Attachment 14 to PLA-6002

Steam Dryer Structural Evaluation

Non-Proprietary

PPL SUSQUEHANNA, LLC

EXTENDED POWER UPRATE

STEAM DRYER EVALUATION

MARCH 2006

Information Notice

This document is a Non-Proprietary version of Attachment 10 which has the GE proprietary information removed.

Portions of the document that have been removed are indicated by white space with open and closed bracket as shown here [[ ]].

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Acronym List	
Short Form	Description
ACM	Acoustic Circuit Model
AFEM	Acoustic Finite Element Model
ALD	Acoustic Load Definition
BWR	Boiling Water Reactor
BWROG	Boiling Water Reactor Owner's Group
BWRVIP	Boiling Water Reactor Vessel Internals Program
CDI	Continuum Dynamics Incorporated
CDI-SMT	Continuum Dynamics Incorporated Scale Model Test
CLTP	Current Licensed Thermal Power
CPPU	Constant Pressure Power Uprate
OLTP	Original Licensed Thermal Power
EPU	Extended Power Uprate
ERV	Electro-Magnetic Relief Valve
FEA	Finite Element Analysis
FEM	Finite Element Model
FIV	Flow Induced Vibration
FOIA	Freedom of Information Act
FPS (fps)	Feet Per Second
GE	General Electric (Nuclear Energy)
GE-SMT	General Electric Scale Model Test
HPCI	High Pressure Core Injection (System)
Hz	Hertz (Cycles per Second)
IGSCC	Inter Granular Stress Corrosion Cracking
LIA	Load Interpolation Algorithm
MC	Moisture Content or Moisture Carry-Over
MS	Main Steam (System)
MSIV	Main Steam Isolation Valve
MSL	Main Steam Line
NA	Not Applicable
OLTP	Original Licensed Thermal Power

Acronym List	
Short Form	Description
PPL	PPL Susquehanna, LLC
PSI (psi)	Pounds per Square Inch
PSD	Power Spectral Density
RMS	Root Mean Square
RPV	Reactor Pressure Vessel
SG	Strain Gauge
SIL	Service Information Letter (General Electric)
SMT	Scale Model Testing
SRV	Safety Relief Valve (Main Steam)
SSES	Susquehanna Steam Electric Station
uS	Micro-Strain
2Q2006	2nd Quarter 2006
3Q2006	3rd Quarter 2006

1.0 Executive Summary

Steam dryer structural failures have occurred after implementation of a constant pressure power uprate (CPPU) at a BWR-3 facility. This Attachment contains the PPL Susquehanna, LLC (PPL) approach to evaluate the structural adequacy of steam dryer for CPPU conditions.

Specifically this Attachment summarizes the following:

- The PPL steam dryer analysis plan;
- The results of acoustic resonance analysis (Strouhal Calculations) for main steam line piping configurations;
- The results of Continuum Dynamics Incorporated (CDI) scale model testing (SMT) of the main steam line (MSL) piping configurations; and,
- Observations from recent Susquehanna Steam Electric Station (SSES) steam dryer inspections.

In addition to the above information, PPL will submit two additional licensing supplements which will present a comprehensive evaluation of CPPU steam dryer loading and the resulting steam dryer structural evaluations. The two licensing supplements will contain the following:

- The first supplement will be based on data obtained from main steam line strain gauge (SG) data, which will include main steam isolation valve (MSIV) slow closure testing during the startup of SSES Unit 1 in the Spring of 2006. The data obtained will be incorporated into a finite element analysis (FEA) to determine existing steam dryer structural margins at the current licensed thermal power (CLTP). In addition, the data collected during the MSIV slow closure, which will simulate the approximate steam velocities up to the first step power ascension (113% OLTP), will be also be incorporated into a finite element analysis (FEA) to project dryer stresses at full CPPU conditions (120% OLTP). These results will be used to identify any potential modifications required for the dryer.
- The second supplement will provide the results of the General Electric (GE) 1/18 scale model testing. The intent is to confirm the results obtained from the analysis of strain gauge data taken during the Unit 1 plant startup and to assure all loads are quantified and addressed prior to CPPU implementation. In addition, a limit curve for CPPU power ascension will be provided to confirm acceptable steam dryer structural performance.

This overall approach addresses concerns related to continued integrity of the SSES steam dryers, while allowing for a concurrent review of the balance of the SSES CPPU licensing submittal.

2.0 Background

Steam dryer structural failures have occurred after implementation of a CPPU at a BWR-3 plant in the United States. The failure mode was high cycle fatigue due to fluctuating steam line pressure. The fluctuating pressure induced stresses in the steam dryer components adjacent to the main steam lines in excess of the endurance limit of dryer components. This fluctuating pressure has been traced to flow induced resonance in the relief valve branch lines off of the main steam lines. High main steam line velocities and a susceptible geometry associated with the relief valves combined to create a situation in which the resonance could be sustained at significant amplitude.

As a result of various analyses and tests, PPL has identified several pressure frequency peaks at the current license thermal power (3489 MWth). None of the loads resulting from these peaks appears to be of sufficient amplitude to cause unusual stress levels upon the SSES steam dryer. These peaks will continue to be present at CPPU conditions. The amplitudes of the pressure pulsations are expected to increase as the square of the flow. Analytical techniques, validated by scale model testing and full scale testing will confirm that no new acoustic resonant frequencies will be excited at CPPU power levels.

The SSES main steam (MS) system is being evaluated for susceptibility to fluctuating pressure loads. Several techniques have been identified to evaluate and assure these loads do not develop to the point of causing damage to the SSES steam dryer at CPPU conditions. A balanced approach utilizing analytical methods, scale modeling of the SSES main steam system, plant specific instrumented dryer data, main steam flow data (including data from controlled MSIV slow closures), a structured start-up testing methodology, and continued monitoring of fluctuating pressure within the main steam system will be applied. These methods are described in detail in the body of this report. PPL's approach adequately addresses concerns related to the continued integrity of the SSES steam dryers.

Methods of analysis with regards to steam dryer evaluation are constantly evolving. This has led to difficulties in completing these analyses. As a result, PPL proposes to provide the staff with a comprehensive steam dryer assessment plan in the CPPU license amendment request, and supplemental information in the second and third quarters of 2006. Initial evaluations for predicting and confirming the acoustic loads affecting the SSES steam dryer have been completed. Additional evaluations are ongoing. These additional evaluations are expected to add confidence to the overall prediction of steam dryer stresses, and will determine the need, and scope of dryer modifications, if required. PPL intends to present the additional dryer analyses in two supplements to this document, as described later.

3.0 Discussion

In June 2002, a BWR-3 was operating at approximately 113% of original licensed thermal power (OLTP) when it experienced a failure of a steam dryer cover plate resulting in the generation of loose parts, which were ingested into a main steam line. The most likely cause of this event was identified as high cycle fatigue caused by a flow regime instability that resulted in localized high frequency pressure loadings near the MSL nozzles. In May 2003, the same plant experienced a second steam dryer failure. This second failure occurred at a different location with the root cause identified as high cycle fatigue resulting from low frequency pressure loading.

In August 2003, General Electric issued Services Information Letter (SIL) No. 644 that recommended monitoring steam moisture content (MC) and other reactor parameters for BWR-3-style steam dryers. SIL No. 644 also recommended inspection of the cover plates at the next refueling outage for those plants operating at greater than OLTP.

In October 2003, a hood failure occurred in the sister unit to the BWR-3 which had experienced the previously noted failures. This unit was also operating at CPPU conditions. The observed hood damage and associated root cause determination were virtually the same as the May 2003 failure described above. Subsequent inspections of the above two plants and other BWRs identified incipient and extant cracking at various locations on the dryer.

SIL No. 644 Supplement 1 broadened the earlier recommendations for BWR-3-style steam dryer plants and provided additional recommendations for BWR-4 and later steam dryer design plants planning to, or already operating at greater than OLTP. Following this revised guidance, inspections were performed on plants operating at OLTP, stretch uprate (~5% OLTP), and CPPU conditions. These inspections indicated that steam dryer fatigue cracking could also occur in plants operating at OLTP. Revision 1 to SIL No. 644 described additional significant fatigue cracking that has been observed in steam dryer hoods and provided inspection and monitoring recommendations for all BWR plants.

