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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 1 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 a maintenance outage in May 2006 for Quad Cities Nuclear Power Station (QCNPS) Unit 1, 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. David Gullott at (630) 657-2819.

Respectfully,

Kenneth M. Nicely

Kenneth M. Nicely
Manager – Licensing

A001

Attachment: Exelon Report AM-2006-003, "Quad Cities Unit 1 Main Steam Line Acoustic Source Identification and Load Reduction," Revision 0

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

ATTACHMENT

Exelon Report AM-2006-003, "Quad Cities Unit 1 Main Steam Line Acoustic Source Identification and Load Reduction," Revision 0

Quad Cities Unit 1 Main Steam Line Acoustic Source Identification and Load Reduction

Document Number AM-2006-003
Revision 0

Nuclear Engineering Department
Exelon Nuclear Generating Co.

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(Date Issued)

Abstract

This report documents the results of extensive data collection on the Quad Cities Unit 1 Main Steam Lines after the installation of the acoustic side branch (ASB) modifications to the pressure relief branch line lines. The modifications were installed on the Electromatic Relief Valve (ERV) and Main Steam Safety Valve (MSSV) branch lines. The subsequent post-modification testing confirmed the effectiveness of the modifications. Review of the data confirmed that vortex shedding coupled column resonance in the relief and safety valve standpipes was significantly reduced at the power levels tested.

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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. The sources of these pressure oscillations were identified in Reference 1 as being the ERVs and main steam safety valve (MSSV) standpipes. 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 Quad Cities Unit 2 power ascension test data concluded very strong acoustic sources in the 140-160 Hz range accounted for the oscillating pressure loading on the dryer and the remainder of the steam path. Subscale testing performed by Continuum Dynamics, Inc. identified the likely acoustic sources as being the ERV and main steam safety valve (MSSV) standpipes. Steam line strain and accelerometer measurements confirmed the ERV and MSSV standpipes as the sources. The standpipe column resonance frequency is excited by the vortex shedding frequency at EPU steam flow rates producing the oscillating pressures that caused the fatigue damage to the steam dryer and steam line components. Prior main steam line vibration measurements as documented in References 2 and 3 have demonstrated these same sources were active in Quad Cities Unit 1.

An acoustic side branch (ASB) was designed to decouple the standpipe column resonance frequency from the vortex shedding frequency. The ASB was also designed with acoustic damping to further suppress potential acoustic response at non-EPU flow rates. The effectiveness of the ASB modification in reducing the acoustic loads in the main steam system was demonstrated during the Quad Cities Unit 2 power ascension testing performed in the spring of 2006 and documented in Reference 1. The ASB modifications proved to be highly effective in reducing the acoustic loads. Identical ASB modifications were installed in the Quad Cities Unit 1 main steam standpipes in Q1M19, May 2006.

This report provides a summary of the subsequent start-up testing results and confirms the effectiveness of the ASB modification on Quad Cities Unit 1.

2. Main Steam System Acoustic Load Reduction

The Quad Cities Unit 1 ASB designs and locations were similar to those installed in the Quad Cities Unit 2 steam system. The 24" long ASBs were installed in the MSSV standpipes for the B, C and D steam lines. For the A steam line, the lengths of the ASBs installed in the 4A and the 4E MSSV standpipes were reduced by 6" and 12" to reduce the potential for these standpipes to acoustically couple with the Target Rock valve standpipe. The 34" long ASBs were installed in all the ERV standpipes. Similar to Unit 2, the Target Rock valve standpipe was not modified.

3. Main Steam System Instrumentation

The main steam lines and valves were instrumented with the same instruments and locations as were used for the Quad Cities Unit 2 ASB start-up testing. The unsteady steam line pressures were obtained by measuring the piping hoop strains using 8 strain gages at two locations on each line. The ERV valves were instrumented with multiple sets of accelerometers. Two sets of accelerometers measuring the three orthogonal directions were installed on the inlet flanges to the ERVs. Accelerometer sets measuring three orthogonal directions were also installed on the ERV pilot valves and actuators. An accelerometer set was also installed at the end of an MSSV standpipe ASB on each steam line. Additional accelerometer sets were installed on other steam components to provide specific component responses.

During the start-up test two strain gages were non-functional and were disconnected from the half-bridge for the pair. The remaining functional strain gage in the pair was reconfigured into a typical ¼ bridge configuration and the measurements were averaged with the remaining pairs. The S2A strain gage at the A main steam line upper location and the S28B strain gage at the B main steam line lower location were not functioning.

4. Start-Up Test for ASB Installation

After installing the ASBs in the MSSV and ERV standpipes, steam line pressure and acceleration measurements were taken during the Quad Cities Unit 1 start-up test, Reference 6. This start-up test collected steam line oscillating pressures and vibration measurements at several different power levels during the unit power ascension to demonstrate the reduction of the steam line acoustic loads. Table 1 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 comparison is made to the Unit 1 strain gage and ERV acceleration measurements at EPU and OLTP power levels prior to the installation of the ASBs. Using just these measurements, instead of the enveloped measures, demonstrates the actual reduction in oscillating steam line pressures and vibration levels for Unit 1.

Table 1. Test Condition Summary

Test Condition	Generator Power (MWe)	Core Thermal Power (MWth)
2	114	515
3	242	892
4	307	1072
5	503	1659
6	545	1785
7	587	1934
8	651	2115
9	702	2250
10	751	2394
11	798	2519
11-2 [1]	795	2504
12	822	2607
13	855	2700
14	880	2764
15	904	2840
16	913	2868
17	921	2895
18	927	2912

Note: 1. Test Condition 11 was retaken.

5. Main Steam System Performance with ASBs Installed

5.1 Steam Line Strain Gage Measurements

FFTs of the steam line strain measurements obtained during the start-up test are presented in Attachment A 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 data are provided in Reference 4. The current steam line data presented were obtained at TC18, with the unit operating at 2912 MWt. These measurements were compared to the pre-ASB EPU data, obtained during TC15 with the unit operating at 2887 MWt and the OLTP obtained during TC11 with the unit operating at 2642 MWt. All data sets were identically processed to develop these spectra. Details of the data processing for these comparisons are provided in Reference 5.

Subsequent to the completion of the start-up test, the steam lines continued to be monitored and additional strain gage measurements were obtained. The charts provided in Attachment A include an additional data set that was obtained on July 13, 2006 when the unit was operating at 2907 MWt.

Reviewing the steam line strain gage FFTs presented in Attachment A, the results of the strain measurement comparisons are very similar to the results seen from the Unit 2 comparisons in Reference 1. The only substantial change in strain magnitudes occurs from approximately 140 to 160 Hz. The reduction in strain magnitudes between 140 and 160 Hz is readily seen to be below the pre-ASB EPU levels by an order of magnitude. 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, the TC18 measurements showed increased frequency content at 36 Hz, although the measured amplitude was still small compared to the pre-ASB magnitudes at 140 to 160 Hz. However, this 36 Hz increase is not seen in the subsequent strain gage measurements as demonstrated by the July 13, 2006 measurements, and it is not measured at the MSL A lower strain gage. This would suggest that this is not a propagating pressure response. It should also be noted that the first acoustic mode of the standpipe with ASB is above 100 Hz at all locations, and therefore the modification could not yield an increase in 37 Hz acoustic response. These facts indicate this frequency is not caused the piping breathing mode and is the result of a higher order shell mode response. This frequency content along with other lower frequency increases in the MSL B upper, MSL C lower and MSL D upper locations are determined to be insignificant when compared to the more significant reduction in almost all the other frequencies, but most importantly in the 140 to 160 Hz range.

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 pre-ASB OLTP levels.

Further confirmation of the steam line oscillating pressure reduction relative to prior steam line operating conditions can be seen in Table 2. The main steam line strain gage rms and maximum-minimum measurements for each test condition are summarized in Table 2. The maximum value for any test condition is compared to the pre-ASB OLTP value and in all cases is now less than the OLTP values. 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 B. On these charts the Quad Cities Unit 2 trend data are also plotted for comparison to the Unit 1 data. The Unit 1 data trends are very similar to those seen from Unit 2. These trends demonstrate the oscillating pressures are generally increasing with the square of the thermal 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. Based on these trends and the 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.

Based on these results, the Unit 1 dryer pressure loads that caused the prior dryer failures have been eliminated for EPU power levels.

Table 2: Summary of Main Steam Line Strain Measurements from Q1M19 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	TC11-2	TC 12	TC 13	TC 14	TC 15	TC 16	TC 17	TC 18	Max TC	% of OLTP
MSL A Upper	0.46	0.37	0.05	0.05	0.06	0.06	0.09	0.10	0.10	0.11	0.14	0.23	0.16	0.17	0.16	0.16	0.16	0.16	0.17	0.23	0.63
MSL A Lower	0.28	0.23	0.01	0.03	0.03	0.03	0.06	0.06	0.07	0.08	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.50
MSL B Upper	0.22	0.31	0.04	0.05	0.05	0.05	0.09	0.10	0.11	0.15	0.15	0.20	0.17	0.18	0.17	0.18	0.18	0.19	0.19	0.20	0.64
MSL B Lower	0.35	0.26	0.02	0.02	0.03	0.03	0.05	0.06	0.07	0.08	0.09	0.11	0.11	0.12	0.11	0.12	0.12	0.12	0.12	0.12	0.46
MSL C Upper	1.11	0.84	0.03	0.04	0.04	0.06	0.06	0.07	0.08	0.09	0.15	0.11	0.12	0.13	0.12	0.12	0.13	0.13	0.13	0.15	0.18
MSL C Lower	0.22	0.18	0.03	0.05	0.05	0.07	0.08	0.08	0.09	0.10	0.11	0.16	0.16	0.16	0.13	0.15	0.15	0.14	0.14	0.16	0.89
MSL D Upper	0.24	0.25	0.02	0.04	0.04	0.06	0.06	0.07	0.08	0.09	0.10	0.12	0.17	0.19	0.12	0.12	0.12	0.13	0.13	0.19	0.75
MSL D Lower	0.32	0.33	0.01	0.02	0.03	0.05	0.05	0.06	0.07	0.07	0.09	0.15	0.15	0.16	0.11	0.10	0.11	0.11	0.11	0.16	0.48

	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	TC11-2	TC 12	TC 13	TC 14	TC 15	TC 16	TC 17	TC 18	Max TC	% of OLTP
MSL A Upper	4.27	3.31	0.44	0.45	0.54	0.54	0.75	0.83	0.95	0.94	1.21	1.56	1.40	1.45	1.44	1.38	1.42	1.58	1.52	1.58	0.48
MSL A Lower	2.36	1.99	0.15	0.23	0.27	0.27	0.51	0.52	0.64	0.68	0.76	0.91	0.92	0.94	0.91	0.96	1.02	0.97	1.10	1.10	0.55
MSL B Upper	1.85	2.22	0.34	0.46	0.43	0.43	0.78	0.86	0.98	1.26	1.40	1.59	1.46	1.63	1.44	1.65	1.63	1.61	1.64	1.65	0.74
MSL B Lower	3.14	2.25	0.15	0.21	0.31	0.31	0.47	0.54	0.60	0.64	0.76	0.88	0.93	1.03	0.93	1.06	1.06	1.15	1.04	1.15	0.51
MSL C Upper	9.62	6.82	0.23	0.31	0.32	0.51	0.59	0.66	0.68	0.85	1.18	0.96	1.12	1.17	1.08	1.11	1.19	1.20	1.15	1.20	0.18
MSL C Lower	1.66	1.53	0.23	0.36	0.40	0.64	0.67	0.74	0.83	0.82	1.03	1.31	1.29	1.25	1.11	1.35	1.34	1.16	1.38	1.38	0.90
MSL D Upper	2.17	2.03	0.20	0.30	0.32	0.46	0.56	0.65	0.74	0.78	0.90	0.98	1.25	1.31	1.14	1.04	1.09	1.22	1.11	1.31	0.65
MSL D Lower	2.53	2.44	0.13	0.19	0.26	0.46	0.46	0.57	0.61	0.64	0.74	1.11	1.10	1.16	0.93	0.88	0.96	0.93	0.94	1.16	0.47

5.2 Steam Line Acceleration Measurements

FFT spectral comparisons for the ERV inlet flange vertical acceleration measurements at TC18, 2912 MWt, are also presented in Attachment A. 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 are also provided in Attachment B. 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. 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.

