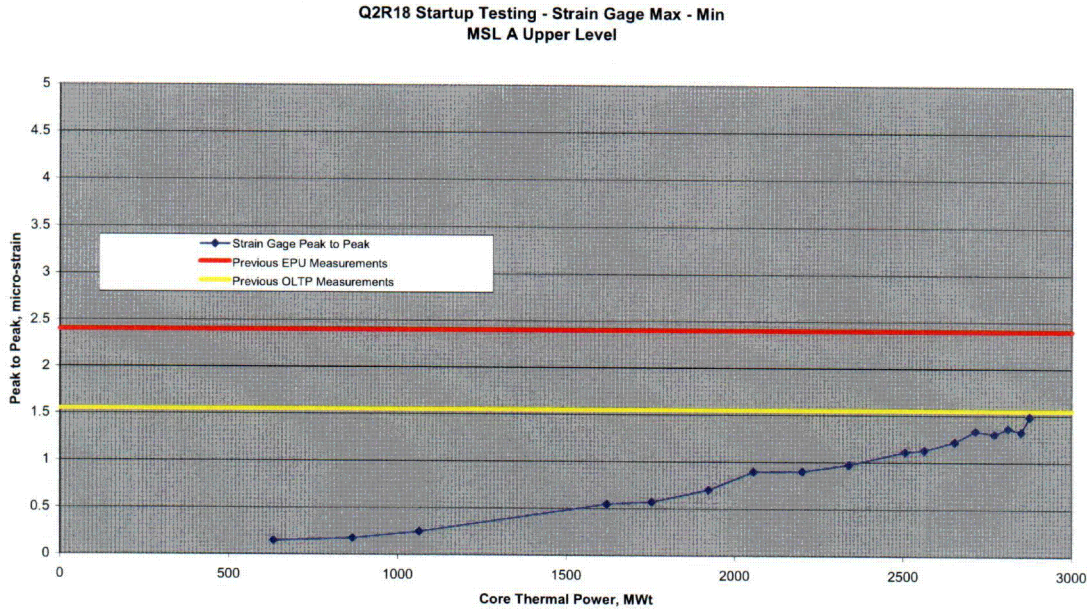


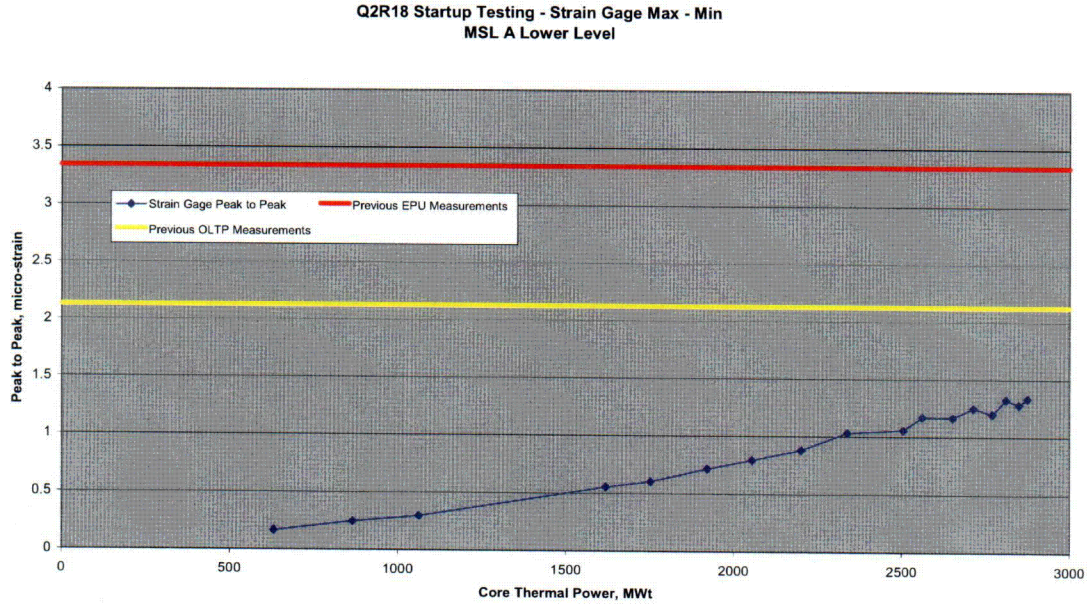
C09

Attachment C

Q2R18 Steam Line Strain Gage and Accelerometer Measurement Trends with Thermal Power

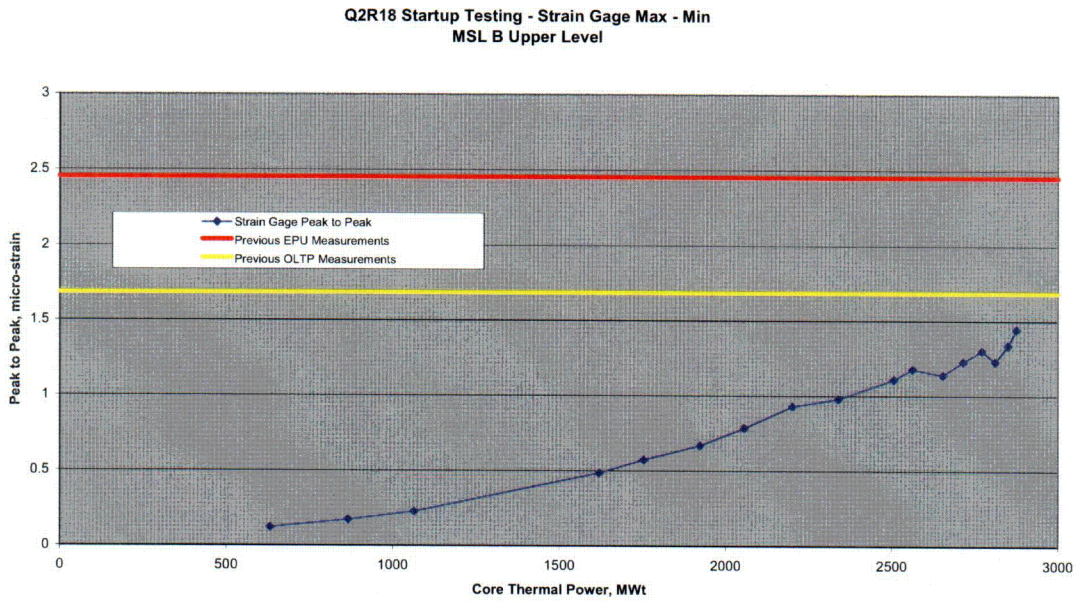
MSL A Strain Gage Measurements Maximum-Minimum Trends:

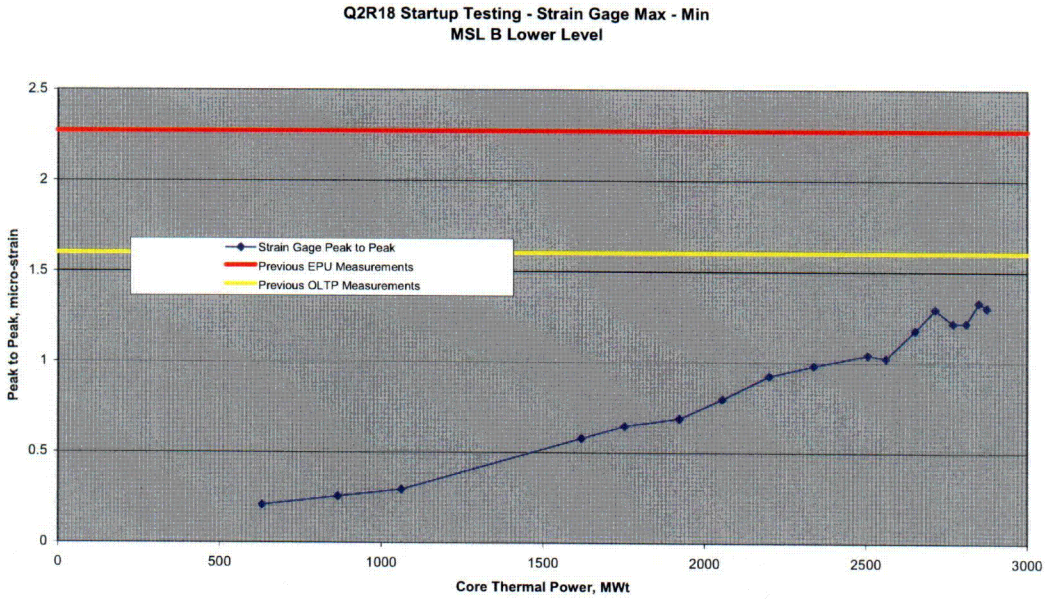




C10

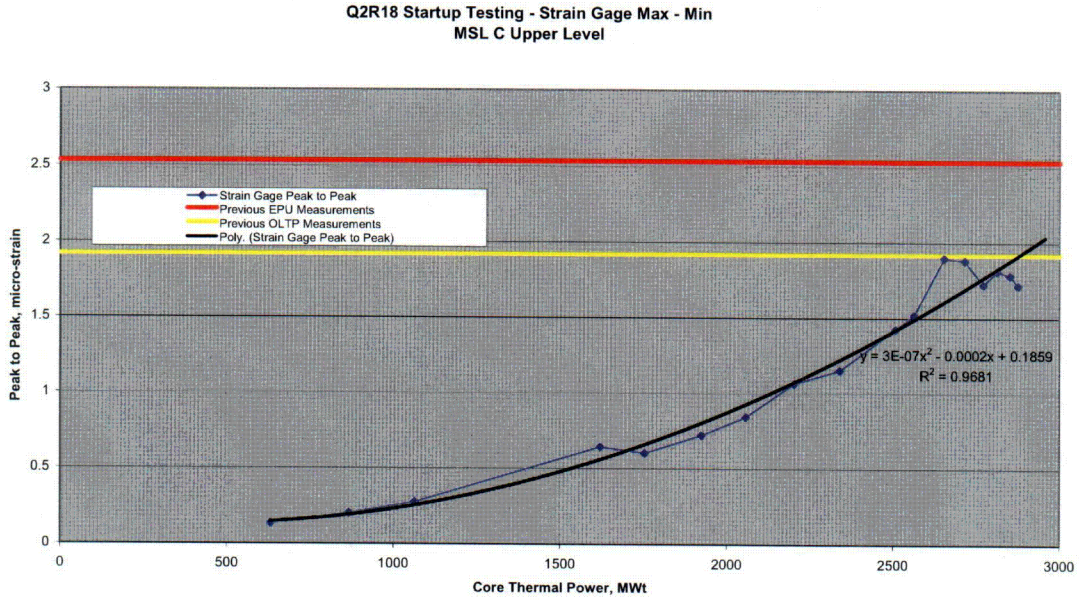
MSL B Strain Gage Measurements Maximum-Minimum Trends:

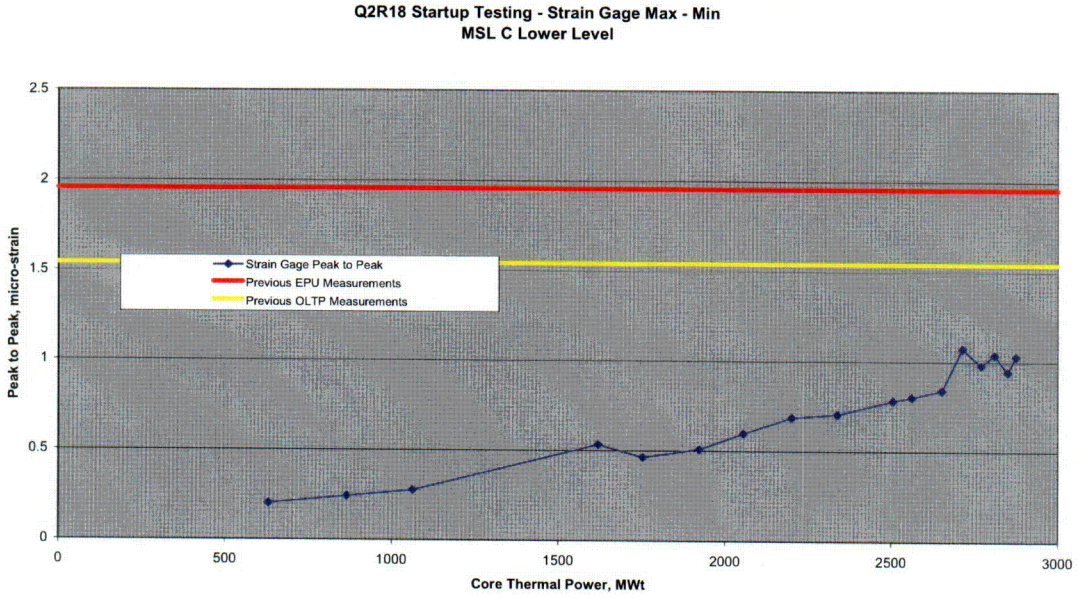




C11

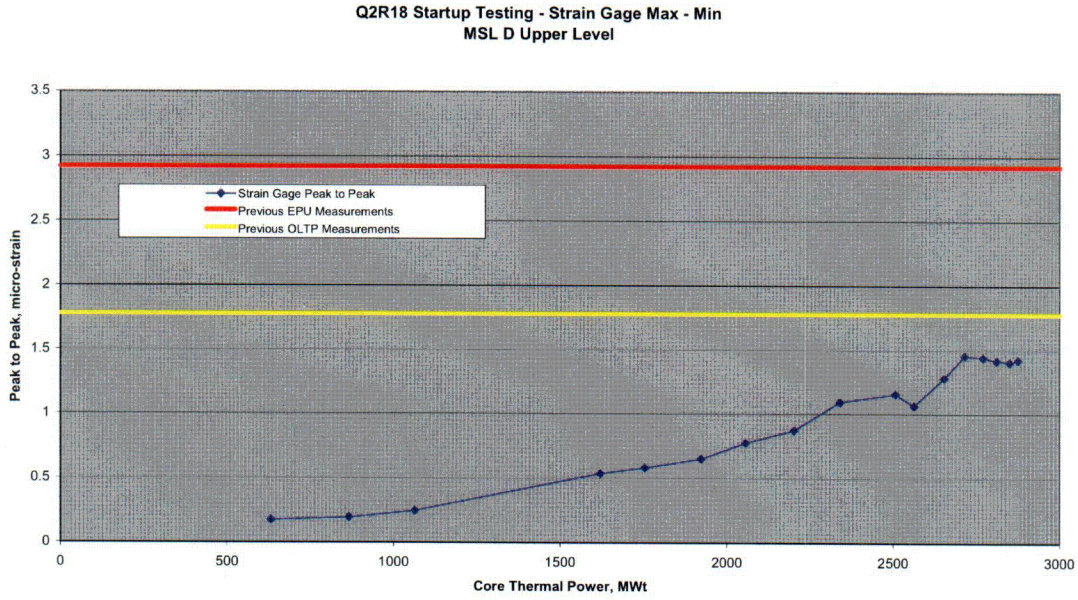
MSL C Strain Gage Measurements Maximum-Minimum Trends:

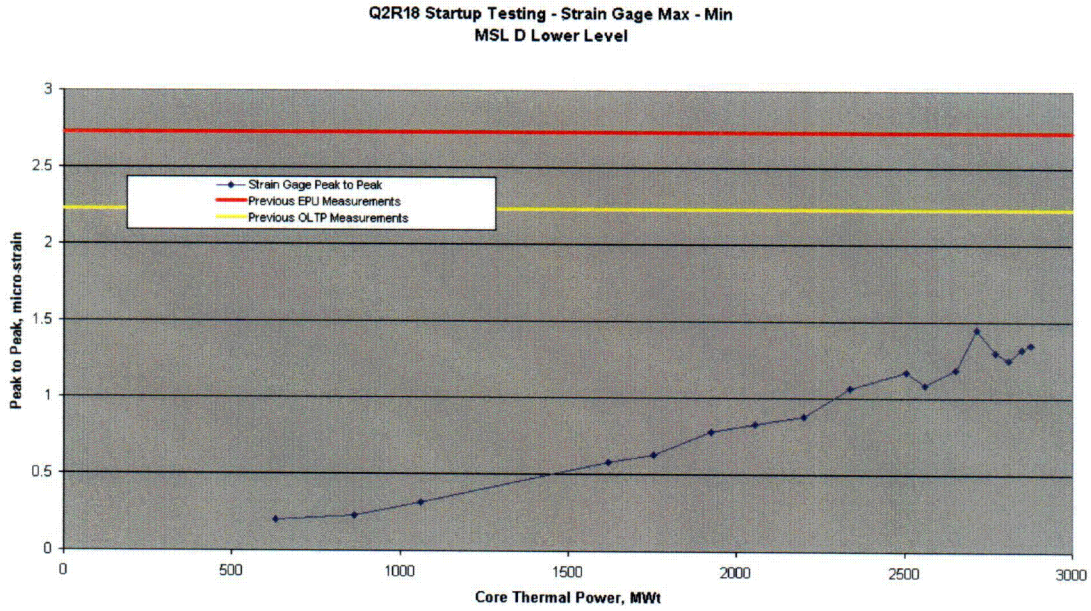




C12

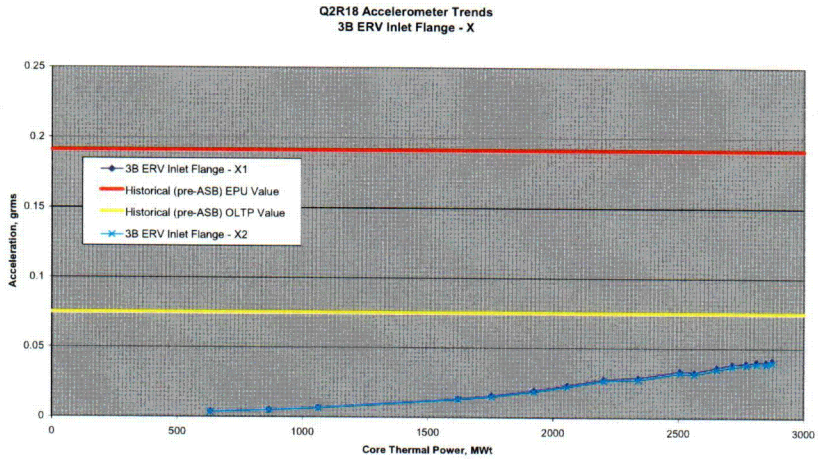
MSL D Strain Gage Measurements Maximum-Minimum Trends:

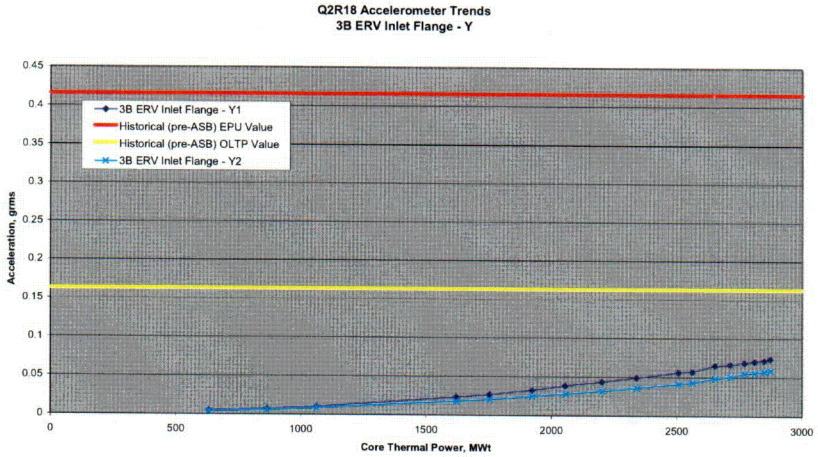


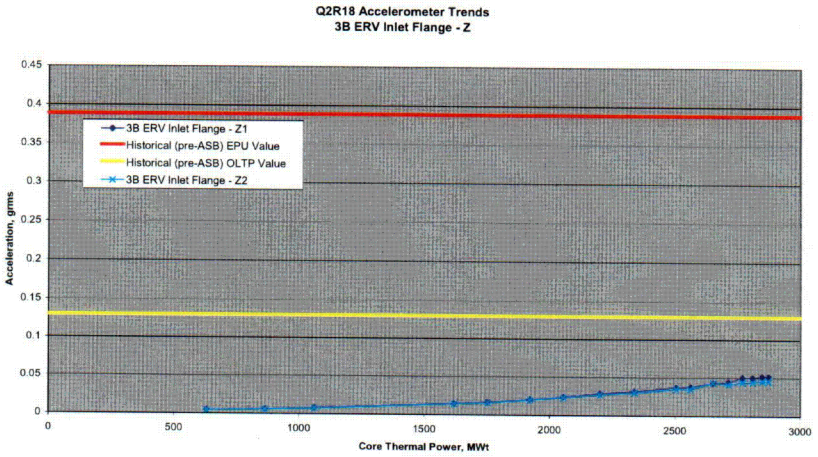


C13

3B ERV Inlet Flange Acceleration Trend:

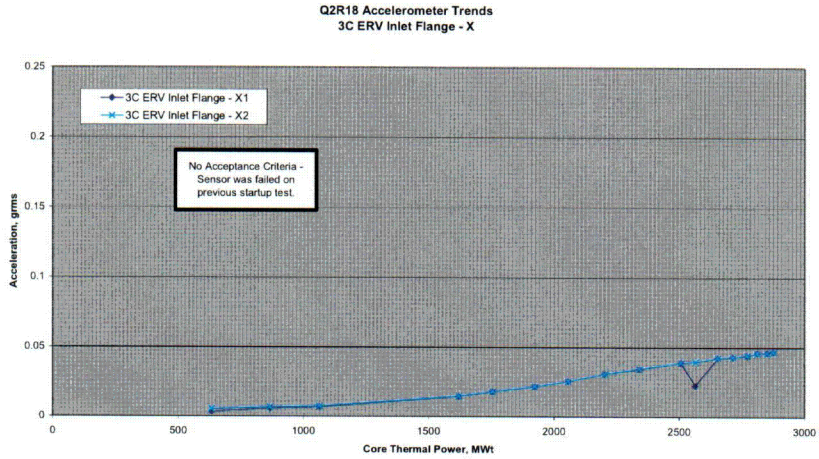


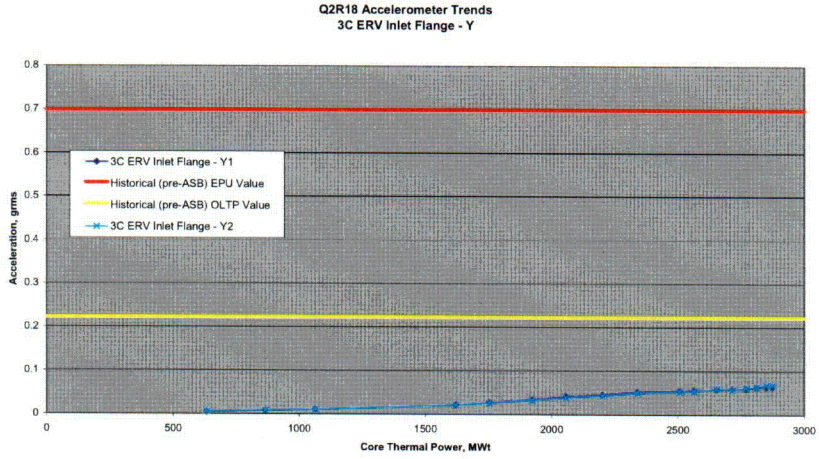


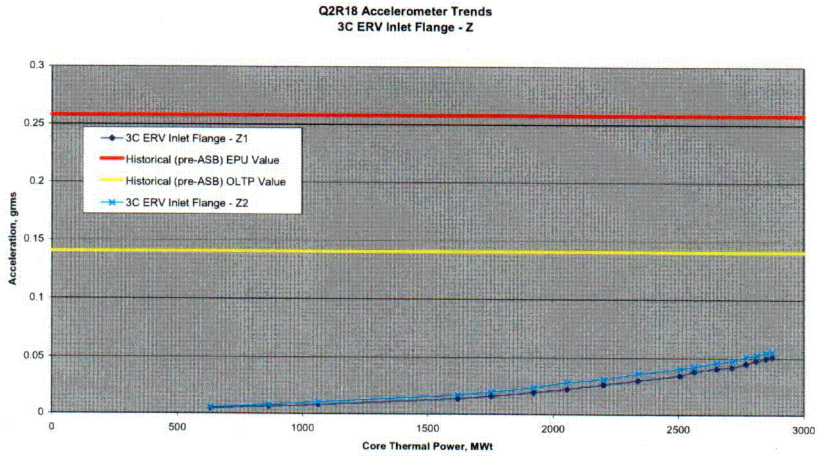


C14

3C ERV Inlet Flange Acceleration Trend:

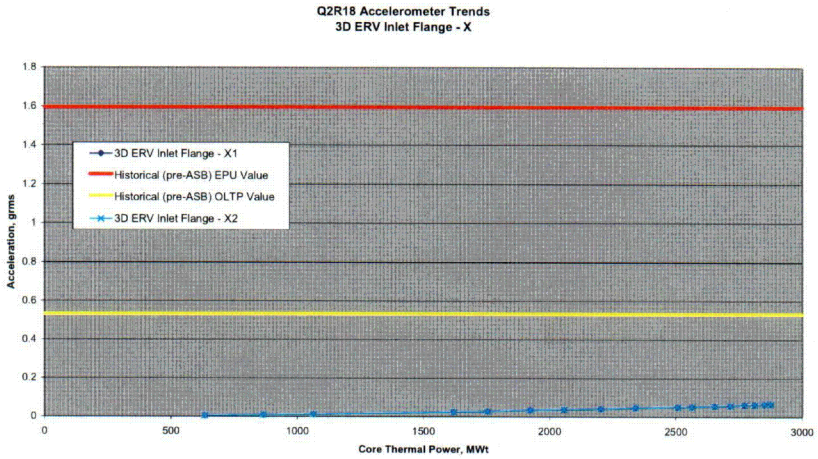


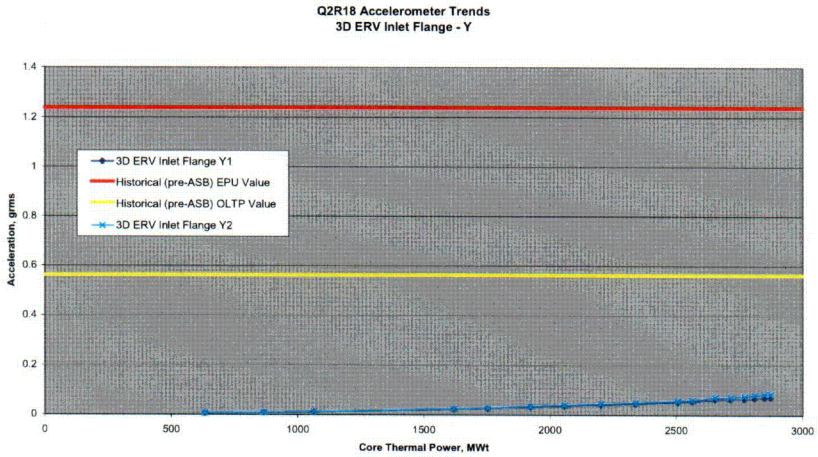


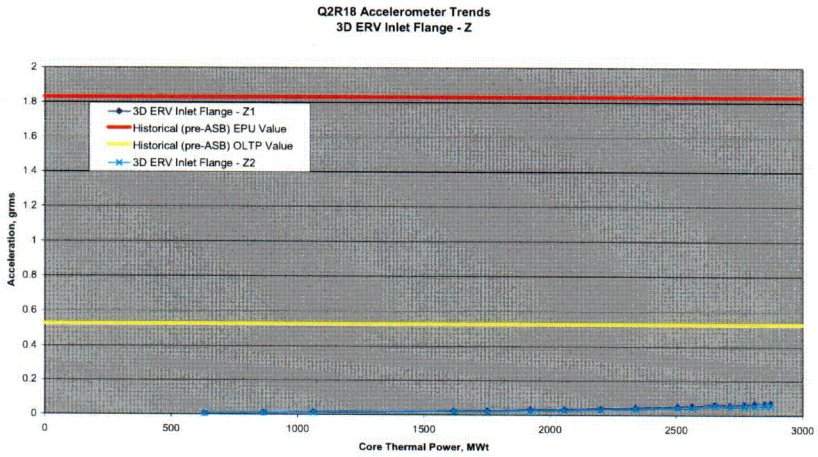


C15

3D ERV Inlet Flange Acceleration Trend:

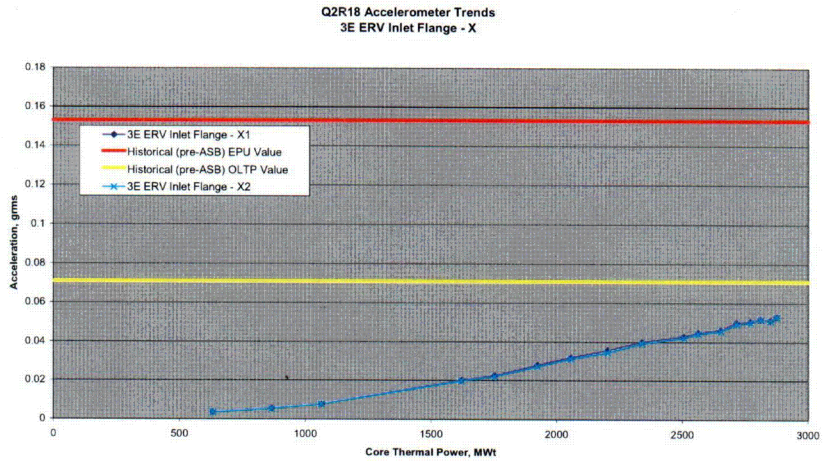


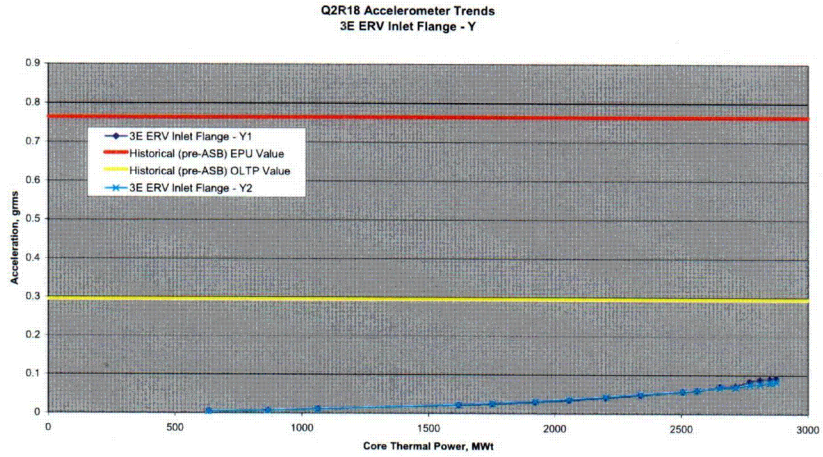


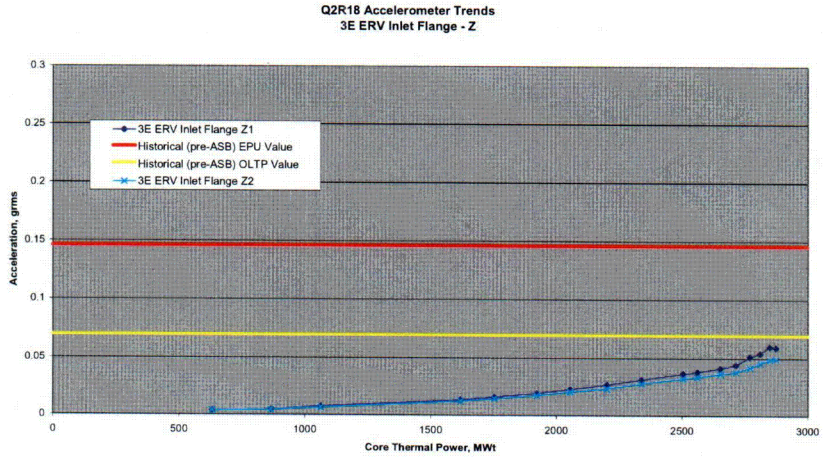


C16

3E ERV Inlet Flange Acceleration Trend:

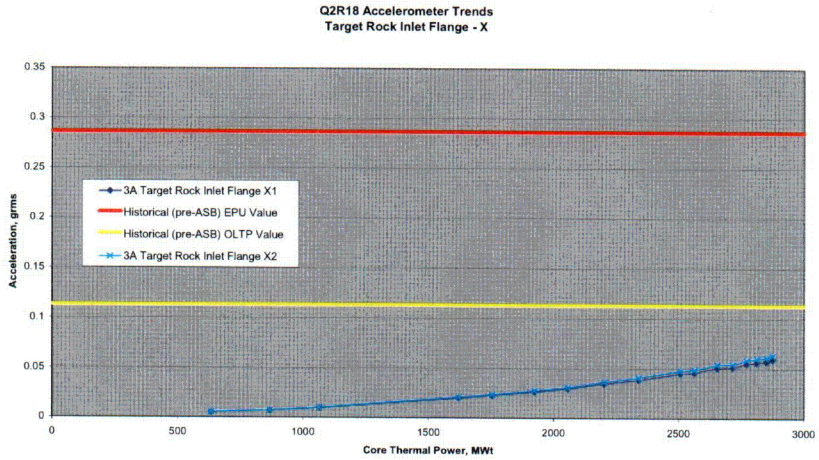


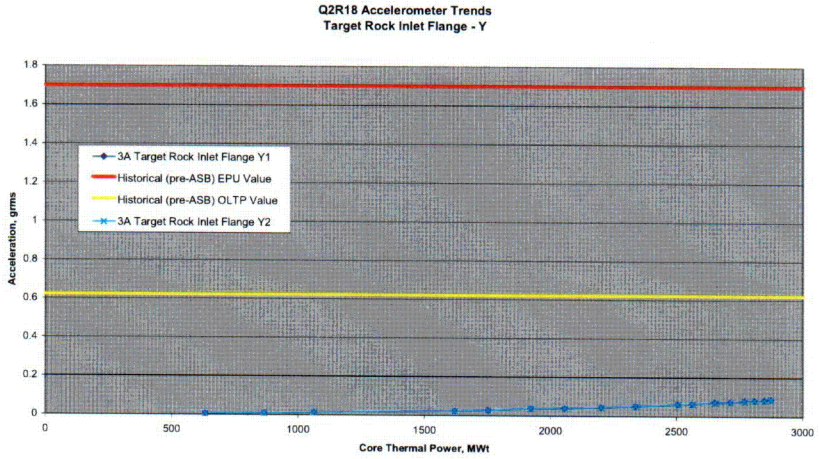


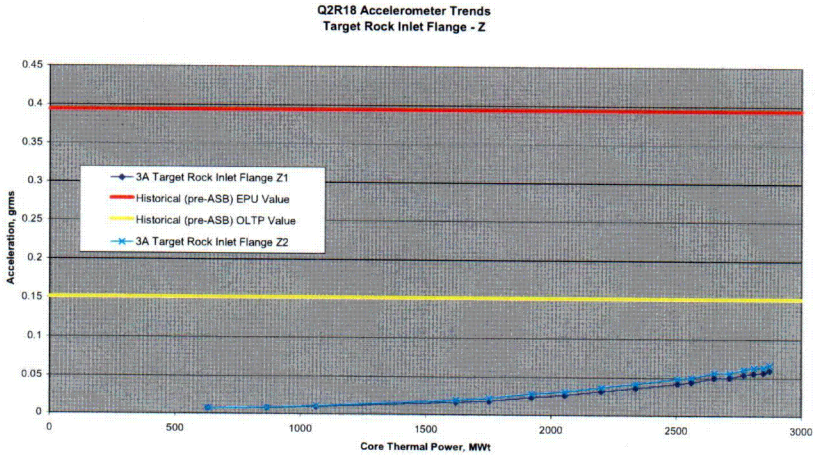


C17

3A Target Rock Safety Relief Valve Inlet Flange Acceleration Trend:

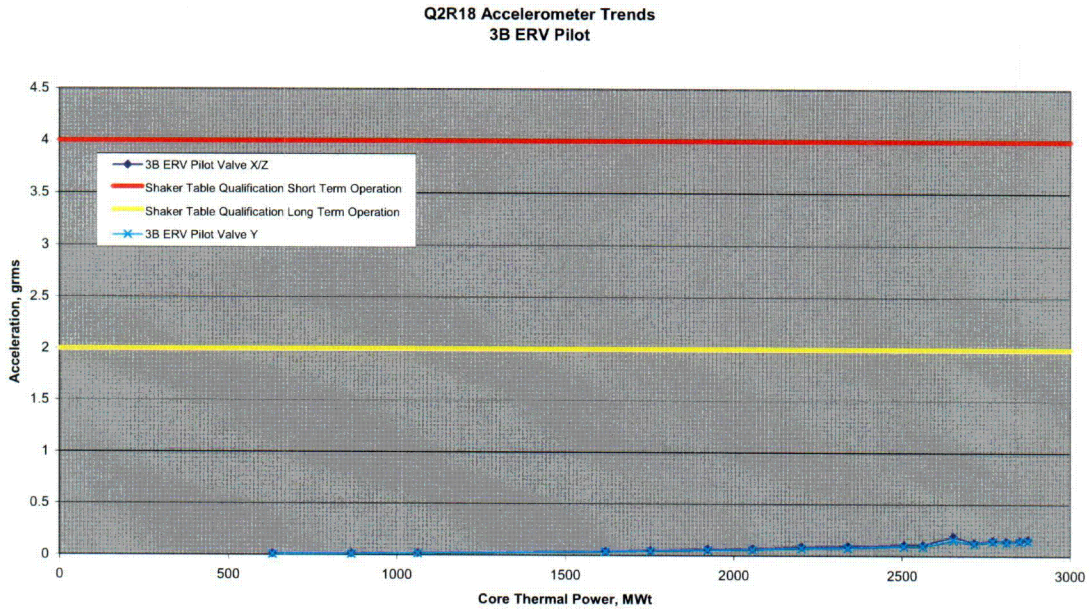




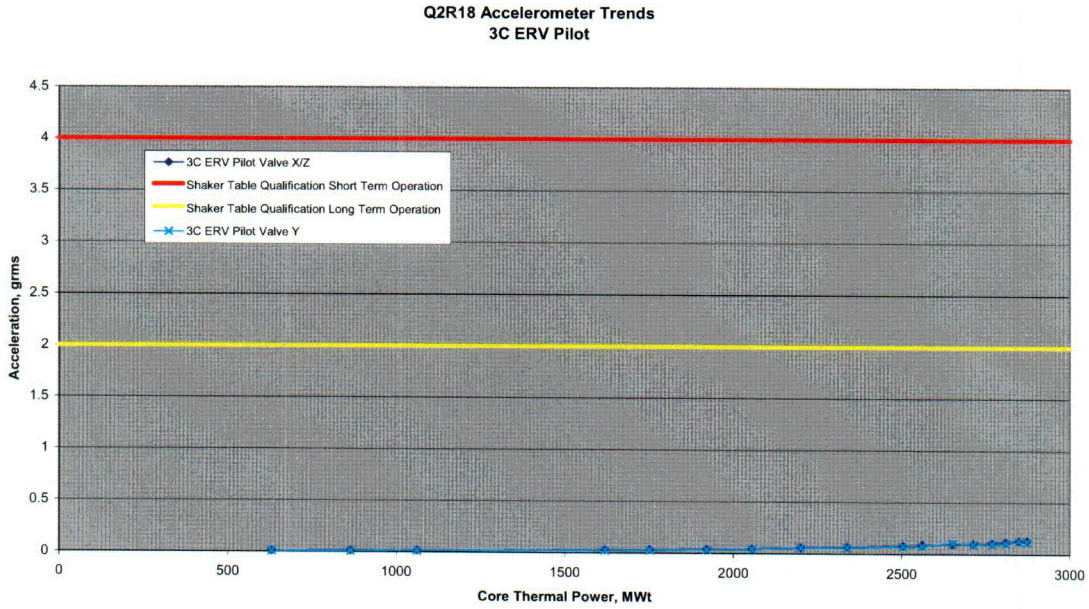


C18

3B ERV Pilot Acceleration Trend:

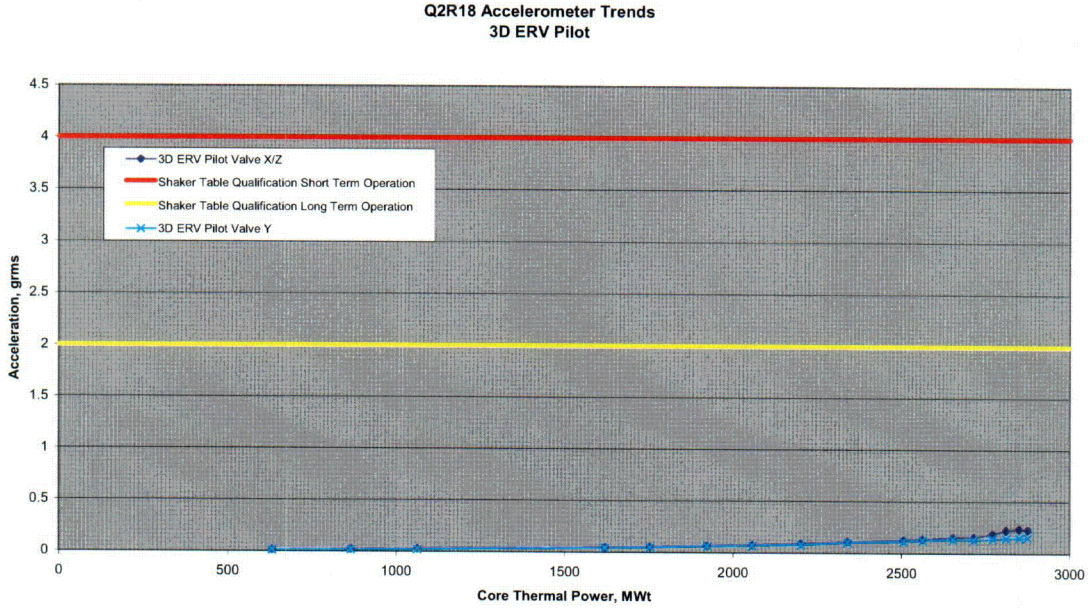


3C ERV Pilot Acceleration Trend:

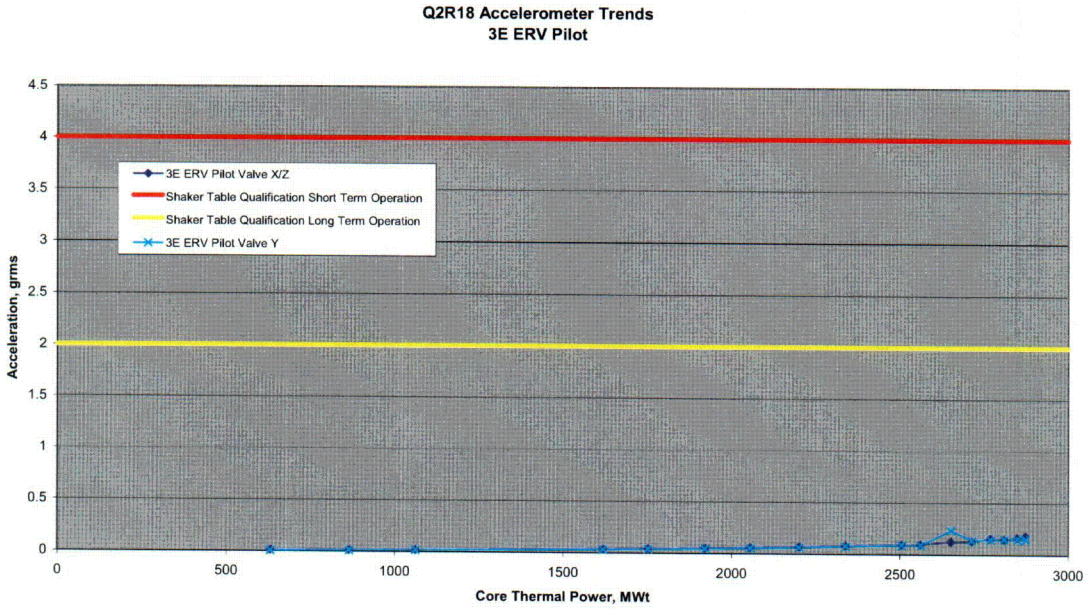


C19

3D ERV Pilot Acceleration Trend:

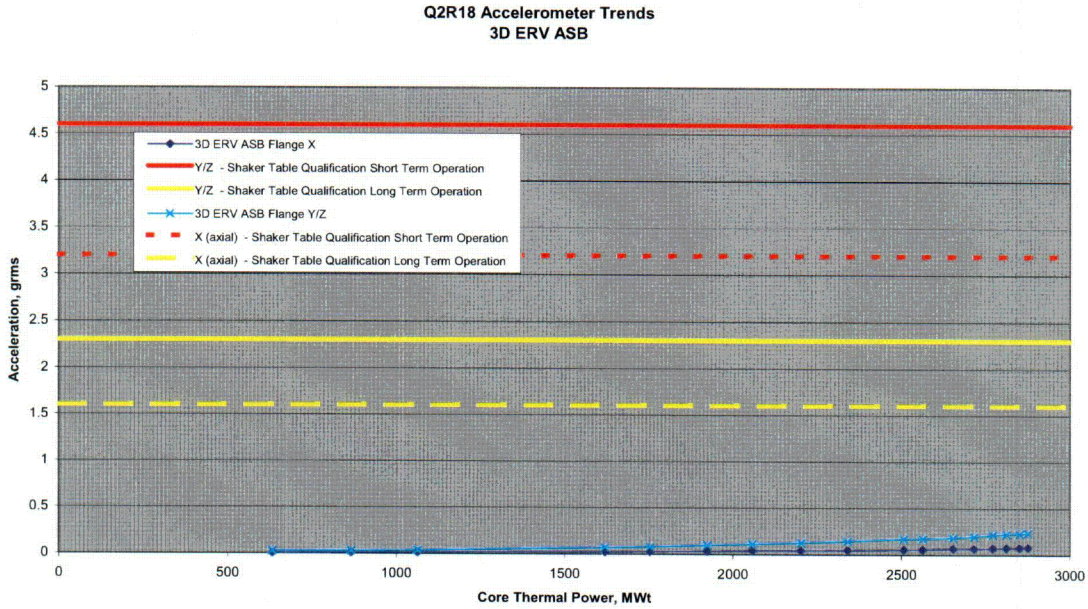


3E ERV Pilot Acceleration Trend:



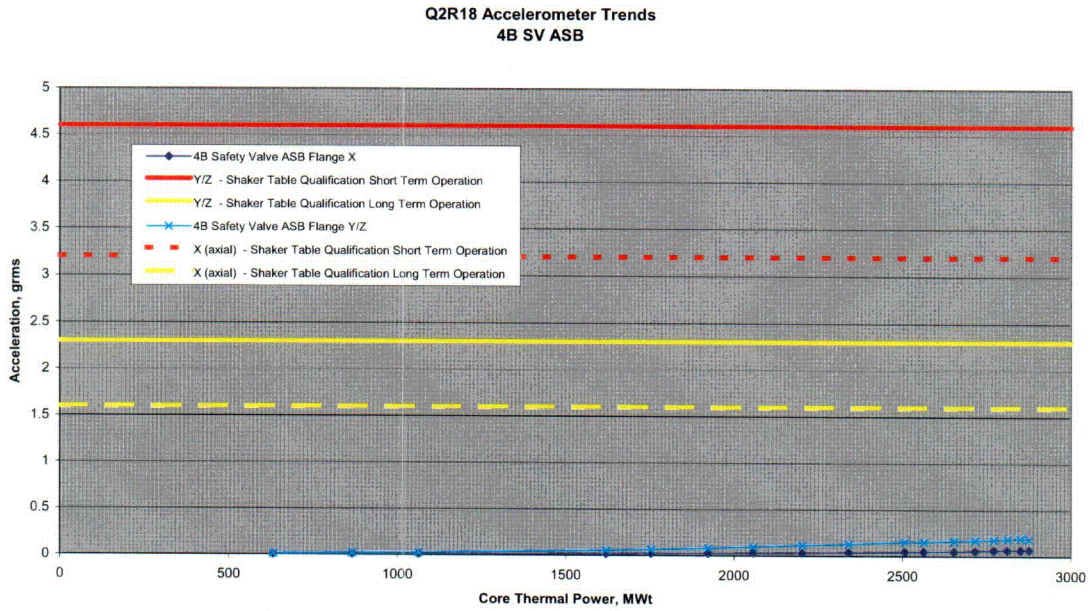
C20

3D ERV ASB Acceleration Trend:

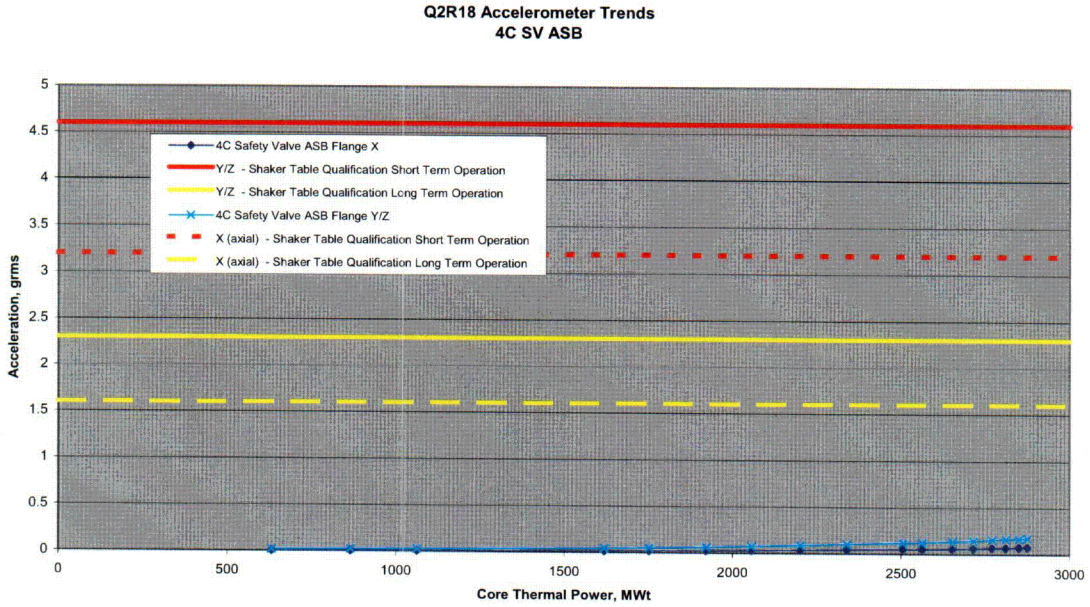


C21

4B Safety Valve ASB Acceleration Trend:

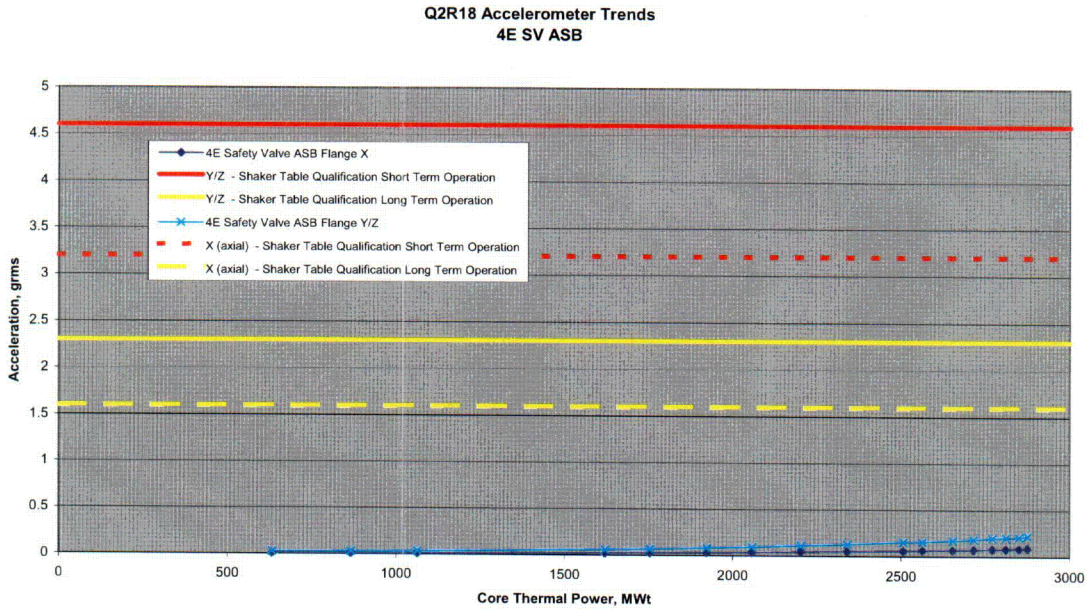


4C Safety Valve ASB Acceleration Trend:

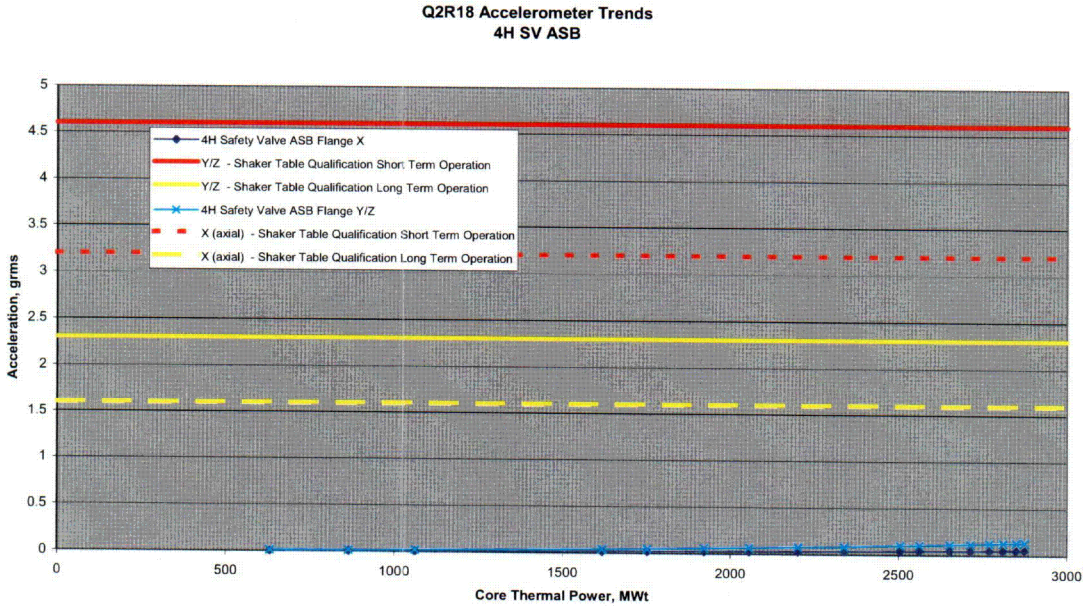


C22

4E Safety Valve ASB Acceleration Trend:



4H Safety Valve ASB Acceleration Trend:



C23