3.1 BWR Fleet Operating History

Steam dryer cracking has been observed throughout the BWR fleet operating history. The operating environment has a significant influence on the susceptibility of the dryer to cracking. Most of the steam dryer is located in the steam space with the lower half of the skirt immersed in reactor water at saturation temperature. These environments are highly oxidizing and increase the susceptibility to inter-granular stress corrosion cracking (IGSCC). Average steam flow velocities through the dryer vanes at rated conditions are relatively modest (2 to 4 feet per second). However, local regions near the main steam outlet nozzles may be continuously exposed to steam flows in excess of 100 fps. Thus, there is concern for fatigue cracking resulting from Flow-Induced Vibration (FIV) and fluctuating pressure loads acting on the dryer. In addition to the recent instances described above, steam dryer cracking has been observed in the following components at several BWRs: dryer hoods, dryer hood end plates, drain channels, support rings, skirts, tie bars, and lifting rods. This cracking has predominately occurred during OLTP conditions, and is described in GE SIL No. 644.

3.2 BWROG Recommendations

NEDO-33159 was produced for the BWR Owner's Group (BWROG) to provide lessons learned and recommendations for plants implementing CPPU. Sections 3.5 and 3.6 of that document address steam dryer loads and inspections/evaluations, respectively. The two recommendations specific to steam dryers are quoted below:

- An evaluation of steam dryer loads for EPU conditions should be made prior to implementation of EPU. Modifications of the dryer or bases for not making modifications should be made based on the results of this evaluation.

- Follow the inspection and monitoring recommendations of GE SIL 644 and the BWR Vessel Internals Program (BWRVIP) steam dryer inspection guidelines. Incorporate the generic loose parts evaluation included in Section 4 of BWRVIP-06 in future plant specific loose parts evaluations.

PPL has implemented both recommendations, and will continue to follow these guidelines in the future.

3.3 Other Industry Efforts

Since the issue of steam dryer failures has surfaced, utilities considering implementation of CPPU have endeavored to understand the fundamental principles governing the fluctuating pressure loads acting upon their steam dryers. Several techniques have been developed to help understand these principles. The current state of the art relies upon analyses, scale model testing and indirect measurement of steam line pressure fluctuations. These techniques have been continuously refined over the last several years. This refinement has led to the ability for different techniques to compliment each other and add confidence to the results.

3.4 Dryer Design and Fleet Operating Experience

Dryer design, main steam line configuration, and EPU operating conditions have been identified as contributing factors to dryer failures and the subsequent generation of loose parts.

Flow induced loads upon the dryer typically increase as the square of the velocity. The main steam line flow velocities, considered a contributing factor to the dryer failures at two BWR-3 plants, are significantly higher than the MSL flow velocities at SSES. The predicted SSES flow velocities at CPPU are less than the previously mentioned BWR-3 flow velocities at OLTP.

BWR-3 dryers (square hood) are a different design from the SSES dryers, which are of the curved hood design (See Figure 3-1). The square hood dryer designs have structural issues that plants operating with the SSES-type dryer do not. For example, some BWR-3 dryers have diagonal bracing in the square hoods, which contribute to stress concentrations that have led to hood failures.

The lower CPPU MSL flow velocities and the BWR-4/5/6 curved hood design make the SSES dryer less vulnerable to FIV effects. The SSES current licensed thermal power MSL velocities are 136 fps, and are forecasted to increase to 153 fps under maximum licensed CPPU operating conditions. Selected relative plant MSL velocities are shown in the following table:

Table 3-1 - Comparison of Steam Line Velocities Before and After EPU

Reactor Type	*Station/Plant Dryer Design*	*MSL Velocities (average)*	*EPU Operation*	*Notes*
BWR 3	Dresden 2, 3 Square hood	@ OLTP – 168 fps @ CPPU - 202 fps	117% OLTP	207 fps maximum MSL velocity
BWR 3	Quad Cities 1, 2 Square hood	@ OLTP - 168 fps @ CPPU - 202 fps	117% OLTP	226 fps maximum MSL velocity
BWR 3	Vermont Yankee Square hood	@ OLTP – 140 fps @ CPPU – 168 fps	120% OLTP (Pending)	
BWR 4	Brunswick 1, 2 Slanted hood	@ OLTP – 129 fps @ CPPU – 149 fps	U1 – 120% OLTP U2 – 120% OLTP	U1 had satisfactory dryer inspection after a cycle of 113% OLTP. No cover plate/hood fatigue failures.
BWR 4	Hatch 1 Slanted hood Hatch 2 Curved Hood	@ OLTP H1 – 119 fps H2 – 121 fps @ EPU H1 – 134 fps H2 – 140 fps	115% OLTP	No cover plate/hood fatigue failures
BWR 4	Browns Ferry 1, 2, 3 Slanted hood	@ OLTP – 128 fps @ CLTP – 136 fps @ CPPU – 153 fps	120% OLTP (Pending)	U1, 2, and 3 planning 120% OLTP operation
BWR 4	Hope Creek Curved hood	@ CLTP – 145 fps @ CPPU – 167 fps	117% OLTP (Pending)	
BWR 4	**SSES Curved Hood**	**@ OLTP – 128 fps @ CLTP – 136 fps @ CPPU – 153 fps**	**120 % OLTP (Pending)**	

The Brunswick units (slanted hood) are currently licensed to operate at 120% of OLTP. Brunswick Unit 1 had operated for an entire fuel cycle at 113% OLTP prior to increasing power to 120% OLTP. This BWR-4 dryer was inspected after a full cycle of 113% operation and no deleterious FIV effects were identified. The Brunswick Units have now operated near 120% OLTP for more than a year with no observable indications of steam dryer failure.

The slanted hood design used in some BWR-4 units incorporates a slanted hood face section and additional dryer bank stiffener plates, which provide additional restraint to the hood face over the BWR-3 design. The BWR-4 Hatch units have operated at uprated conditions without evidencing significant FIV failures, as experienced on the subject BWR-3 plants of concern. This suggests the combination of BWR-4 dryer design and lower relative MSL velocities has contributed to successful CPPU operation. The SSES curved hood design used in some BWR-4 units and all BWR-5s and BWR-6s incorporate further improvements over the slanted design.

3.5 SSES Steam Dryer and Comparison to Earlier Designs

As stated earlier, the SSES steam dryers are a third generation, curved-hood design as shown in Figure 3-1. The SSES steam dryer curved hood design is an upgrade to the earlier, square hood dryers that failed previously. These upgrades include improved flow characteristics and improved structural strength in the upper part of the dryer.

The early square hood design has 4-foot high dryer vanes, sharp 90 degree corners at various flow points and includes a steam dam (raised plate perpendicular to the top of the dryer). This design inherently generates turbulence as the steam flows through the dryer into the reactor steam dome. Furthermore, the square hood design results in turbulence as the steam flows from the steam dome towards the MS nozzles since the steam encounters the outside 90 degree corners of the outer hoods. The curved hood design has 6 foot high vane banks, eliminates the 90 degree corners and eliminates the steam dam; all of which provide an advantage in reducing turbulence.

The significant structural failures in the uprated BWR-3 dryers were at the outer hood, facing the main steam nozzles. Some square hood designs originally used internal diagonal bracing, which provided support to the hoods only at the upper corner of the hood. The SSES curved hood dryer uses interior, vertical support plates, which provide continuous support along the entire height of the hood and eliminate the need for external gusset plates. The SSES outer hoods consist of 0.5 inch thick curved plate welded to a 0.375-inch thick horizontal cover plate.

Another attribute of the curved hood design is that it has a total of four wide drain channels welded to the outside of the dryer skirt. Each drain channel spans approximately 45 degrees along the circumference of the skirt and spans nearly the full height of the skirt (from the bottom of the upper support ring to just above the bottom ring). These four wide drain channels provide added stiffness to the skirt.

3.6 SSES Recent Dryer Inspection Results

Steam dryer cracking has been observed throughout the BWR fleet operating history. The operating environment has a significant influence on the susceptibility of the dryer to cracking. Most of the steam dryer is located in the steam space with the lower half of the skirt immersed in reactor water at saturation temperature. These environments are highly oxidizing and increase the susceptibility to IGSCC.

IGSCC has been observed on the SSES steam dryer. When these types of cracks are found, they are documented in the SSES Corrective Action Program, and tracked for further degradation.

For the purposes of this evaluation, cracking associated with structural fatigue is the primary concern. GE SIL 644, Supplement 1, as well as BWRVIP-139 describe in detail, inspections to be performed for the evaluation of the SSES dryer type. PPL has adopted the inspection guidelines for both Unit 1 and Unit 2 steam dryers per BWRVIP-139.