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.

6. 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 2912 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 QC1 steam system at flows up to the full licensed thermal power of 2957 MWt is acceptable.

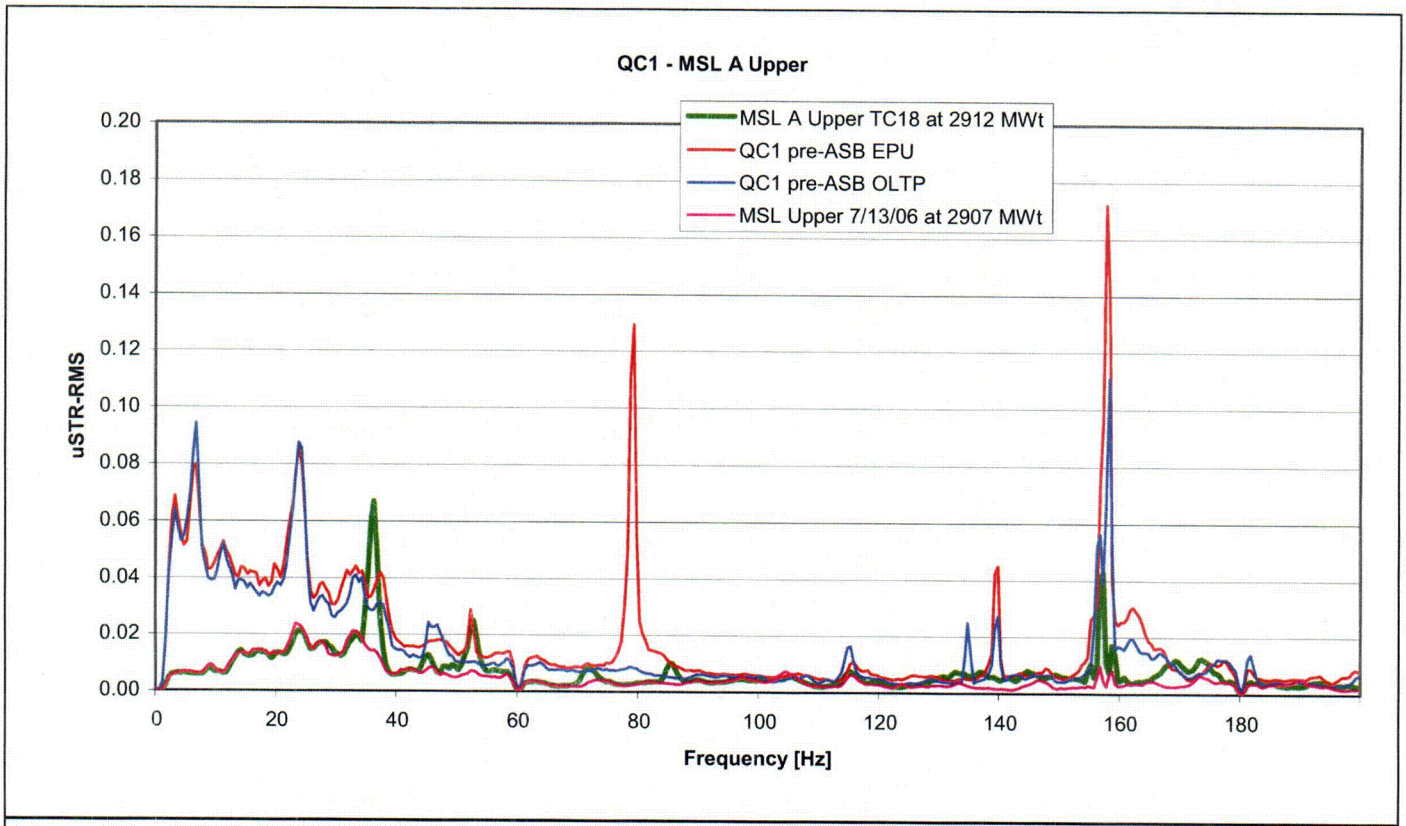
7. References

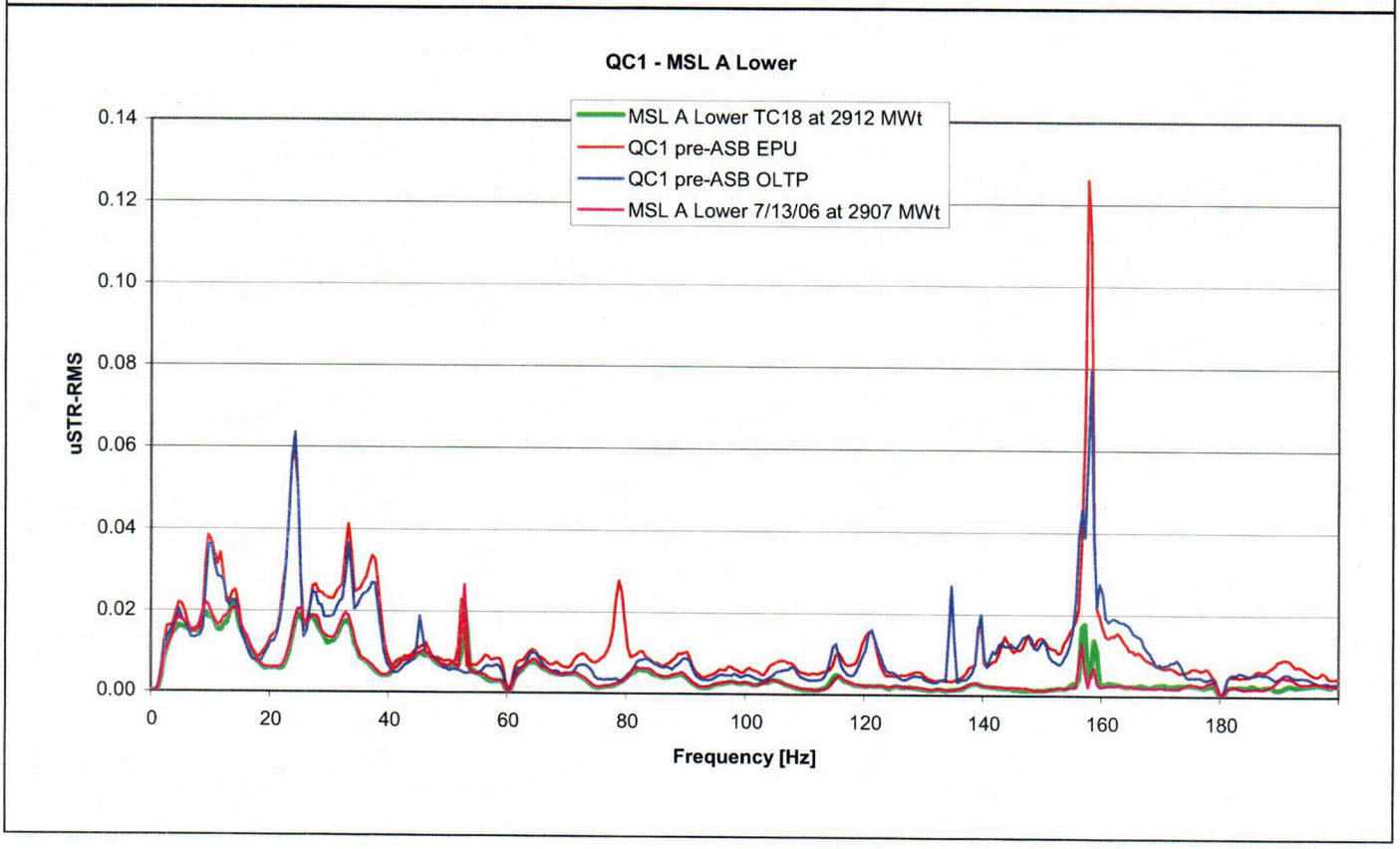
1. Exelon Report AM-2006-002, "Quad Cities Unit 2 Main Steam Line Acoustic Source Identification and Load Reduction," May 3, 2006.
2. SIA Calculation, QC-11Q-302, "Quad Cities Unit 1 Main Steam Line Component Vibration Assessment," Revision 0, January 7, 2004.
3. SIA Report No. SIR-06-005, "Quad Cities ERV Accelerometer Data Reduction New Dryer Design," February 2006.
4. SIA Report, SIR-05-208, "Quad Cities Unit 1 Main Steam Line Strain Gage Reductions," Revision 2.
5. SIA Calculation, QC-39Q-303, "QC1M19 Main Steam Line Strain Gage Data Reduction," Revision 0, June 14, 2006.
6. Exelon Procedure, TIC-1468, "Quad Cities Unit 1 Power Ascension Test Procedure for the Acoustic Side Branch (ASB) Installation," Revision 0.

Attachment A

QC1 ASB Modification Startup Test Results for TC18, 2912 MWt

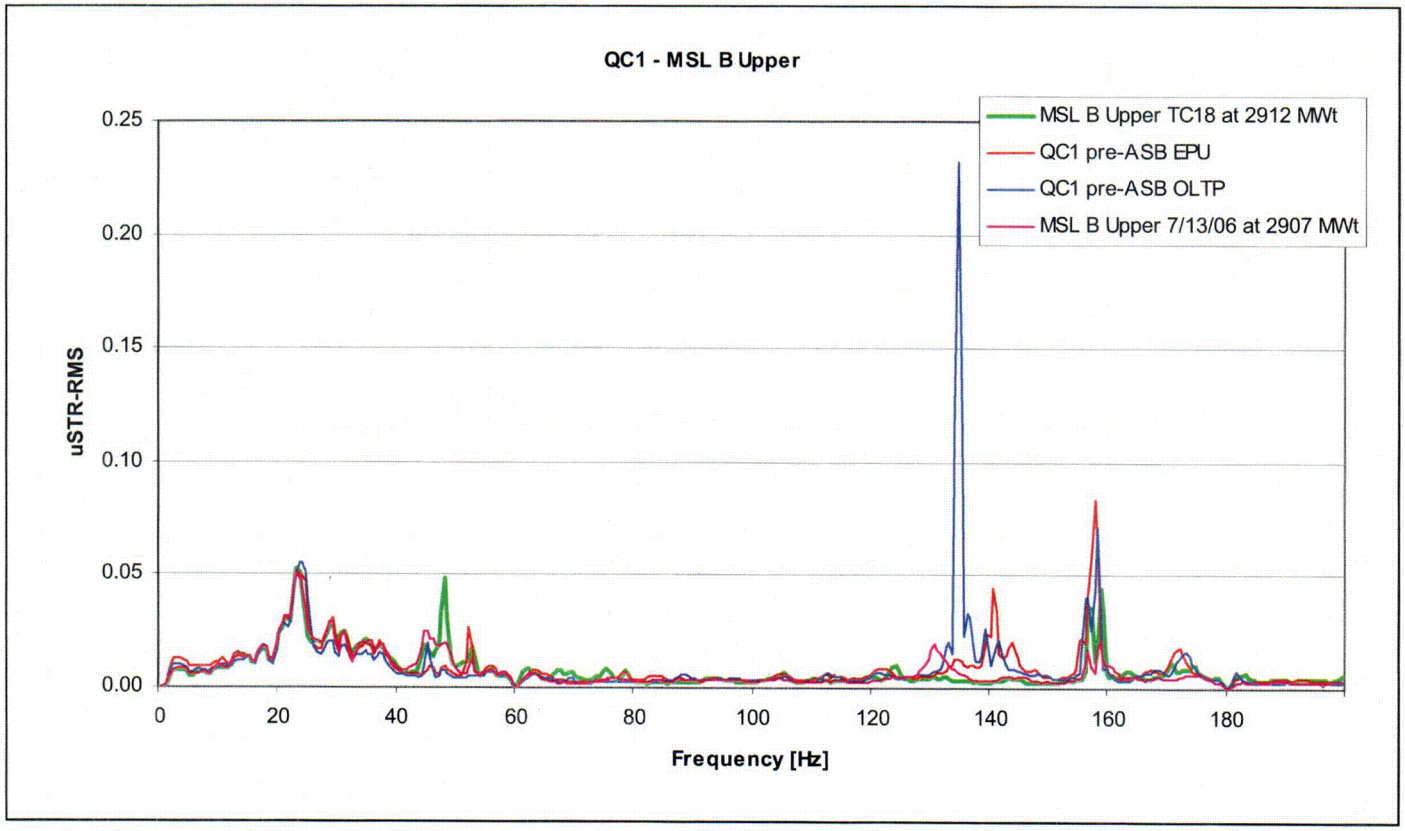
A Steam Line Strain Gage Spectra Comparisons:

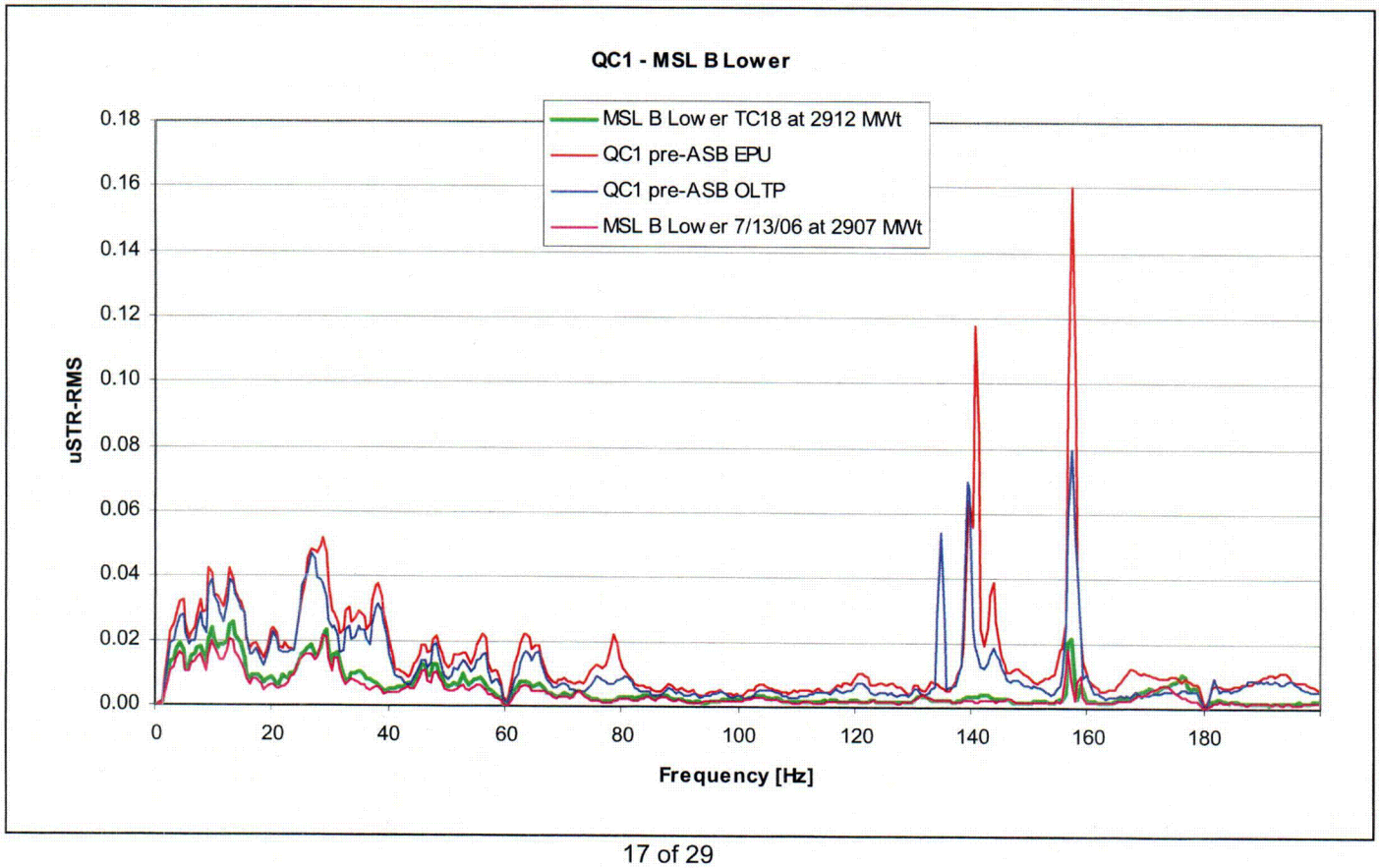




C-01

B Steam Line Strain Gage Spectra Comparisons:





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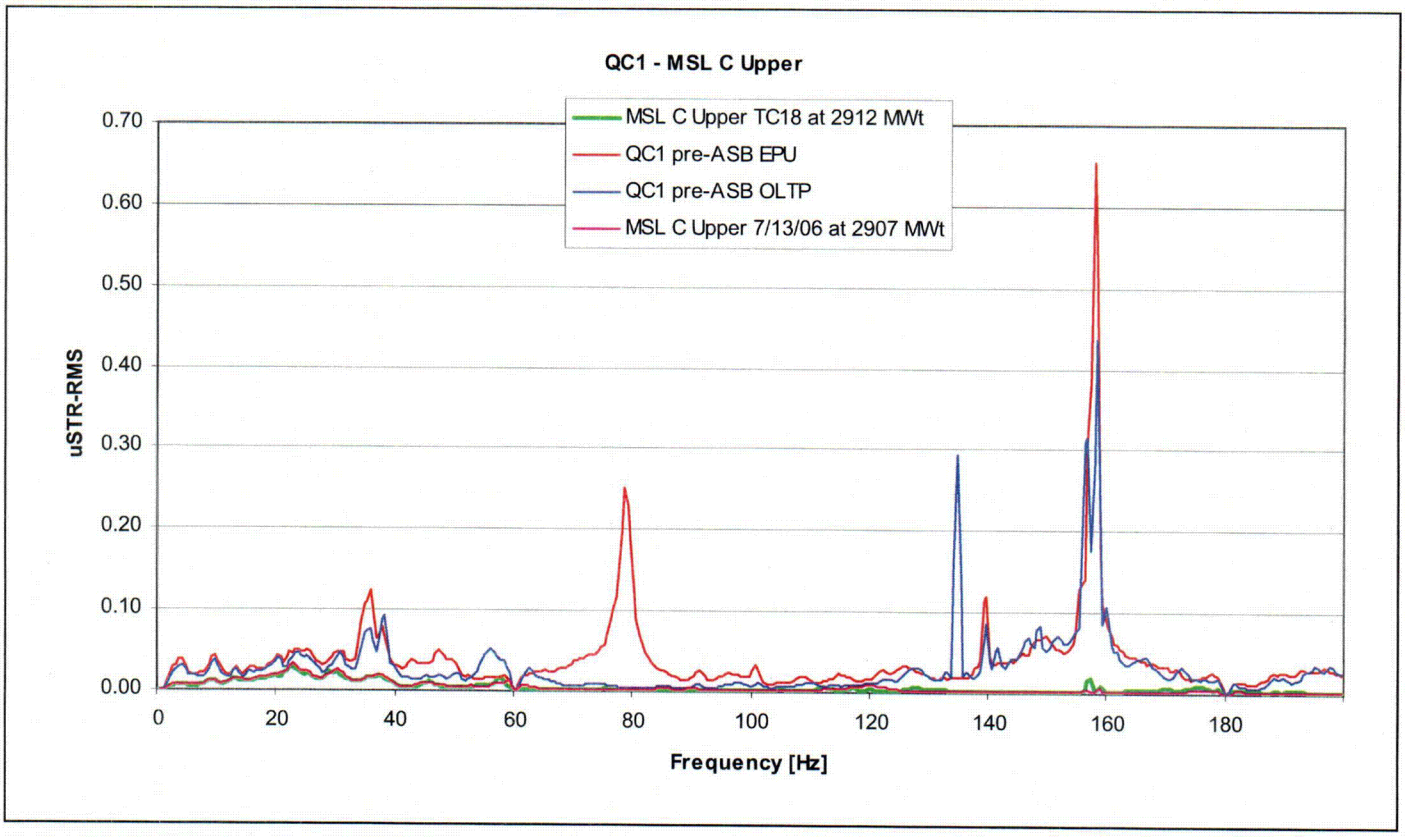
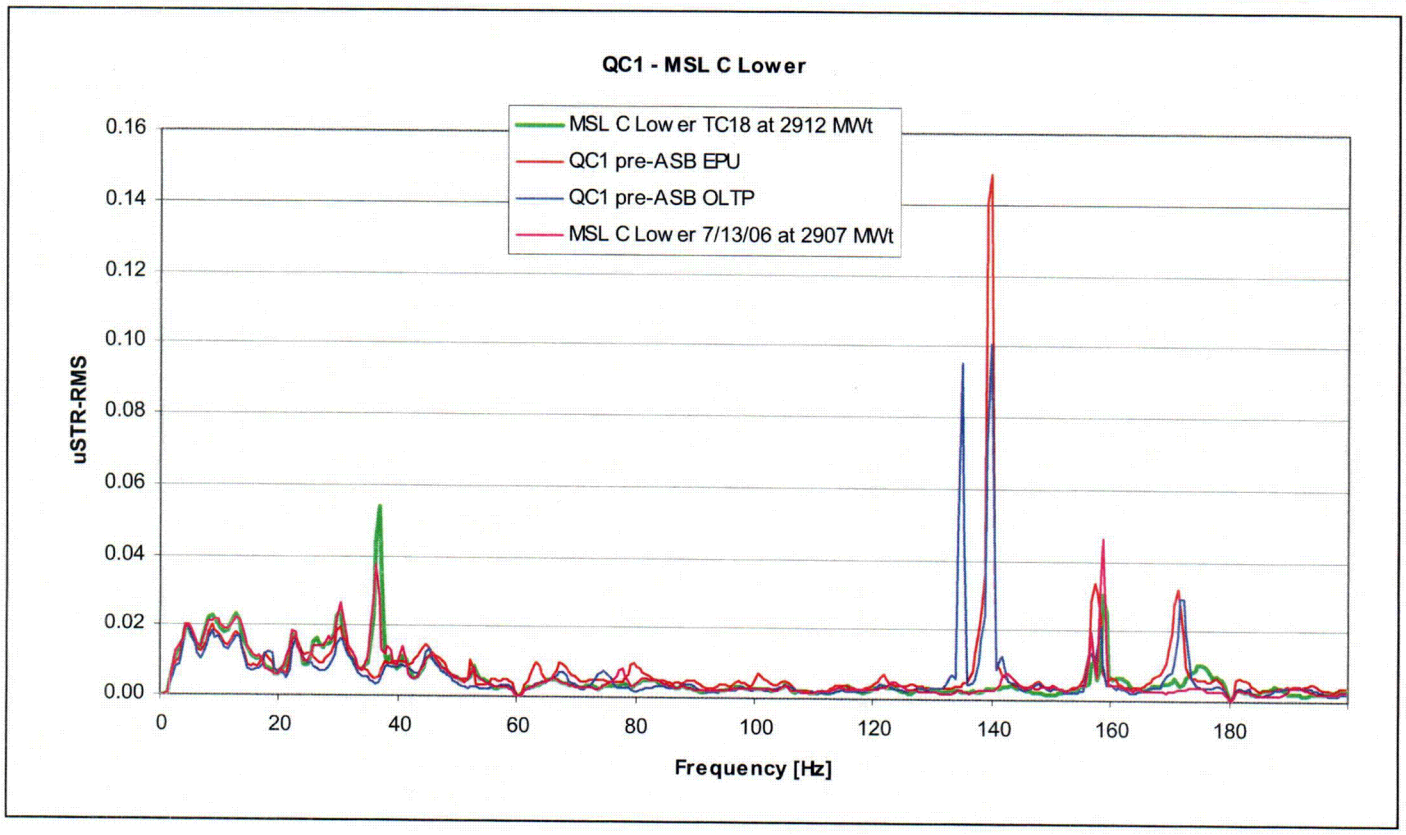
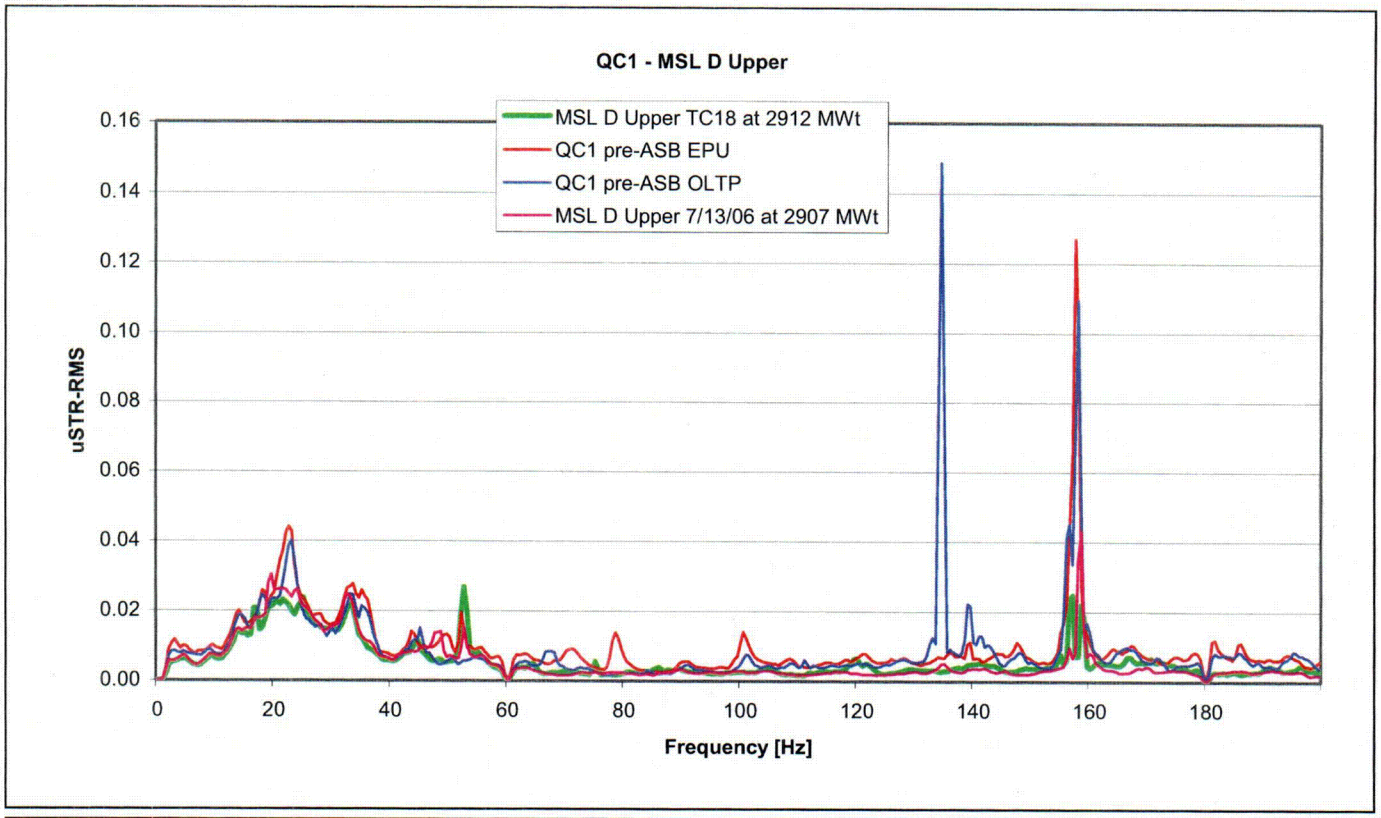
C Steam Line Strain Gage Spectra Comparisons:

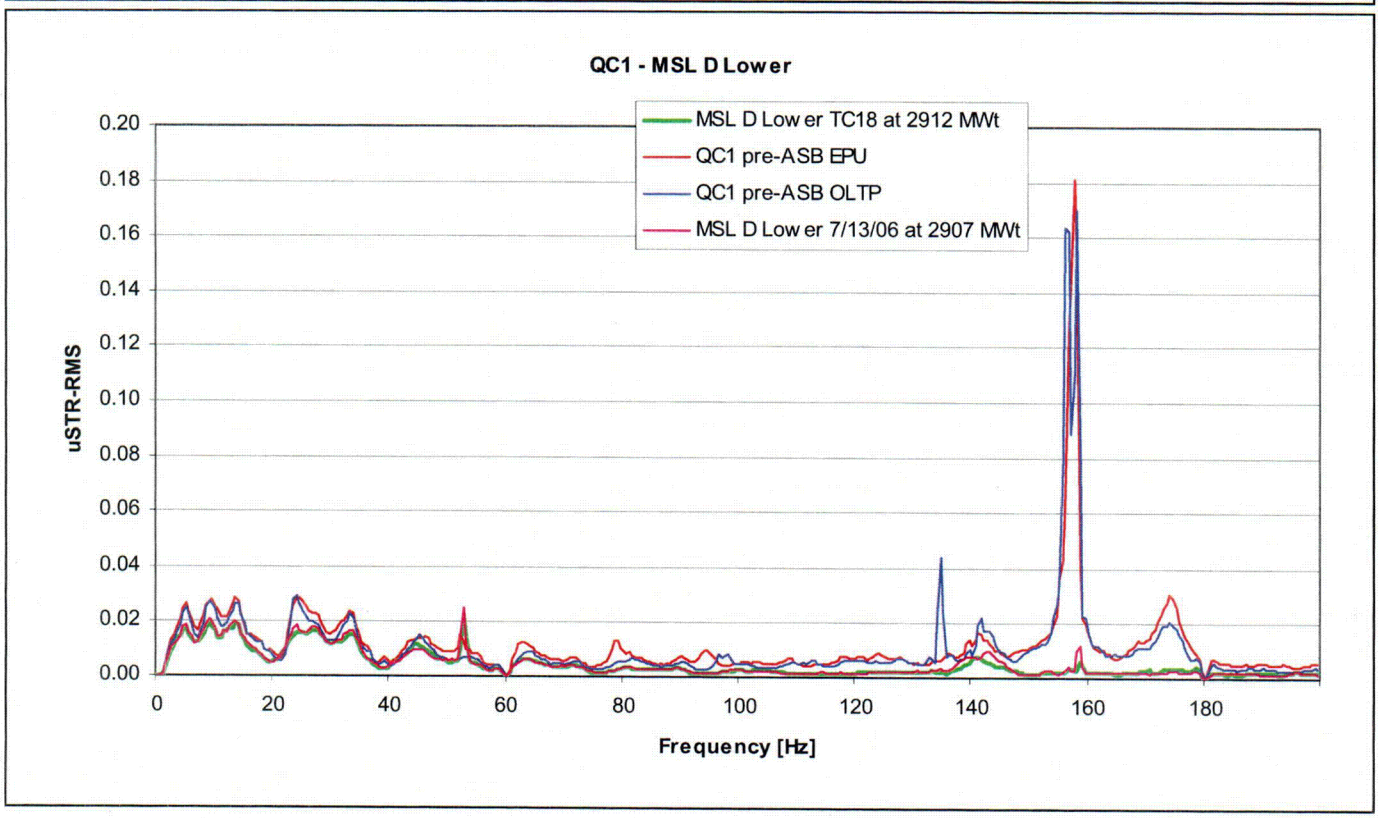




C-03

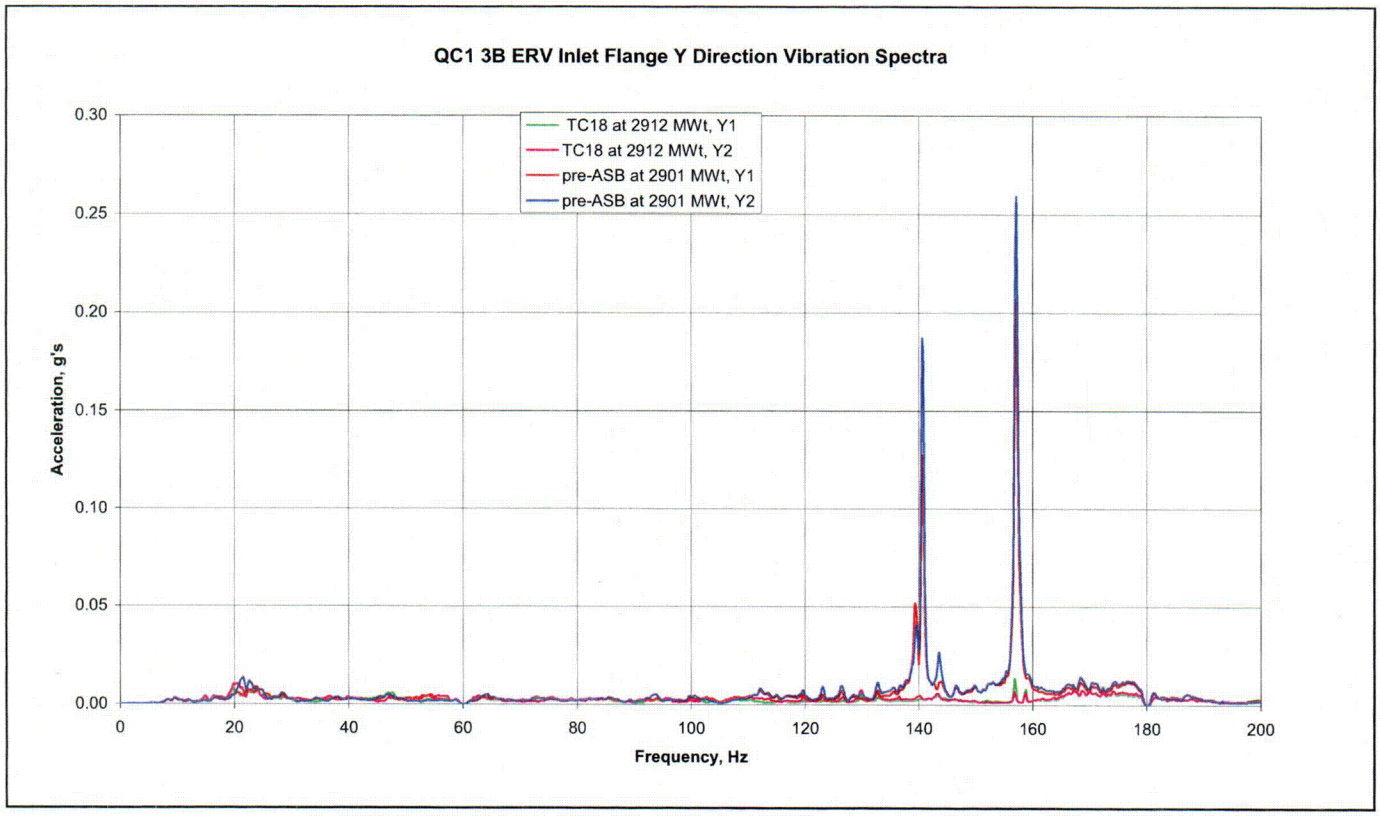
D Steam Line Strain Gage Spectra Comparisons:

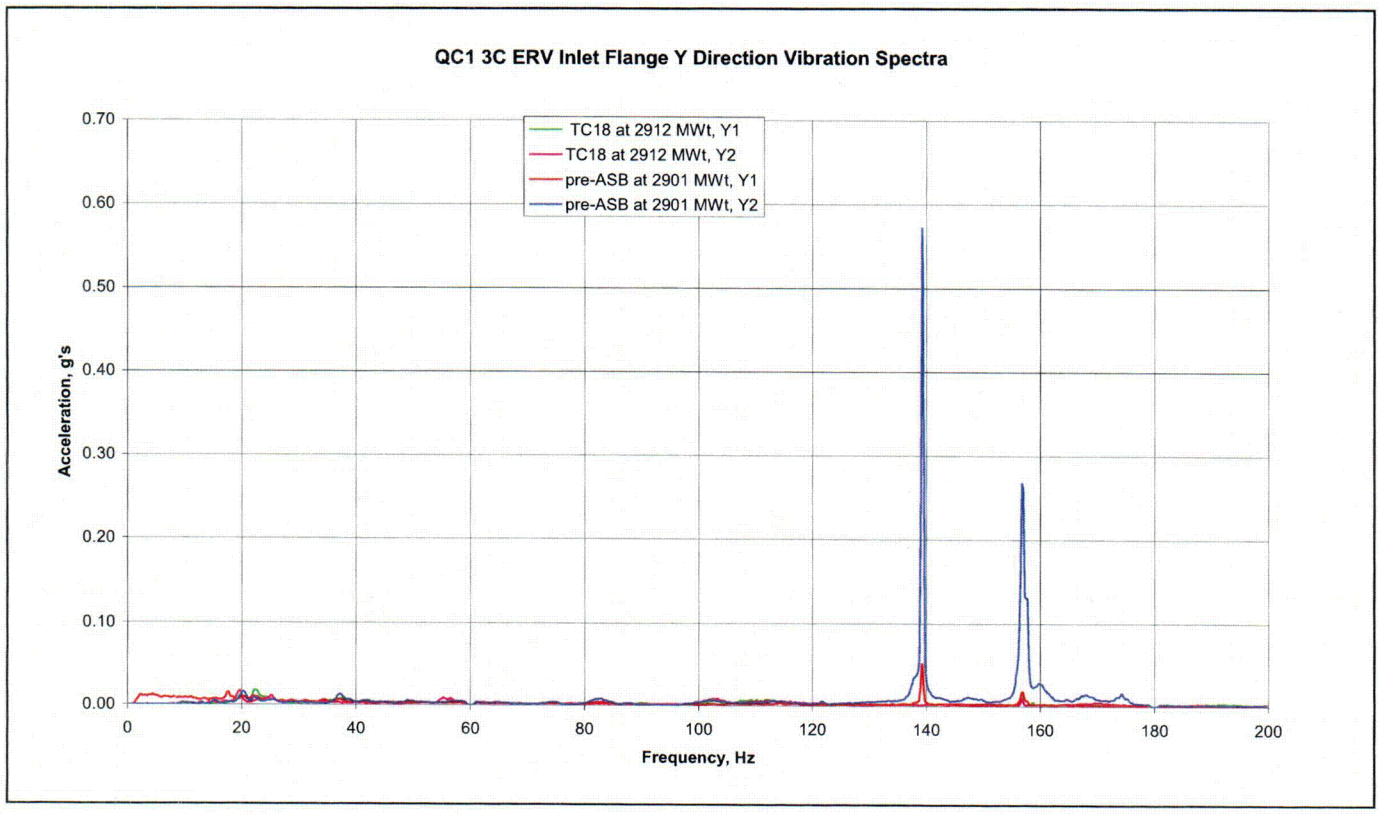




C-04

ERV Inlet Flange Vertical Acceleration Spectra at 2912 MWt:



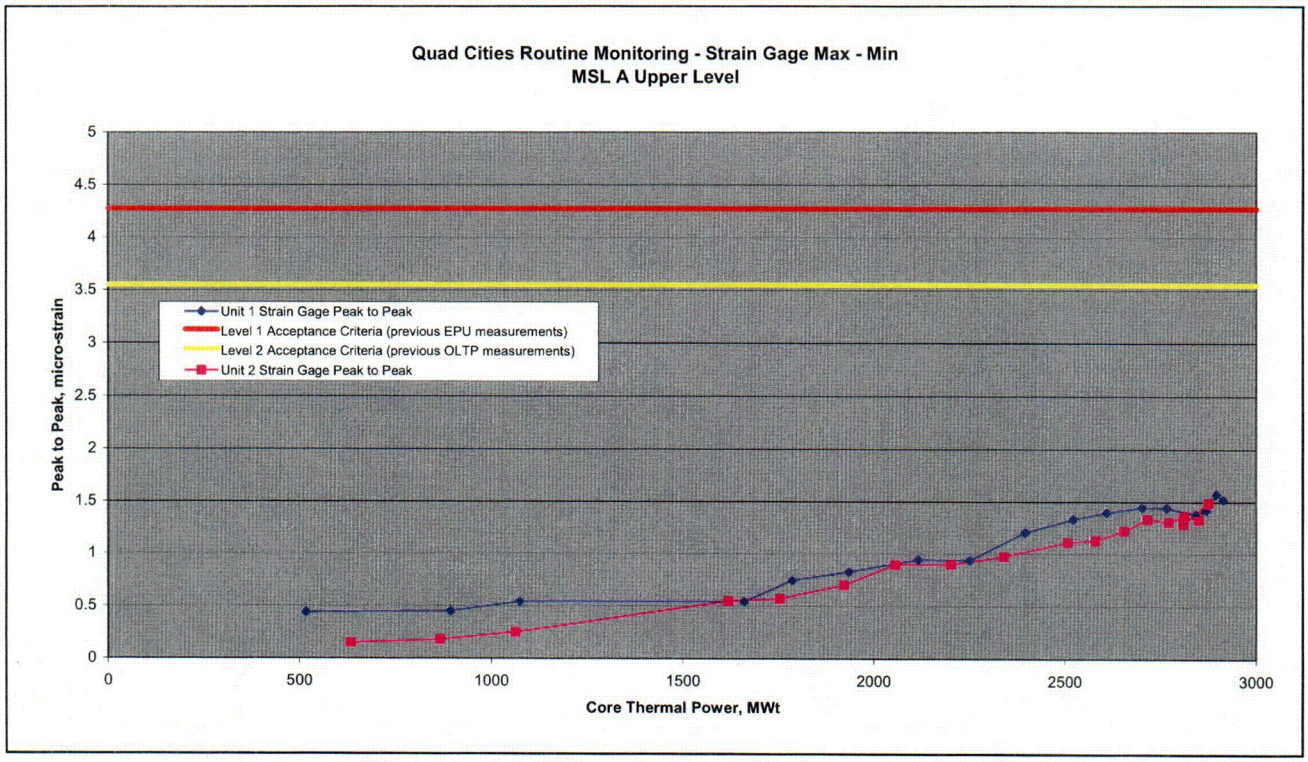


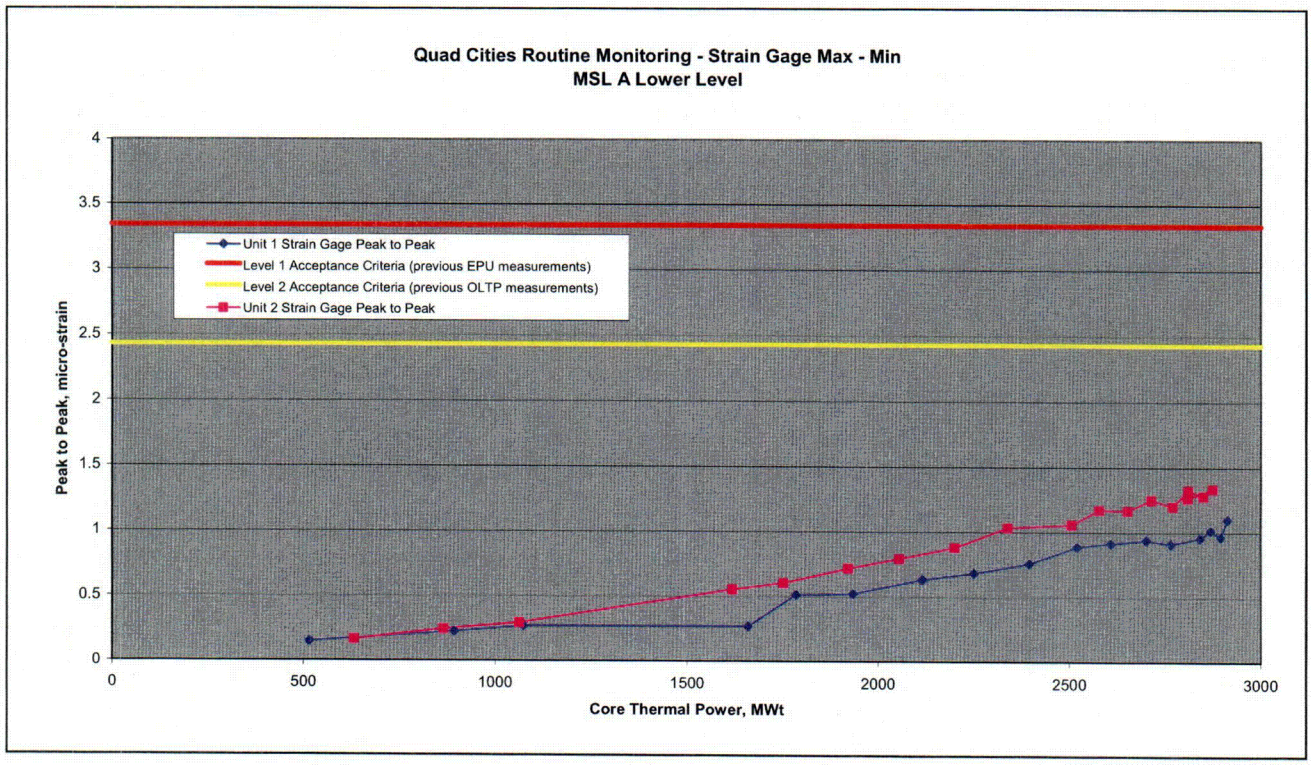
C-05

Attachment B

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

MSL A Strain Gage Measurements Maximum-Minimum Trends:





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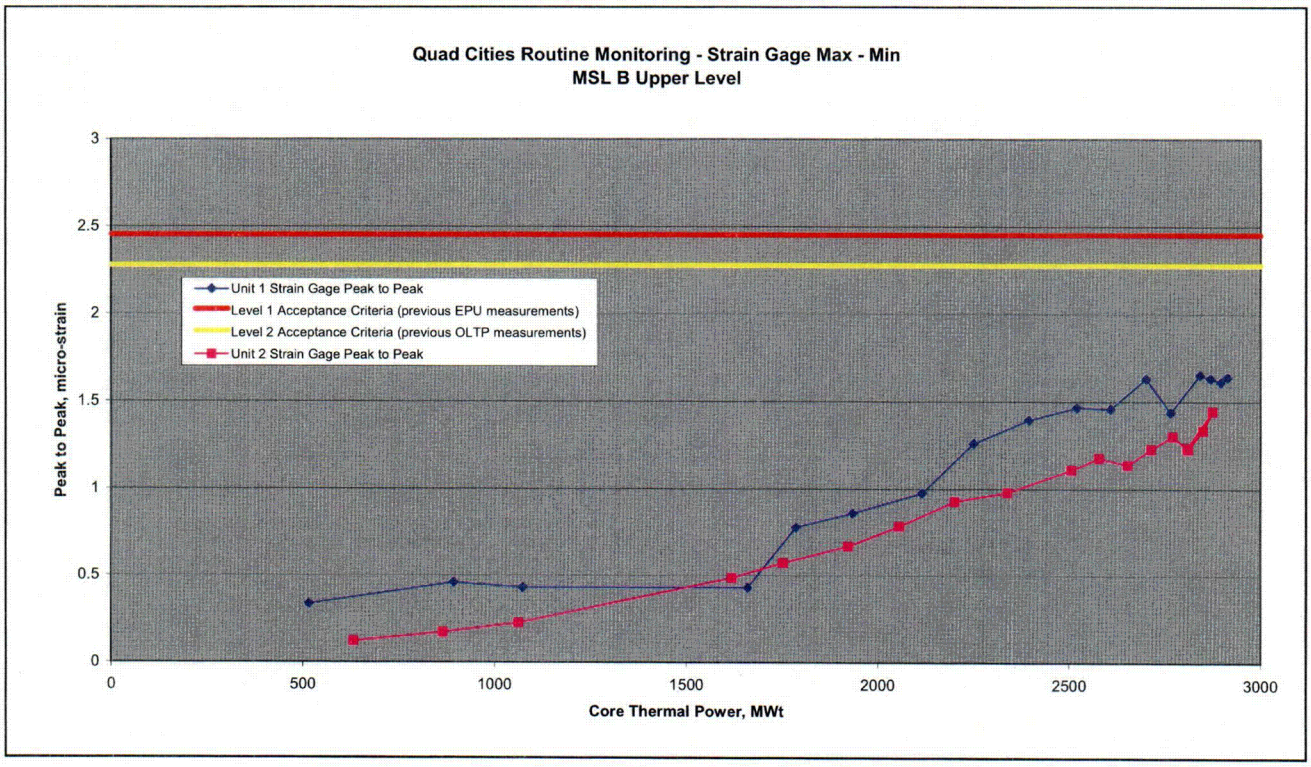
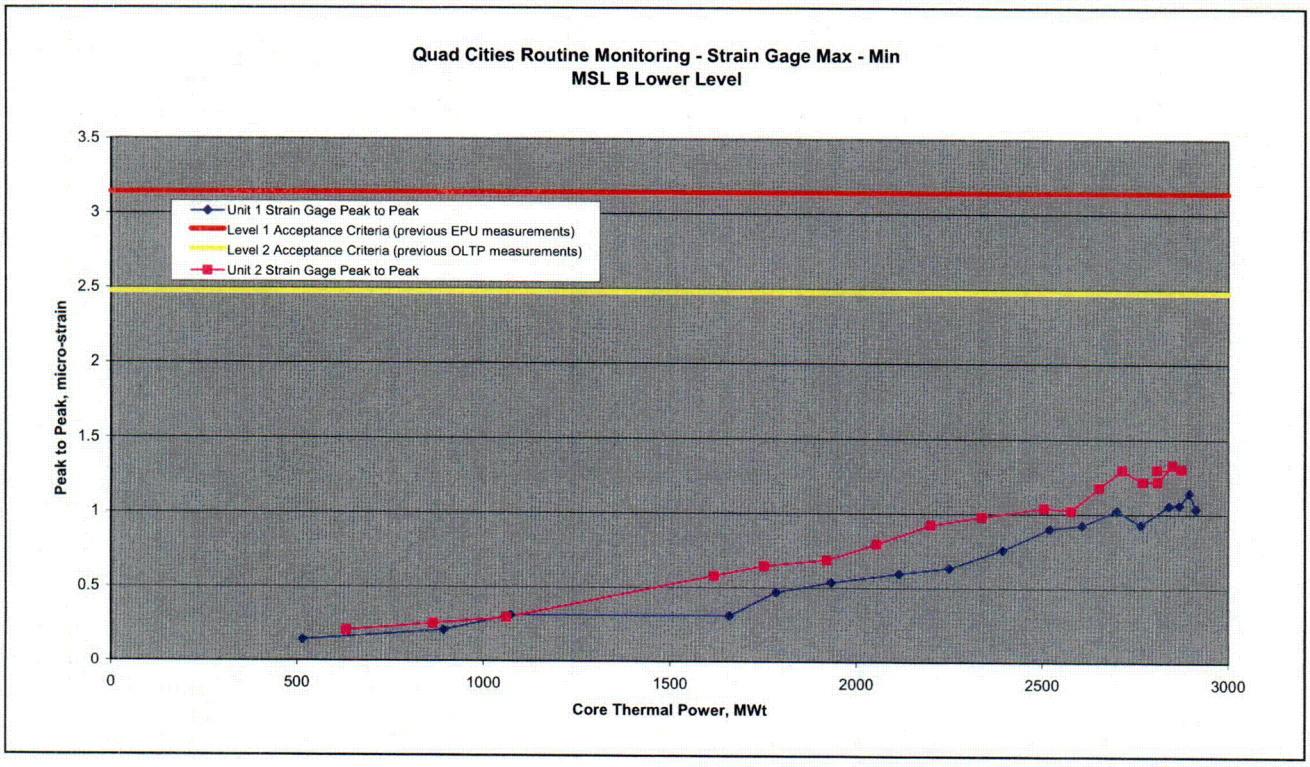
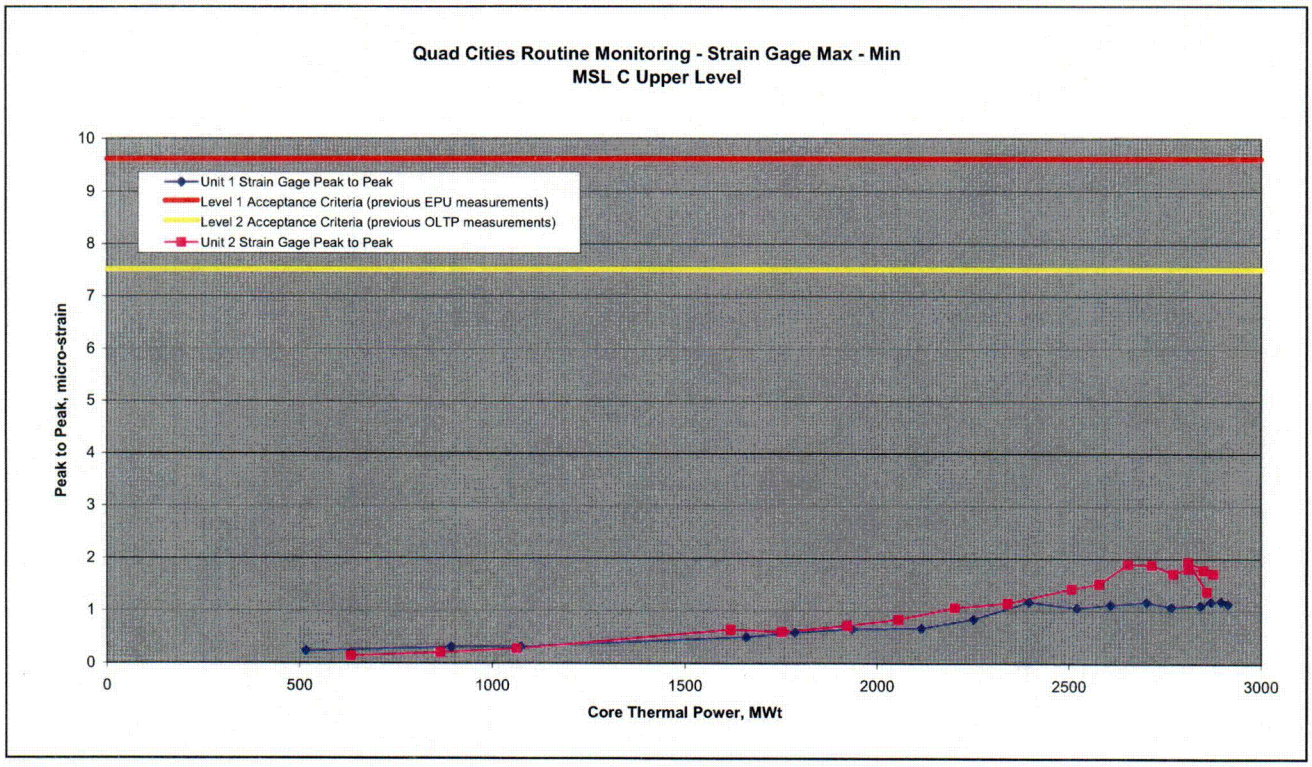
MSL B Strain Gage Measurements Maximum-Minimum Trends:

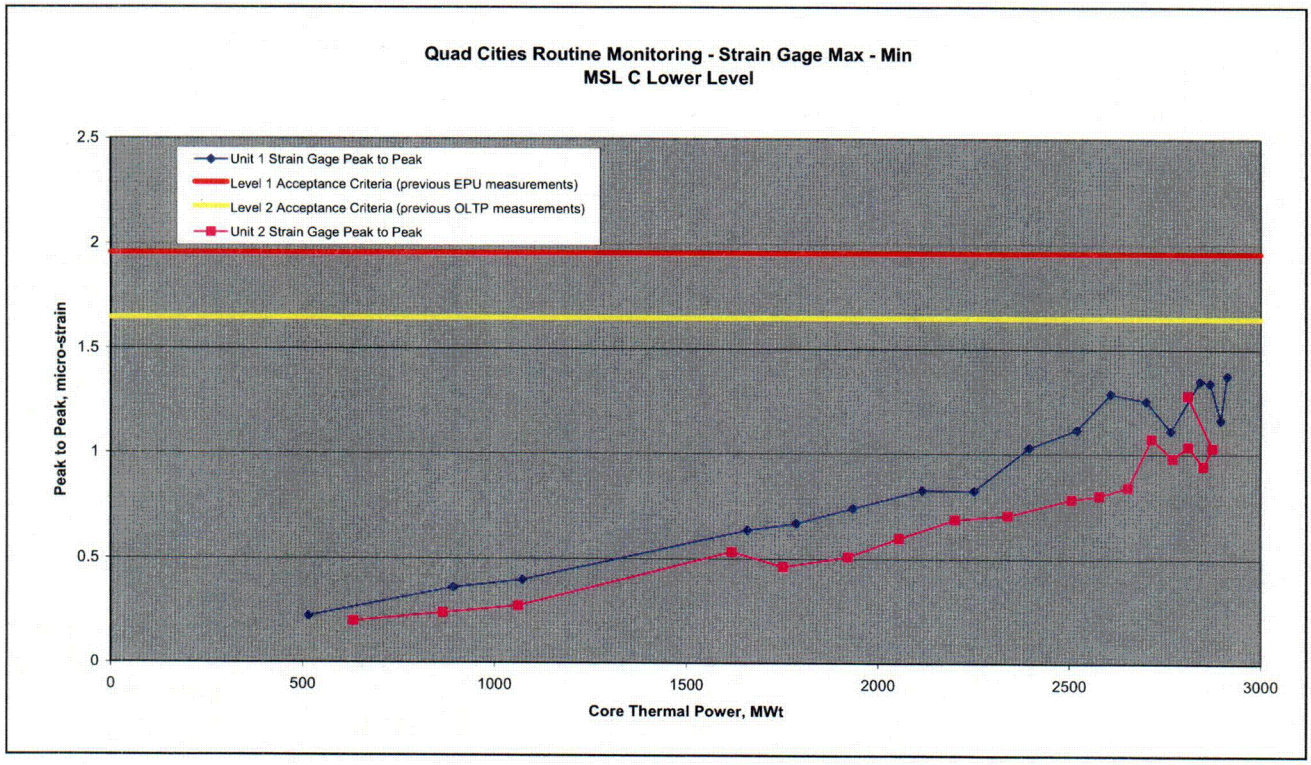




C-07

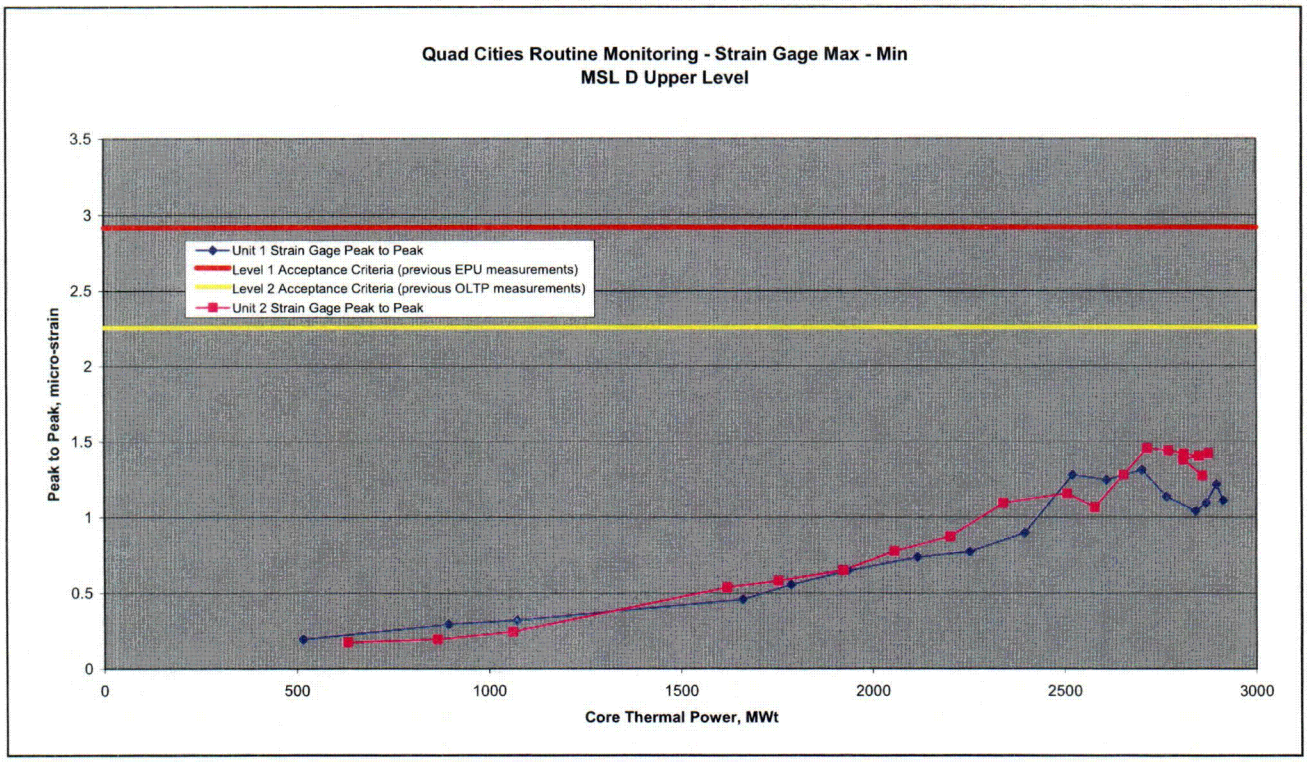
MSL C Strain Gage Measurements Maximum-Minimum Trends:

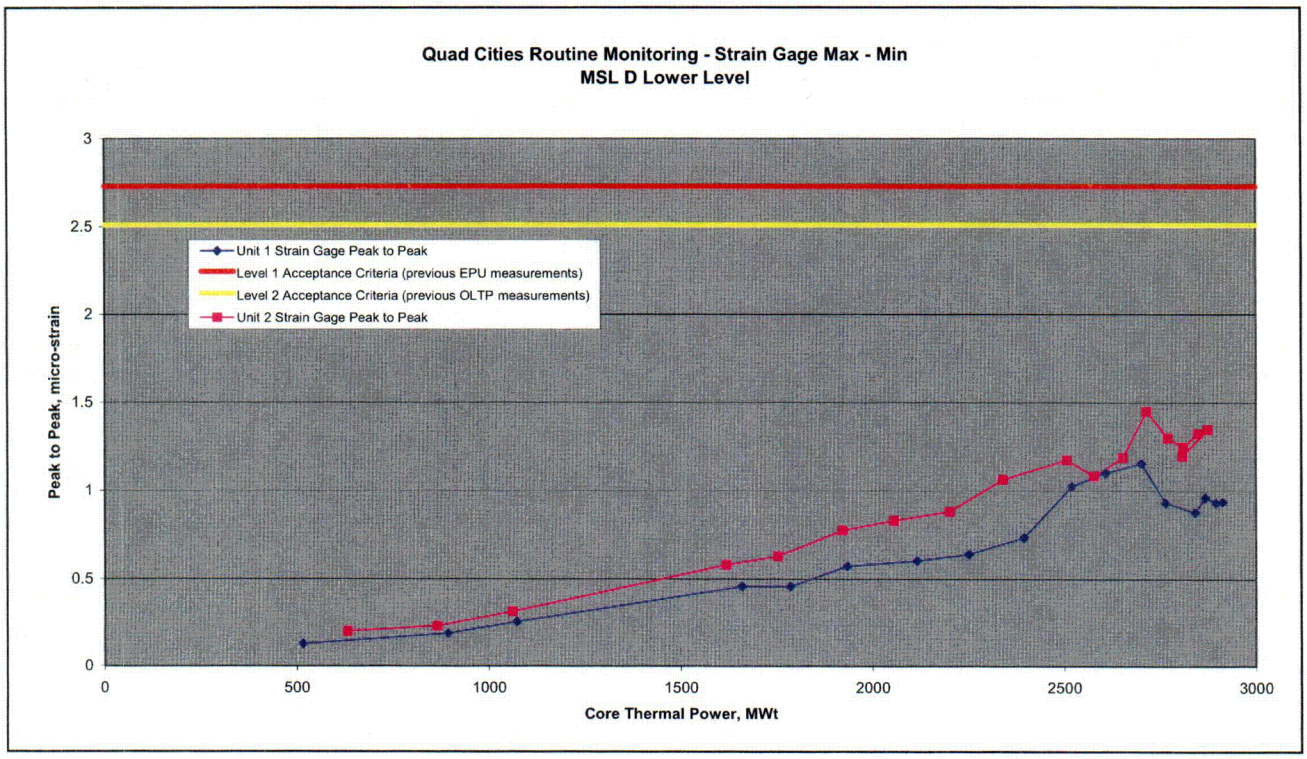




C-08

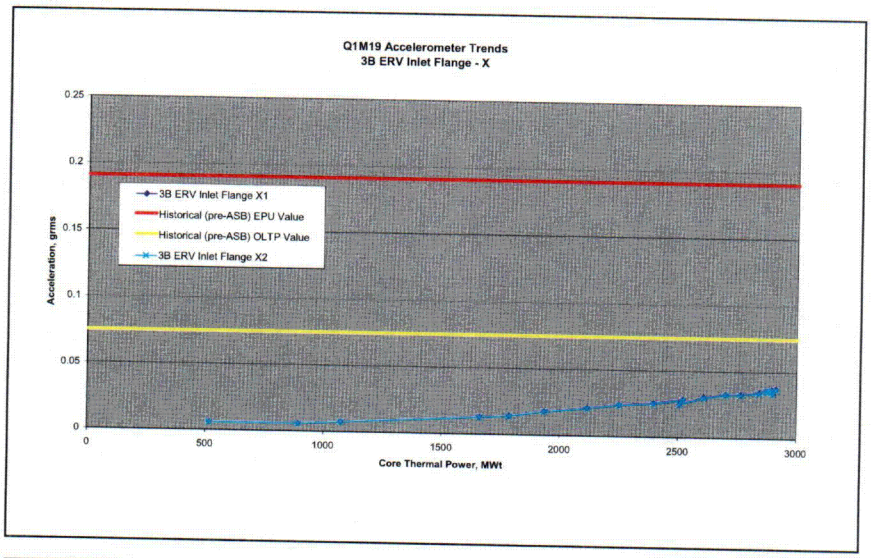
MSL D Strain Gage Measurements Maximum-Minimum Trends:

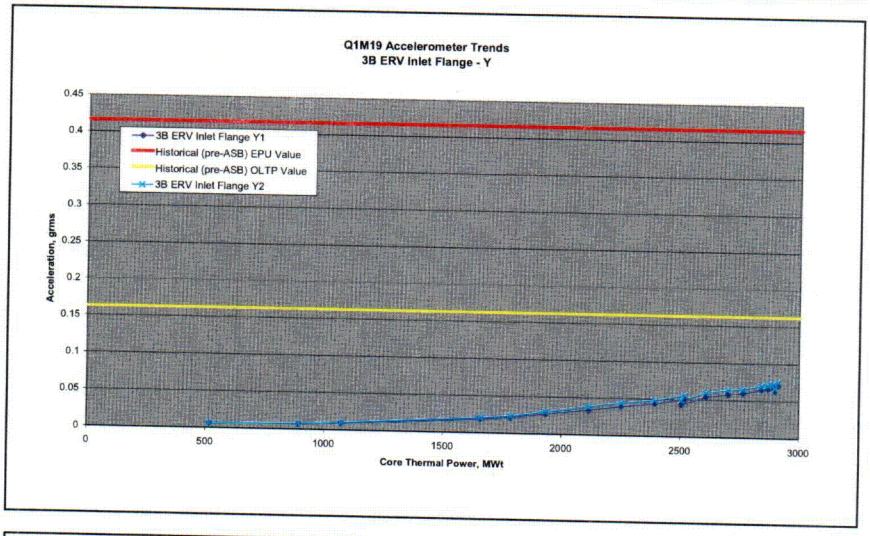


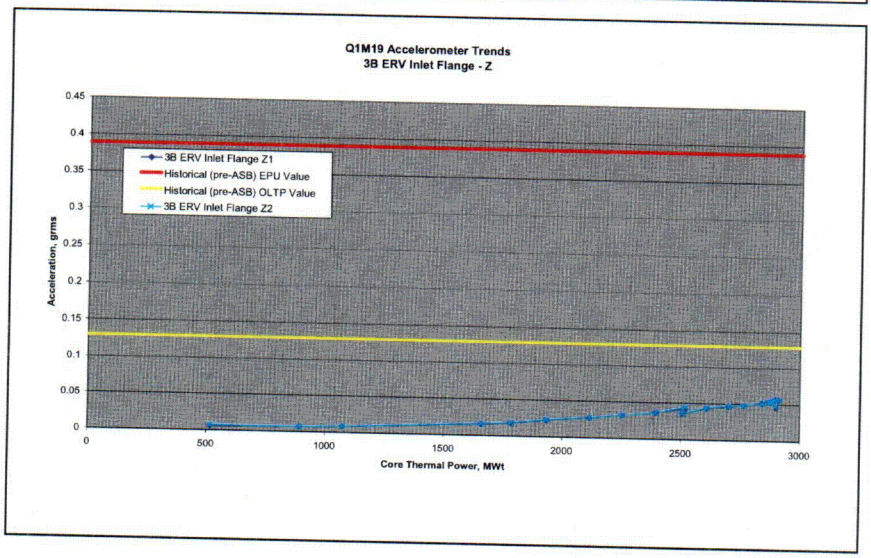


C-09

3B ERV Inlet Flange Acceleration Trend:

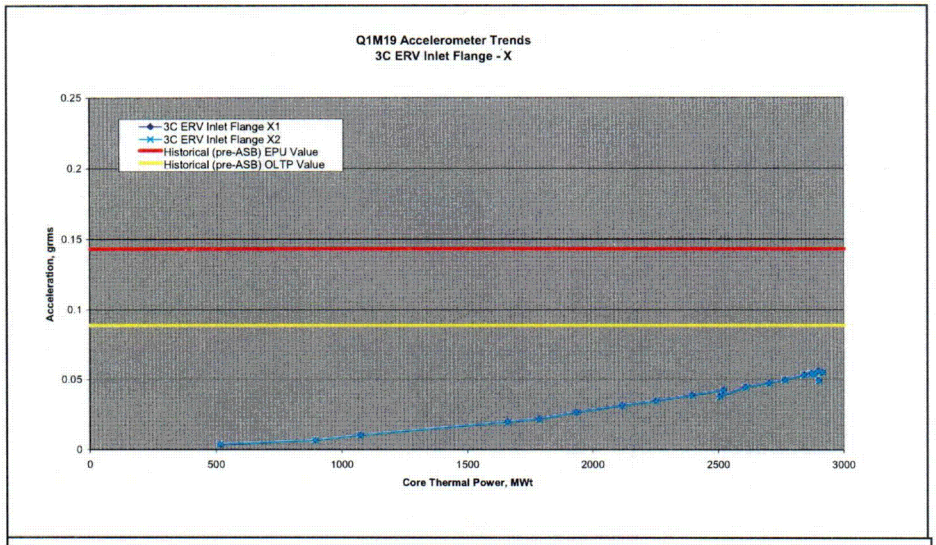


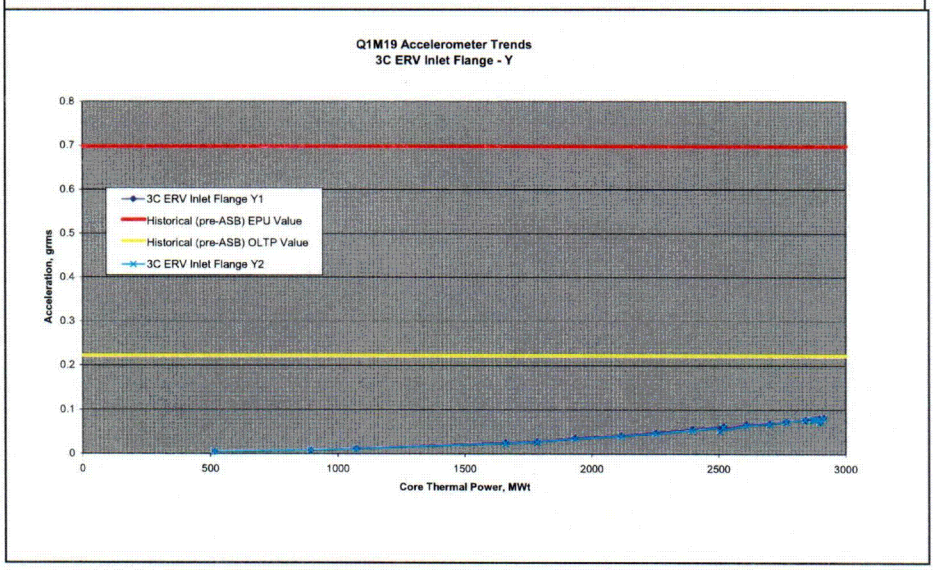


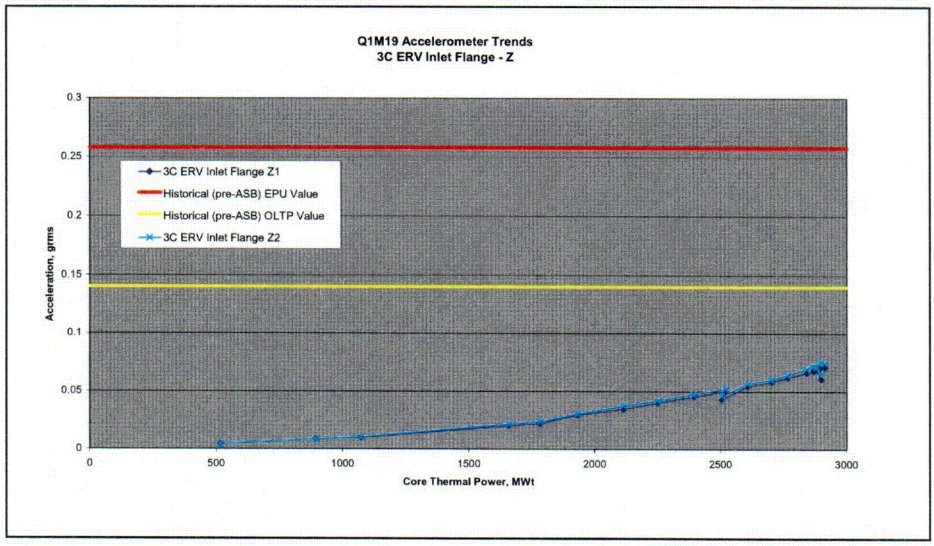


C-10

3C ERV Inlet Flange Acceleration Trend:







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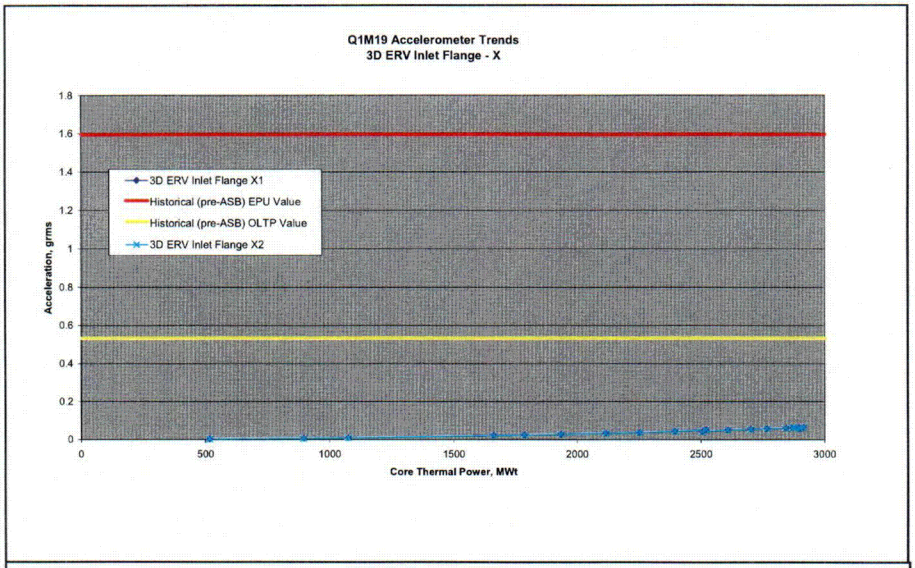
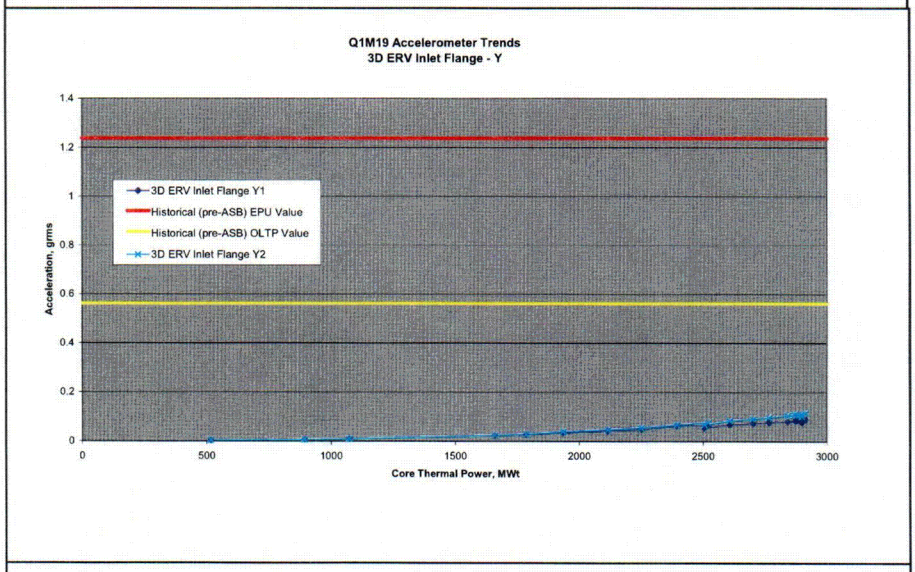
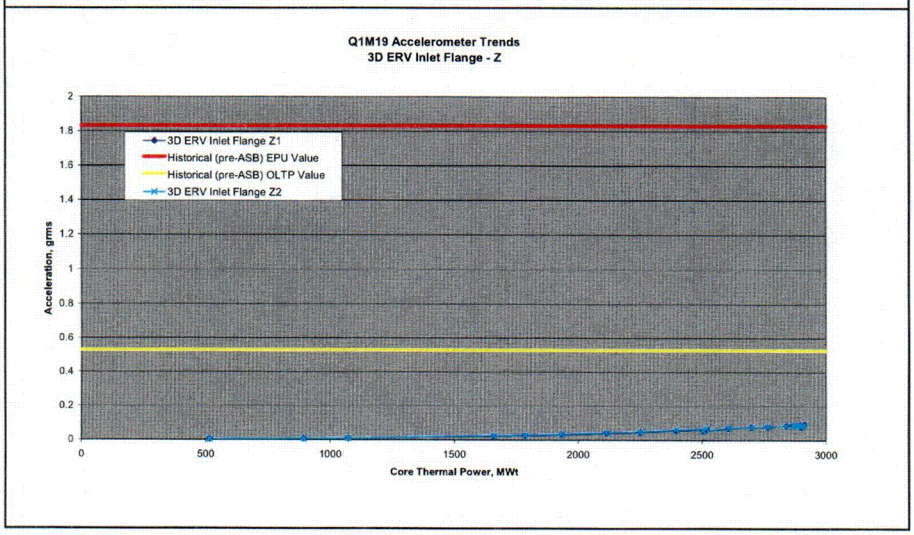
3D ERV Inlet Flange Acceleration Trend:







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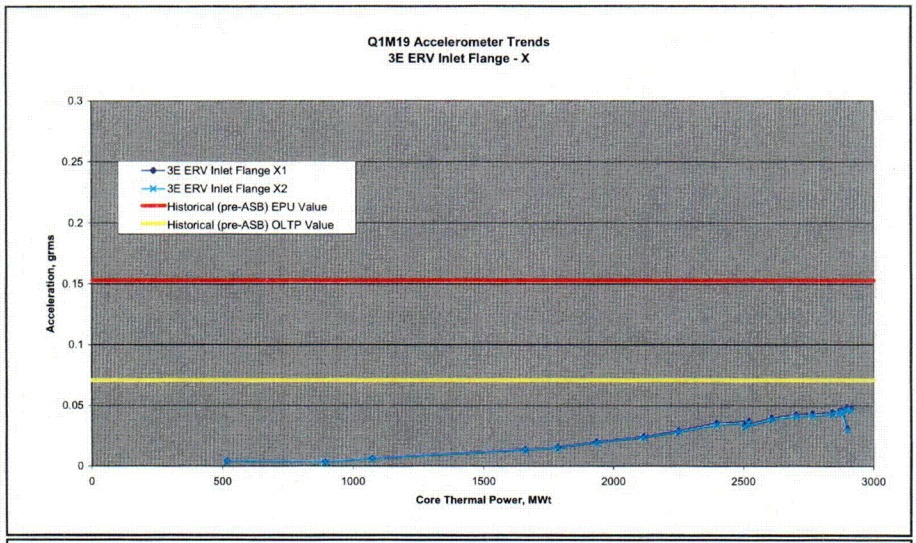
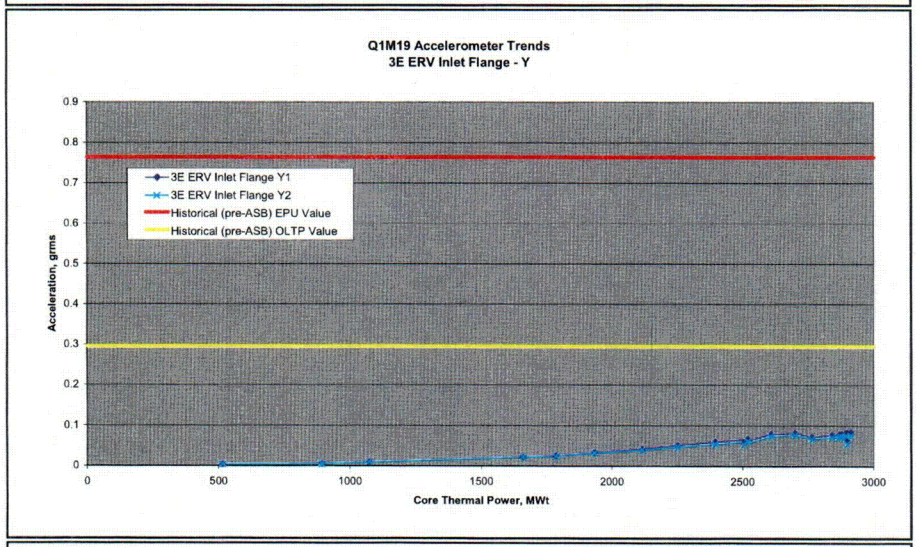
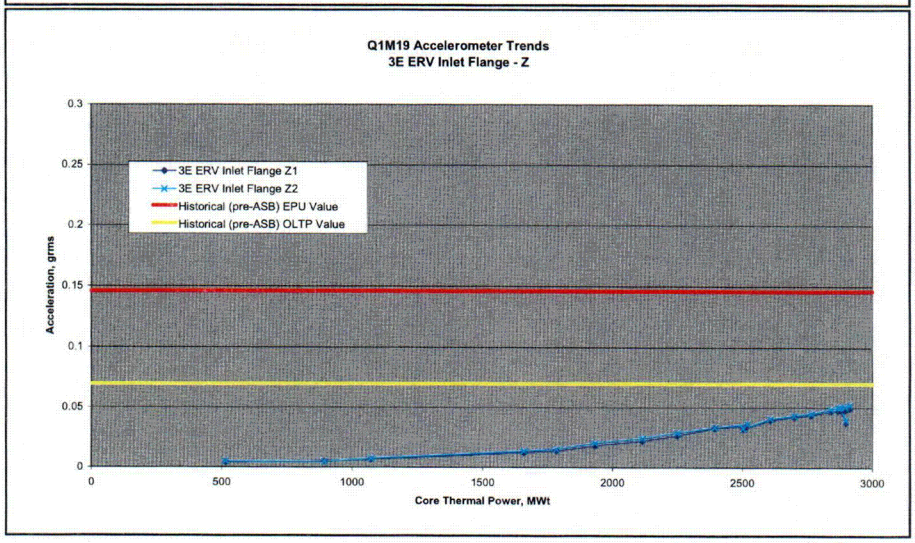
3E ERV Inlet Flange Acceleration Trend:







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