Inspection of the Unit 2 dryer in 2005 identified a possible fatigue crack in a dryer bank exhaust end plate weld. At that time, it has been postulated that the weld was of inadequate size or improper depth, since the crack formed down the middle of the weld. The weld was repaired and the dryer returned to service. Subsequently, recent inspections of the Unit 1 dryer in 2006 identified a crack in a symmetrical location, as compared to the Unit 2 crack identified in 2005. The weld will be repaired prior to the dryer being returned to service. Recent finite element analyses of the steam dryer have identified these locations as points of high stress. As a result, this area is acknowledged as requiring a potential need for modifications.

A mechanical failure of the steam dryer can result in increased moisture carry-over past the dryer. One method of identifying whether a dryer has mechanically failed is to periodically measure the main steam moisture carry-over (MC). PPL has begun a program of periodic moisture carry-over measurements. Currently moisture carry-over at SSES is extremely low (0.003%).

3.7 Instrumented Dryer Historical Data

During the first refueling outage for Unit 1, several anomalies were identified on the SSES steam dryer. Most pertinent to this discussion was a fatigue failure of one of the second bank hoods at an end plate. The hood was repaired with a 3/16 inch thick strip 2 inches wide welded over the vertical length of the end of the hood. The other hood to end bank welds were not modified at that time. After repairs were completed, the SSES steam dryer was instrumented with strain gages and accelerometers, and then returned to service.

The data provided by the instrumentation installed on the Unit 1 SSES steam dryer clearly showed a reduction in stress of approximately an order of magnitude at the repair. Subsequently, the other second bank hoods to end plate welds were modified to match the repair. This repair was also applied to the SSES Unit 2 dryer, as well as other curved hood dryers in the BWR fleet.

An additional benefit provided by the instrumentation of the SSES steam dryer in 1986 is a limited set of data which can be used for benchmarking current analyses. These analyses are discussed in the following sections.

4.0 SSES Steam Dryer Analyses

4.1 Strategy

PPL has developed a diverse program of analytical and empirical methods for determining the flow induced loads that the SSES steam dryer will be exposed to during normal operation at CPPU conditions. During the evaluation phase of the SSES CPPU project, the technology and methodology for the evaluation of dryer loads has been evolving. PPL has been following and evaluating industry developments. Improvements in methodologies and applied technologies at other utilities have caused PPL to alter various elements of the dryer program during this time to better model dryer behavior under CPPU conditions. Primary vendors who provide PPL with analyses of the SSES steam dryer have also been refining and changing their methodologies. Some of these changes have impacted the ability of PPL to supply a complete analysis. Therefore, PPL proposes to provide an analysis strategy, with the evaluations completed to-date, and provide a schedule for finalizing the additional analyses.

PPL's strategy employs an analytical evaluation of the SSES main steam system to characterize potential resonant sources. These analyses will be described in detail later in this attachment.

Other evaluations of the SSES main steam system either support, or are expected to support the conclusions drawn from that analytical evaluation. For example:

- MSIV closure tests during the 1986 instrumented dryer tests generated steam line velocities approaching first step CPPU values (111% OLTP), [[

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- One sixth scale mode testing of the specific SSES steam line geometries was utilized to confirm the resonant frequencies analytically predicted for the main steam safety relief valve (SRV) stand-pipes and the A and D dead legs. (See Figure 4-1 for a schematic of the SSES MSL configuration, and Appendix 1 for 1/6 SMT results.)

- An acoustic circuit model (ACM) analysis of the SSES steam lines will be performed in 2Q2006. Numerous strain gages, in close proximity to the vessel, will be utilized to provide accurate measurement of steam line pressure pulsations for baseline load confirmation, and later for power ascension load definition. The loads generated at CLTP will be determined by CDI using a bounding ACM methodology for SSES, based on main steam Mach number. This load definition will be based on either peak pressure, peak root mean square (RMS), or the peak power spectral density (PSD), and will be input to an FEA for baseline stress confirmation.

- MSIV slow closure tests at approximately 80% CLTP will produce approximate flow velocities up to the first step power ascension (113% OLTP) for measurement using the strain gage acoustic circuit model. As with the CLTP load definition discussed above, CDI will use a bounding ACM methodology for SSES; the results of which will be used for an FEA to project dryer stresses at full CPPU conditions (120% OLTP).

- GE is currently analyzing the SSES main steam system utilizing their scale model test facility. The loads generated by this model will be input to multiple FEAs at various power levels between CLTP and full CPPU. These results will become available during the 3Q2006. This effort will also be used to confirm steam dryer stresses at CPPU conditions, as predicted by the MSIV closure strain gauge FEAs.

- Uncertainty evaluations for the various methodologies will be provided.

- A power ascension test plan will be implemented to assure the allowable dryer loads will not exceed predictions during CPPU operation.

PPL will issue supplements to this document as identified in Table 4-1. That table outlines the pertinent elements of the submittal, as described above, and the timeframe for inclusion in the docket. Elements of the program which are provided, or summarized in this attachment are delineated with the letter "A". Those elements to be completed in the second quarter of 2006 (2Q2006) are designated in Table 4-1 with the letter "B", and those elements of the SSES dryer analysis program to be completed in the third quarter of 2006 (3Q2006) are designated with the letter "C". A brief summary of the two supplements follows:

- The first supplement will be provided in 2Q2006. It will be based on data obtained from main steam line strain gauge data, which includes MSIV slow closure testing during the startup of Unit 1 in the Spring of 2006. The data obtained will be incorporated into a finite element analyses to determine existing steam dryer structural margins at CLTP, and projected dryer stresses at CPPU conditions. These results will be used to identify any potential modifications required for the dryer.

- The second supplement will be provided in 3Q2006. This analysis will provide the results of the GE 1/18 scale model testing. The intent is to confirm the results obtained from the plant startup, and assure all loads are quantified and addressed prior to CPPU implementation.

The following sections describe techniques and methodologies for predicting and measuring acoustic dynamic loads upon the SSES steam dryer.

Table 4-1 - SSES Steam Dryer Analysis Summary

Power level	1986 Instrumented Dryer	Instrumented Dryer FEA	CDI-ACM Venturi Input	GE ACM FEA	CDI SMT	CDI & GE Strouhal calc	CDI-ACM Strain input	GE ACM Strain FEA	GE-SMT Input	GE-SMT FEA	Un-certainty analysis	Power ascension limit curve
OLTP	A	A	NR	NR	A	A	NR	NR	NR	NR	NR	NR
CLTP	X	X	A	X	A	A	B	B	C	C	C	NR
113% OLTP	X	X	X	X	X	A	B	B	C	C	NR	C
120% OLTP	X	X	X	X	X	A	X	B(1)	C	C	C	C
Peak Strouhal	X	NR	X	X	A	A	X	X	X	X	X	X

Legend:

- A Denotes an element of the dryer strategy which is provided or summarized in this attachment to the SSES CPPU Licensing Submittal.
- B Denotes an element of the analysis which will be submitted via a supplement to the submittal in the 2Q2006.
- B(1) The results of the strain gauge acoustic FEA at 113% OLTP will be projected to the 120% CPPU level stress conditions.
- C Denotes an element of the analysis which will be submitted via a supplement to the submittal in the 3Q2006.
- X Denotes information that cannot be obtained.
- NR Denotes information that is not required, or not used for the SSES RPV steam dryer evaluation.

4.2 Primary Factors Contributing To Increased Dryer Loading

Steam line velocity is a contributing factor to dryer acoustic loads. The minimum contribution is a flow-velocity-squared increase in some existing loads as steam line velocity increases due to CPPU. If resonant sources are excited due to the increase in steam velocity, a rapid increase in amplitude of fluctuating pressure pulsations can occur. The previously mentioned BWR-3 dryer damage is believed to be a direct result of excitation of an acoustic resonance in the relief valve stand pipes at the affected units. Due to the design of BWR main steam piping systems, the relief valve stand pipes are the most likely source of resonant behavior affecting the steam dryer.

It is possible to calculate the resonant frequency of branch lines which are of interest from a dryer acoustic loading standpoint. To excite the resonance of a branch line, the steam line velocity must fall into a critical range. The physical behavior associated with this critical velocity is the formation of specific vortices at the opening of the branch line. The velocity that generates these vortices has been defined in academic papers and is typically represented by the Strouhal number.

There are variations of the Strouhal number used for different applications. Two values of the Strouhal number are of interest. One represents the onset of acoustic resonance and the other represents the peak acoustic resonance. Generally, resonant onset occurs at Strouhal numbers less than about 0.55. Peak resonance occurs around values of 0.40. These values can be affected by branch line to steam line transition geometry.

The Strouhal numbers described above identify the primary and most significant onset velocities for acoustic resonance of branch lines. There is, however, a less significant onset velocity which can generate a pair of vortices at the branch line opening. This velocity is approximately one-half of the primary onset velocity defined above. This secondary velocity onset occurs at Strouhal numbers of about 0.9 with a peak at approximately 0.85. The magnitude of the resonance, however, is very low compared to the resonance at Strouhal values around 0.40.

4.3 SSES Analytical Results

The range of critical flow velocities in the SSES Main Steam Lines (MSL) which are most likely to cause shear wave resonance were estimated for the HPCI line, RCIC line, Drain lines, and Relief Valves. In addition, Strouhal calculations have been performed by to estimate the effects of the "A" & "D" SSES MSL dead legs.

4.3.1 Methods

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4.3.2 Analysis

Table 4-2 shows the estimated acoustic frequencies for the HPCI, RCIC, Drain lines and Relief Valve.

Table 4-2 SSES Acoustic Frequencies

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Table 4-3. GE Test Data – Strouhal Numbers

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Figures 4-2 through 4-5 illustrate the acoustic modes for the HPCI, RCIC, Drain lines, and Relief Valve. [[

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The acoustic mode of the SSES "A" and "D" dead leg MSLs was characterized utilizing a similar approach. Strouhal calculations indicate that these lines would result in a 16.4 Hz response.

4.3.3 Analytical Conclusions

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- The acoustic mode of the SSES "A" and "D" dead leg MSLs indicate that these lines result in a 16.4 Hz response. [[

]] The CDI Scale Model Testing, described in Section 4.6.1, has concluded that the acoustic pressure of this response should increase as a function of the flow-velocity-squared relationship.

4.4 Acoustic Circuit Model

Analytical methods for determining the frequency of acoustic loads is well developed, as is the ability to determine the steam flow rates for onset of these loads. However, a method for analytically determining the magnitude of these loads to a high degree of certainty is not well developed. Therefore, a method to empirically determine acoustic loading on the steam dryer is desired.

The most common practice for BWR plants wanting to quantify acoustic loads upon steam dryers is to utilize an acoustic circuit model (ACM). This method has been utilized for several years and has undergone various refinements. These refinements have resulted in improved confidence in the ability of the model to predict dryer loads due to acoustic phenomena.

The model relies on detailed dimensions of the steam lines and steam dome area of the reactor pressure vessel (RPV). The steam line information feeds into the acoustic circuit analysis and the steam dome/steam dryer information feeds a Hemholtz solution. This information supports the creation of the analysis portion of the model.

The model requires dynamic inputs of steam line pressure pulsations. These are typically supplied as pressure-time history profiles. The dynamic inputs to the model can be supplied by several different methods. Some of the original acoustic circuit models used pressure-time histories generated from main steam line flow venturis, and vessel level reference leg data. Subsequent analyses have utilized strain gages installed on the main steam lines for input. The strain gage approach is generally accepted as the more accurate method for measuring steam line pressure fluctuations.

PPL has produced an acoustic circuit model using main steam line venturi instrument leg data. PPL has also made preparations for installation of strain gages during the Spring 2006 refueling outage to provide more accurate pressure-time histories. In addition, the strain gage approach will be utilized to monitor steam dryer loading during power ascension for both SSES Units. In the future, the acoustic loads will be determined by CDI using a bounding ACM methodology for SSES, based on main steam Mach number. This load definition will be based on either peak pressure, peak root mean square (RMS), or the peak power spectral density (PSD), and will be input to the planned finite element analyses.

4.4.1 Venturi Instrument Leg Data Source

An acoustic circuit model of SSES Unit 2 was performed utilizing main steam line venturi instrument leg pressure transducers to generate the raw data for the pressure-time histories. For that analysis, the "Modified 930 Mwe Benchmark" model was utilized.

The venturi instrument leg acoustic circuit model of the steam lines has inherent inaccuracies introduced for several reasons. In particular, the distance from the steam lines to the measurement transducers is large, with several branch lines adding complication to the circuit analysis.

At the time it was first decided to use the acoustic circuit model, instrument leg measurements were thought to be the most practical method for obtaining the pressure-time histories. It has subsequently been determined that using strain gages for pressure measurement is more desirable. PPL intends to supplement the results of the instrument leg ACM with results from strain gage measurements.

As a result of these inaccuracies, the measurements obtained to-date do not provide meaningful data which can be used to asses current dryer margins. However, the data collected does provide evidence that dryer loads at SSES increase as a function of the flow-velocity-squared relationship (see CDI Figures 4-7 through 4-10), [[

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4.4.2 Main Steam Line Strain Gage Data Source

The sensitivity of strain gages is more than adequate to measure the behavior of the main steam lines due to pressure pulsations within those lines. The strain gage approach to generate pressure-time histories necessary for the acoustic circuit model is significantly more accurate than the instrument leg approach. However, a shortcoming of the strain gage method is the effect of pipe movement (vibration) on the results. To eliminate the effect of the signals generated by pipe movement, the strain gages are arranged in a manner that cancels those superfluous signals. This is accomplished by placing four sets of gauges 90 degrees apart circumferentially at each location on the steam line.

Some other applications of main steam strain gauges for pressure measurement have not eliminated the effects of pipe movement. None-the-less, this is an acceptable approach, as it is conservative, since the pipe movement is an additive signal to the SG measurements. In most recent applications, strain gages are positioned at points on the steam lines that:

- Give rise to accurate determination of attenuation from the source of acoustic loads by locating the sets of strain gages on any line approximately 40 feet apart, particularly improving low frequency (>15 Hz) amplitude resolution.
- Improve extrapolation of loads to the steam dome by placement of the strain gages in close proximity of the main steam nozzles.

PPL will be installing strain gages on the SSES Unit 1 main steam lines during the Spring 2006 outage. The installation will incorporate recent improvements mentioned above to improve both reliability and accuracy of the pressure measurements. Some of these recent improvements also improve the resolution of the acoustic circuit model. In addition, PPL will install similar instrumentation on Unit 2 in the Spring of 2007 to support CPPU power ascension testing.

Installation of strain gages and refinement of the acoustic circuit model for SSES is being undertaken in order to improve confidence in the results of the various other methods used to characterize dryer loads at current conditions and predict loads at CPPU conditions. PPL is using steam line acoustic circuit analysis to add confidence to the analytical predictions.

The results of the GE Scale Model Tests (GE-SMT) of the SSES steam dryer, which will be complete in the third quarter of 2006, will be used to supplement and confirm the Unit 1 steam line acoustic analysis.

4.5 MSIV Closure Tests

During the 1986 instrumented dryer tests, pressure measurements were taken during the sequenced closing of MSIVs at 84 percent OLTP. Closure of a single MSIV at 84 percent OLTP results in velocities for the other three steam lines increasing to the equivalent of approximately 111% OLTP, or more than 5 percent above CLTP nominal steam velocities.
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Using this same principle, PPL intends to perform MSIV closure tests at approximately 80% CLTP during the Spring of 2006. These tests will simulate approximate steam velocities up to the first step power ascension (113% OLTP). This data will be projected to CPPU loadings, which will be used as inputs to a CPPU FEA. The results of this CPPU FEA will be used to determine the need for, and potential scope of modifications, if required.

At this point it should be noted that this technique may not be 100% representative. Closure of MSIVs will yield useful steam line behavior for individual lines. It may not, however, fully capture the effects of steam line interactions within the steam dome. It also cannot isolate the interactions beyond the equalizing header in the turbine building. (Drip legs are unaffected by steam line isolation since they are located beyond the equalizing header). Nonetheless, the data obtained from this technique is expected to be useful in identifying high amplitude resonance in individual steam lines, should it occur.

Since it is acknowledged that data from the MSIV closures may not completely represent main steam line velocities and interactions at CPPU conditions, PPL is proceeding with the GE 1/18 scale model testing as described below. The results of the GE scale model testing results will then be used to supplement and confirm the data from the MSIV closures.

4.6 Scale Model Testing

Another method for predicting dryer acoustic loads is to utilize reduced scale test facilities to model the behavior of the SSES steam system. Two methods are being utilized by PPL.

The first is specific to the most likely expected sources of acoustic loads. This method models just the section of pipe containing the SRVs, and the section of pipe adjacent to the SSES main steam dead legs (see Figure 4-1). Since these are the expected sources of acoustic phenomena at SSES, the sections are modeled in order to define the precise acoustic components produced by the sections. This is referred to as the Continuum Dynamics Inc. Scale Model Test (CDI-SMT).

The second scale model utilized is produced by GE, and models the entire steam line system from the dryer to the turbine. The GE model will be referred to herein as the GE-SMT. It is modeled in sufficient detail to reproduce significant acoustic signals that may be generated from many different sources. The GE-SMT produces a composite of loads upon the dryer, as opposed to the CDI-SMT, which is specific to two acoustic sources (i.e., the main steam dead legs, and SRV standpipes). The load definition produced by the GE-SMT will be used as inputs to FEA, the results of which will be provided to the staff in 3Q2006.

4.6.1 CDI Scale Model Testing (CDI-SMT)

The CDI-SMT is described, and results presented in Appendix 1. As stated above, this model is specific to the two acoustic sources considered to be most likely to produce significant acoustic loads. It's main purpose is to verify analytical results for resonance frequency, onset steam velocities, and peak steam velocities.

The findings from the CDI scale model testing suggest that no new discrete frequency sources of acoustic excitation from the main steam lines are expected when increasing power from CLTP to CPPU conditions. This subscale testing indicates that no new flow induced vibration loads should play a role in the pressure loads to be experienced by the SSES steam dryers at CPPU conditions. This also supports the expectation that the steam dryer loads will increase as a function of the flow-velocity-squared relationship. (See Appendix 1.)

With respect to SSES "A" and "D" dead leg MSLs, a 16.4 Hz response, [[ ]], was expected (based on Strouhal calculations), and observed. It is interesting to note that this frequency response has also been observed at other BWR plants without dead legs. For these plants, this response has been attributed to a turbulent flow phenomenon in the RPV steam dome. Quantification of this response is expected pending the outcome of the GE scale model testing described in Section 4.6.2 below.

The results of the CDI-SMT conclude that normalized acoustic RMS pressures from the dead-headed main steam branch lines, and from the SRV standpipes do not increase in amplitude as power is increased from CLTP to CPPU conditions. It is therefore anticipated that dryer loads will increase from CLTP to CPPU conditions as a function of the flow-velocity-squared relationship. The results of the GE-SMT, described in Section 4.6.2 below will confirm the effects of this response at CPPU conditions.

4.6.2 GE Scale Model Testing (GE-SMT)

Also known as the acoustic load definition (ALD) process, the GE-SMT is a 1/18 scale facility utilized to model the entire steam line system from the steam dryer to the turbine.

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Fluctuating pressure loads for use with the Susquehanna steam dryer will be determined from scale model testing of the dryer design and resultant acoustic modeling performed in the GE scale model testing facility. [[

]] The scale model test apparatus has been benchmarked against Quad Cities Unit 2 instrumented dryer data. This benchmark confirms the capability of the GE scale model test methodology to predict the steam dryer acoustic load definitions.

[[

]] This model [[

]] an input into the load interpolation algorithm. [[

]]

4.7 Finite Element Analyses

The 2005 main steam line venturi instrument leg based acoustic circuit model FEA indicated areas of high stress on the steam dryer. For reasons stated in Section 4.4.1, the venturi instrument leg based ACM generates very conservative loads. Due to these conservatisms, the FEA based upon the main steam line venturi data can not be used to evaluate existing steam dryer stress margins nor determine the need for steam dryer modifications for CPPU conditions. Therefore, PPL intends to submit several future finite element analyses (FEA) to demonstrate the current and predicted behavior of the SSES steam system.

A higher resolution load definition, as determined by strain gauge measurements will be provided to quantify steam dryer structural margins. This FEA will be provided in a submittal supplement during the second quarter of 2006, based upon the strain gage acoustic circuit model at CLTP power levels. PPL will also submit a CPPU power level FEA based on ACM data taken during MSIV closures discussed in Section 4.5. This analysis will provide an initial assessment of CPPU dryer stresses. This analysis will be provided with CLTP FEA results in the 2Q2006 supplement.

In the third quarter of 2006, an FEA based upon the results of the GE Scale Model Test (GE-SMT) will be submitted. The GE-SMT FEA will provide predictions of dryer stresses at CLTP, the interim uprate level (113% OLTP) and the CPPU power level (120% OLTP). Discussions addressing the uncertainties and anticipated CPPU stress levels associated with these FEAs will be provided at that time.

4.7.1 106% OLTP (Current Licensed Thermal Power)

This FEA has been estimated, based on the instrument leg acoustic circuit model. As noted above, the pressure data poses a high degree of uncertainty and is not useful in evaluating steam dryer margins. Although PPL believes this analysis to be conservative, based upon the inherent conservatisms of the ACM, PPL has determined that this data will result in abnormally high predicted steam dryer loads. The result of this high loading would suggest that PPL consider dryer modifications that may be unnecessary.

FEAs will be performed utilizing the strain gage acoustic circuit model. These FEAs will take advantage of improved resolution to demonstrate that margins are actually greater than predicted by using the instrument leg method. The results of these FEAs will include CLTP conditions, and the results of MSIV slow closure, which will simulate approximate steam velocities up to the first step power ascension (113% OLTP). An FEA will project dryer stresses at full CPPU conditions (120% OLTP), which will be used to define the basis for the need, and scope of dryer modifications, if required. These results will be provided in a supplemental report to be issued in 2Q2006.

Additional FEAs will be performed utilizing the GE-SMT dryer loads. These FEAs serve two main purposes. First, they will add confidence to the results previously presented. Second, agreement with the strain gauge ACM FEAs will serve as a benchmark for the SSES specific GE-SMT. These FEAs will be included in the 3Q2006 supplement.

4.7.2 113% OLTP (1st Step CPPU)

An FEA will be performed using the results of MSIV slow closure, which will simulate approximate steam velocities up to the first step power ascension (113% OLTP). In addition, an FEA will be also performed using the GE-SMT data at the interim power CPPU power level (113% OLTP). The results of this FEA will be provided in the 3Q2006 supplement.

4.7.3 120% OLTP (CPPU)

PPL will submit a CPPU power level FEA based on strain gauge data taken during MSIV closures as discussed above. This analysis will provide an initial assessment of CPPU dryer stresses, and will be used to define the need, and scope of potential dryer modifications. This analysis will be provided with CLTP FEA results in the 2Q2006 supplement.

A final FEA will be performed using the GE-SMT data at the full CPPU power level (120% OLTP). The results of this FEA will be provided in a supplemental report to be issued in the 3Q2006.

4.8 Uncertainty Discussion

4.8.1 Acoustic Circuit Method Uncertainty

With respect to the CDI methodology used for acoustic circuit analysis, it is difficult to assign quantitative values of uncertainty. Although the methodology is consistent, each model is unique to the particular plant geometry. An appropriate comparison can be made to computer codes such as those used for containment response. Such codes are generally accepted by the NRC, and are conservative for the approved uses. However, a value of uncertainty cannot be assigned. It is the level of conservatism that is expected to bound the uncertainty.

Generally, the acoustic circuit model is conservative in the loads it predicts for the steam dryer. The following paragraphs are quoted from CDI Report 05-28P (Bounding Methodology to Predict Full Scale Steam Dryer Loads from In-Plant Measurements - CDI Proprietary). In that report, CDI quantifies the conservatism inherent in the acoustic circuit model. From that report, approximately twice the conservatism applied to Quad Cities has been assigned to SSES. Estimates that utilize the SSES venturi acoustic circuit model tends to confirm this conservatism, as mentioned in Section 4.4.1. The following paragraphs are quoted from the subject CDI report:

> "Measured in-plant pressure time-history data in the four main steam lines of Quad Cities Unit 2, inferred from strain gage data collected at two positions upstream of the ERV standpipes on each of the main steam lines, were used with Continuum Dynamics, Inc.'s acoustic model of the QC2 steam dome and steam lines to predict steam dryer loads. The strain gage data were first converted to pressures, and were then used to extract acoustic sources in the system. Once these sources were obtained, the model was used to predict the pressure time histories at 27 locations on the steam dryer, where pressure sensors were positioned. These predictions were then compared against data from the pressure sensors, and the model was modified to meet acceptance criteria based on degree of conservatism in the predictive loads.
>
> These results provide an acoustic circuit model that bounds the pressure loads on a steam dryer, thereby enabling the dryer to be analyzed structurally for its fitness during power ascension and CPPU operations.
>
> Analysis of Quad Cities Unit 2 at power levels of 790, 842, and 930 MWe, which correspond to main steam line Mach numbers of 0.113, 0.122, and 0.135, respectively, show that the predictions are most conservative for lower Mach

numbers. Since the Quad Cities units (1 &2) have the highest main steam line Mach numbers in the domestic fleet at CPPU conditions, the model can be confidently used with data taken from other plants to conservatively compute steam dryer loads during power ascension."

Therefore, the recommended model for CPPU conditions is shown to have acceptable conservatism.

4.8.2 Finite Element Analyses Uncertainty

The analysis at full CPPU will confirm that the steam dryer will accommodate the predicted SMT dryer loads under normal operation, transient and accident conditions at full CPPU. 120% OLTP is the maximum licensed power level that PPL has chosen for CPPU implementation and plans to operate both Susquehanna Units at or near this power level for the remaining life of the plants. Uncertainty analysis in the form of a letter report will be provided by GE to quantify margin to acceptance criteria at 120% OLTP conditions. The following is a discussion of the uncertainty which will be considered in determining the structural adequacy of the dryer and/or modifications.

Modeling Uncertainties

Uncertainties in the finite element analysis can be contributed to:
[[

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Application and Measurement Uncertainties

Uncertainties can be introduced when applying the finite element methodology to a plant analysis. In general, these uncertainties can be introduced by the following:
[[

]]

A review of the geometric differences between the two SSES units will be performed. A single analysis will be performed if it can be determined that the differences between the two units will not produce a significant difference in the fatigue analysis results otherwise a separate analysis will be performed for the second unit.

4.8.3 Scale Model Test Uncertainty

The load definition used for the dryer will be confirmed with a scale model test prediction. The uncertainties associated with the generation of a plant-specific load definition consist of uncertainties and assumptions inherent in the scale model test methodology, test measurement and scaling uncertainties, and plant-specific modeling uncertainties.

Modeling Uncertainties

[[

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Test Measurement Uncertainties

The test measurement uncertainties are introduced in the parameter measurement process. In general, these uncertainties consist of the sensor accuracy, sensor and sensor loop calibration, environmental influences (e.g., reference leg temperature effect on the plant

pressure measurement), and signal conversion (e.g., differential pressure to flow). The parameters of interest in the SMT load definition process are:
[[

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Application Uncertainties

Uncertainties can be introduced when applying the SMT load definition methodology to a plant analysis. In general, these uncertainties are introduced by the following:
[[

]]

For SSES, a review of the geometric differences between the two units will be performed. If necessary, parametric tests will be performed to quantify the uncertainty introduced by the differences between the two units. The uncertainties determined will be documented in the SSES SMT load definition report.

Load Interpolation Algorithm & Acoustic Finite Element Model

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The uncertainty associated with the application of the load interpolation algorithm will be quantified by comparing the algorithm predictions with the input measurements. This will be documented as part of the SSES SMT load definition report.

4.8.4 Power Ascension Testing Uncertainty

Monitoring is performed during power ascension in order to confirm the load definition predictions and, if necessary, to provide input into a corrected load definition for updating the structural analysis. The technique that has been employed in the past has been to measure the dynamic pressures in the steam lines and then use the steam line pressures to infer the loading on the steam dryer. Strain gauges are used to measure the hoop stress in the pipe; the pressure inside the steam line is then calculated based on the hoop stress. The uncertainties associated with power ascension testing measurements are:

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These uncertainties will be addressed as part of the power ascension limit curve development to be submitted with the second supplement.

5.0 Power Ascension Plan

For power ascension, GE will prepare a limit curve to be used to confirm acceptable steam dryer structural performance. This limit curve for power ascension will be based upon FEA stress results from full CPPU conditions.

The main steam lines for both Units 1 and 2 will be instrumented with strain gauges to obtain acoustic vibration data during uprate power ascension. The measured strain values, converted to pressure, will be compared with the allowable values (acceptance criteria) obtained from the scale model steam lines to confirm that the dryer alternating stresses are within the structural analysis basis. An uncertainty analysis will be performed to calculate the expected uncertainty in the measurements.

The primary function of this vibration measurement program is to confirm that the actual pressure loading on the dryer during power operation is consistent with the pressure loading assumed in the structural fatigue evaluation and to verify that the steam dryer can adequately withstand the acoustic vibration forces. The primary objectives are as follows:

a. Provide a controlled approach to power ascension.

b. Provide start-up test acceptance criteria for comparison with measured strain gauge readings during power ascension.

c. Verify the steam dryer analyses performed for the CPPU conditions:

During power ascension, a specific set of hold points will be defined to limit the power ascension to approximately 4 percent steps. The main steam line strain gages will be monitored against established limits to assure the structural integrity of the steam dryer is maintained. If resonant frequencies are identified and increase above the predetermined criteria, power ascension will stop and power will be lowered to a known acceptable level. The acceptability of the dryer for the measured loading will be evaluated and revised operating limits defined as required.

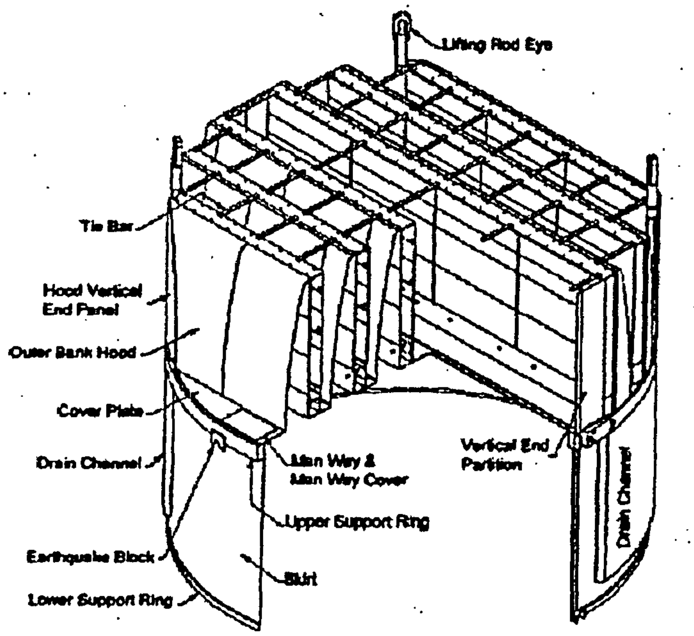

Figure 3-1 - SSES RPV Steam Dryer Curved Hood Design

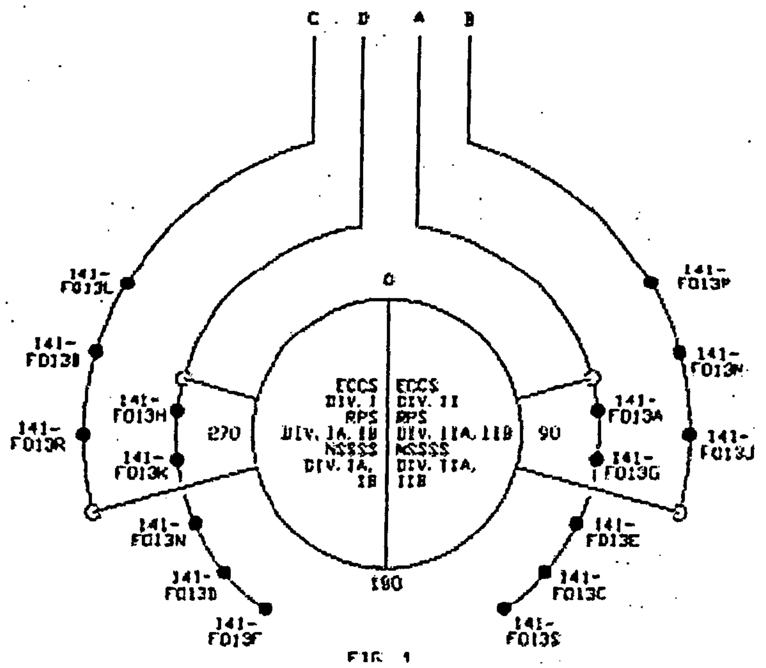

Figure 4-1 - SSES Steam Line Configuration Inside Containment

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Figure 4-2 - HPCI Steam Supply Line Shear Wave Resonance

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Figure 4-3 - RCIC Steam Supply Line Shear Wave Resonance

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Figure 4-4 - Drain Line Shear Wave Resonance

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Figure 4-5 - Relief Valve Standpipe Shear Wave Resonance

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Figure 4-6 - 1986 Instrumented Dryer Test Pressure Data

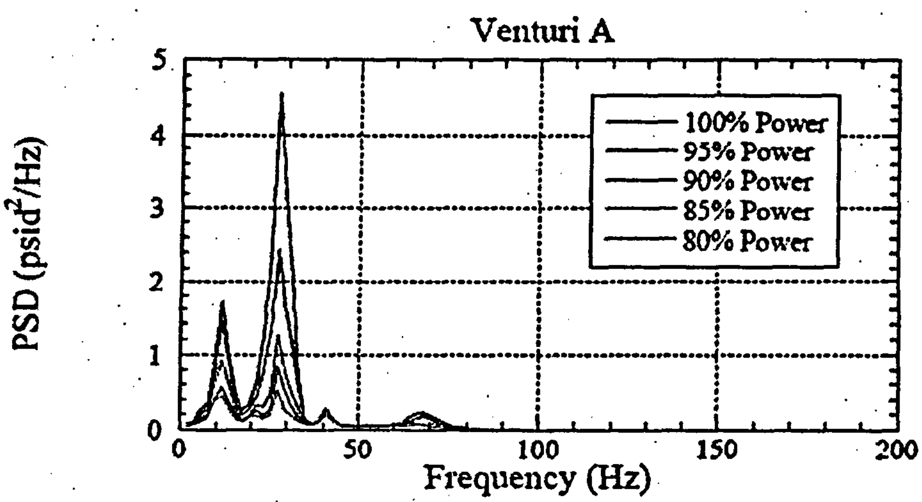


Figure 4-7 - Instrument Leg CDI-ACM Data For Steam Line "A"

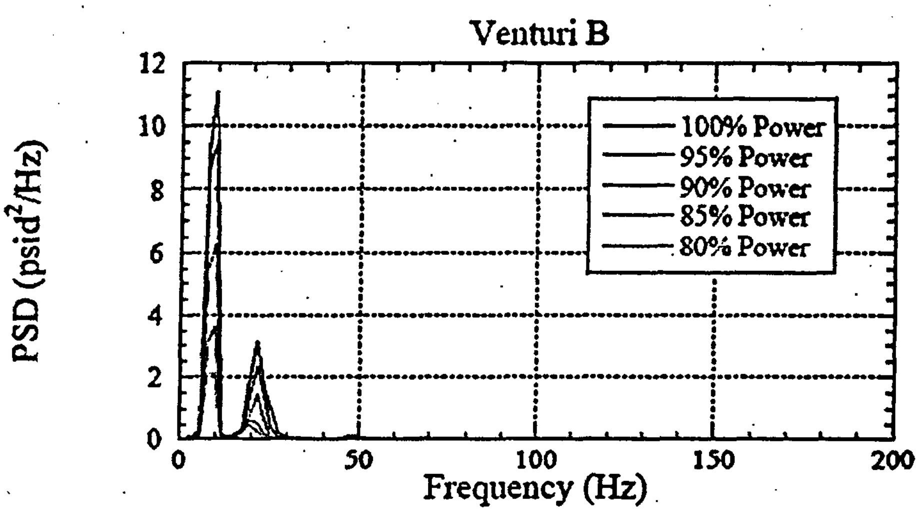


Figure 4-8 - Instrument Leg CDI-ACM Data For Steam Line "B"

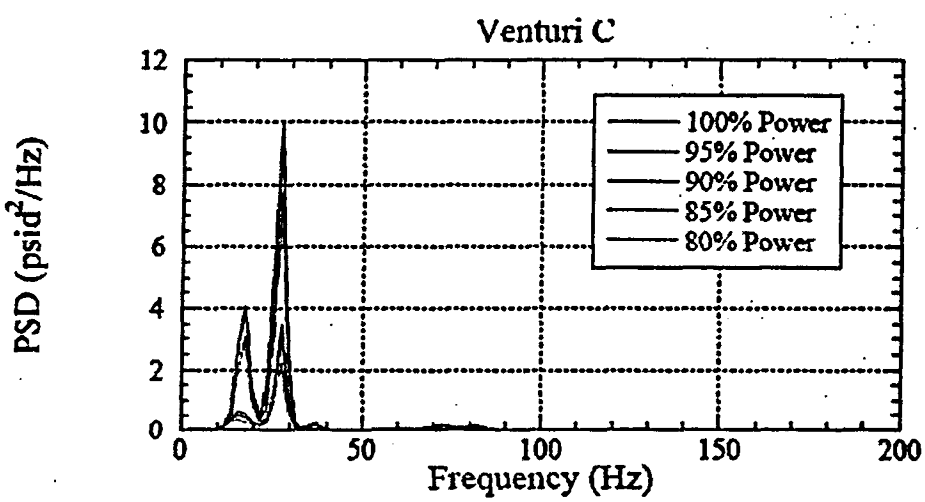


Figure 4-9 - Instrument Leg CDI-ACM Data For Steam Line "C"

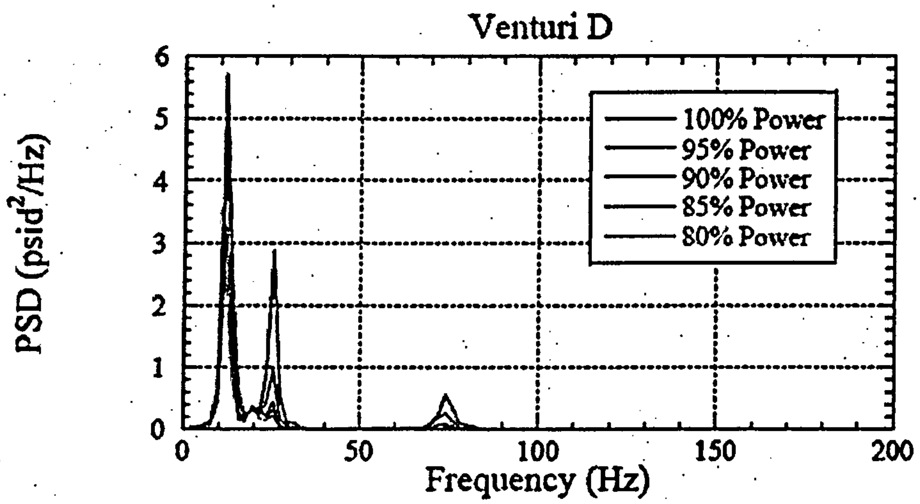


Figure 4-10 - Instrument Leg CDI-ACM Data For Steam Line "D"

APPENDIX 1

Onset of High Frequency Flow Induced Vibration in the Main Steam Lines at Susquehanna Unit 2: A Subscale Investigation of Standpipe Behavior
Continuum Dynamics Inc.
March 2006

(SSES CDI Scale Model Test Report)

C.D.I. Report No. 05-32

Onset of High Frequency Flow Induced Vibration in the Main Steam Lines at Susquehanna Steam Electric Station: A Subscale Investigation of Standpipe Behavior

Revision 0

Prepared by

Continuum Dynamics, Inc.
34 Lexington Avenue
Ewing, NJ 08618

Prepared under Purchase Order No. 303035-C for

PPL Susquehanna, LLC
2 N 9th Street
Allentown, PA 18101-1179

Approved by

Alan J. Bilanin

March 2006

Executive Summary

As part of the engineering effort in support of power uprate at Susquehanna Steam Electric Station, Continuum Dynamics, Inc. undertook a subscale examination of the standpipe/valve geometry on two of the four main steam lines, in an effort to validate the frequency onset at which flow induced vibration, resulting from standpipe/valve resonance, could potentially impact steam dryer loads. In this study Continuum Dynamics, Inc. constructed a nominal one-sixth scale model of two of the main steam lines at Susquehanna Steam Electric Station, then tested the as-built configuration of standpipes and Crosby valves as appropriate. The findings suggest that no new discrete frequency sources of acoustic excitation from the main steam lines are to be expected when increasing power from CLTP to EPU conditions.

This effort provides PPL with a subscale test that suggests that new flow induced vibration loads should not play a role in the pressure loads to be experienced by the Susquehanna steam dryer at EPU conditions.

Table of Contents

I. Introduction

As part of its effort in support of power uprate at Susquehanna Steam Electric Station (SSES), PPL Susquehanna LLC contracted with Continuum Dynamics, Inc. (C.D.I.) to evaluate existing main steam line data (collected on venturi instrument lines) to estimate the pressure loads expected on the steam dryer at Current Licensed Thermal Power (CLTP). These results [1] suggest that the steam dryer stresses are acceptable at CLTP conditions. To go to higher EPU power levels, PPL requested that C.D.I. evaluate the potential for flow induced vibration (FIV) in the main steam lines as a result of resonance of the as-built standpipe/valve combination. Studies conducted by Exelon for Quad Cities Unit 1 and Unit 2 suggested that the excitation of the standpipe/valve should be explored, as this mechanism was most responsible for the pressure loading experienced on the Quad Cities steam dryers [2].

The high frequencies associated with FIV are known to correspond to a resonance associated with the inlet standpipes connected to safety valves, and have been the source of problems in several power plants in recent years [3–6]. Specifically, in [6], C.D.I. conducted a series of tests in support of damage that was observed on Columbia's main steam line safety valves. These tests concluded that the geometry of the Columbia standpipes and safety valve inlets, with flow conditions of approximately 60% to 70% of licensed power, resulted in a resonance at approximately 1050 Hz in a scaled facility (corresponding to approximately 204 Hz in the plant). The observation was made that properly scaled tests could provide data that could be used for design.

At the request of PPL, C.D.I. applied the insights gained from the study on Columbia to the SSES standpipe/valve configuration modeled protypically, as both Susquehanna units are essentially identical for the purpose of this analysis. This report summarizes the test results on two single main steam line scaled configurations.

II. Objectives

Construction of a high Reynolds number subscale test facility, simulating two of the main steam lines at SSES, was done so as to achieve the following goals:

1. Confirm that FIV of the relief valve standpipes will only occur at power levels which exceed EPU conditions.

2. Validate the analytical predictions of FIV onset power level and frequency of oscillation estimated in [7] for Crosby valves and standpipes, as built on Susquehanna main steam lines B and C.

3. Measure the FIV from Susquehanna main steam lines A and D resulting from their dead-headed branch lines as a function of power level.

III. Theoretical Approach

A subscale test facility is proposed as a means of measuring the effect of standpipes on the anticipated acoustic signal to the steam dome. A description of the phenomenon at work, analytical tools to be used, and scaling laws justifying the subscale tests are given here.

3.1 Side Branch Excitation Mechanism

The phenomenon of flow-excited acoustic resonance of closed side branches has been examined for many years (see as early as [8] and [9]). In this situation acoustic resonance of the side branch is caused by feedback from the acoustic velocity of the resonant standing wave in the side branch itself. Figure 3.1 illustrates the typical geometry used here and in the standpipes at SSES. The main steam line flow velocity U approaches an open side branch of diameter d and length L. Pressure p as a function of time t can be measured at the closed end of the pipe. The flow velocity induces perturbations in the shear layer at the upstream separation location in the main steam line. As these perturbations are amplified and convected downstream, they interact with the acoustic field and produce acoustic energy which reinforces the resonance of the acoustic mode. Ziada has studied this effect extensively [10–12], and has shown that the flow velocity of first onset of instability U_{on} corresponds to a typical Strouhal number of St = 0.55, where St is defined as

$$St = \frac{f(d+r)}{U_{on}} \tag{3.1}$$

where d is the diameter of the standpipe, r is the radius of the inlet chamfer, and f is the first mode of acoustic oscillation in the pipe system. A design chart that more accurately infers St, based on d and the diameter D of the main steam line, may be found in [10].

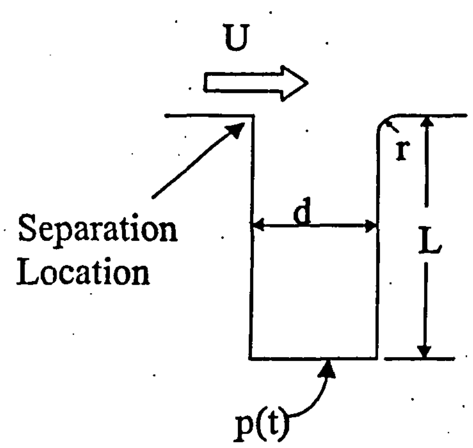


Figure 3.1. Schematic of the side branch geometry.

Solving for U_{on} in Equation (3.1), it may be seen that the onset velocity is linearly proportional to the standpipe diameter, so long as that diameter does not change the first acoustic mode frequency of the standpipe.

The implications of this side branch excitation frequency may be seen by examining the behavior of the pressure response as a function of Strouhal number (Figure 3.2). For large Strouhal numbers (beginning on the right side of the figure), the RMS pressure p_{RMS} begins increasing (at a specific onset Strouhal number and flow velocity U_{on}, depending on acoustic speed a, pipe diameter d, and pipe length L), reaches a peak value, then decreases. Flow velocity increases from right to left in this figure, where it may then be seen that this phenomenon – if it occurs in a standpipe/valve configuration – will occur at a low power level, reach a peak effect, then diminish and possibly disappear at sufficiently high power levels.

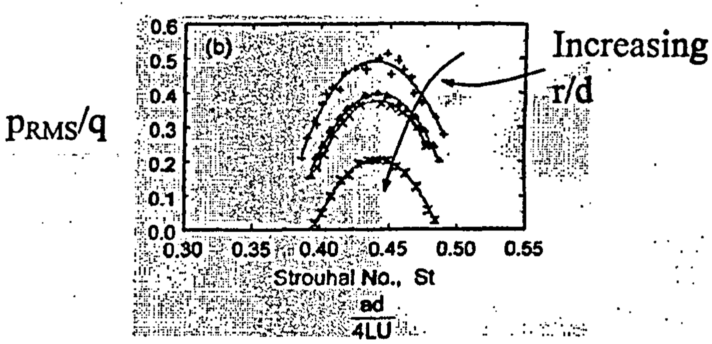


Figure 3.2. Strouhal number behavior, where q is the dynamic pressure ($\frac{1}{2}\rho U^2$), ρ is the fluid density, and a is the acoustic speed.

Initially, it may be anticipated that the first mode frequency f_1 can be approximated by the quarter-standing wave frequency of the standpipe/valve combination

$$f_1 = \frac{a}{4L} \tag{3.2}$$

Since the standpipe/valve combination changes area as a function of distance from the main steam line to the valve disk, a more accurate estimate of f_1 may be generated by including these area change effects. The combination of an accurate excitation frequency f_1 and subsequent calculation of onset velocity U_{on} with the appropriate Strouhal number then characterizes the behavior of the standpipe/valve combination considered.

3.2 Scaling Laws

By non-dimensional analysis, it may be shown from the physical parameters considered in Figure 3.1 that the unsteady pressure p(t) is

$$\frac{p(t)}{\frac{1}{2}\rho U^2} = \text{fcn}\left[M = \frac{U}{a}, Re = \frac{\rho U d}{\mu}, \frac{d}{D}, \frac{d}{L}, \frac{tU}{D}\right] \tag{3.3}$$

where ρ is the density of the fluid, μ is the absolute viscosity of the fluid, M is the Mach number, and t is time. This scaling law, developed previously by C.D.I. under EPRI sponsorship [13], shows that if acoustic phenomena are to be preserved at subscale, it is critical to preserve the Mach number M between full-scale and subscale tests. Since the nuclear power plant uses steam as a working fluid and the tests to be undertaken will use compressed air, the velocities U_s in the subscale facility will be related to the velocities U_f in the plant by

$$U_s = U_f a_s / a_f . \tag{3.4}$$

Since the acoustic speed in steam at plant operating conditions is nominally $a_f = 1600$ ft/sec and the speed of sound in air is $a_s = 1100$ ft/sec, the air speeds in the subscale rig will be less than in the plant by the ratio of 11/16.

Assuming that the scale factor of the facility is $s = L_s/L_f$, where L_s and L_f are characteristic dimensions of the subscale and full-scale plant, respectively, it was also shown in [13] that the frequencies measured in the subscale rig f_s are related to those in the plant f_f by

$$f_s = f_f a_s / (a_f s) \tag{3.5}$$

so that frequencies measured at subscale are in general higher than in the full-scale plant. For the 1.0/5.87 scale tests reported herein, the frequencies measured in the subscale facility are to be multiplied by 0.2478 to obtain full-scale frequencies.

Lastly, it was shown in the previous equation and in [13], and has been reported by others as well [11], that acoustic pressures at fixed Mach number scale with the dynamic pressure in the system, and therefore scale with the system stagnation pressure. Therefore, to maximize the signal to be measured, the subscale tests should be conducted at as high system pressures as practical. It is straightforward to show that the fluctuations in pressure at subscale p_s are related to the pressure fluctuations at full scale p_f by

$$p_s/p_f = (P_s/P_f)\,(a_s^2/a_f^2) \tag{3.6}$$

where P_s and P_f are the stagnation pressures at subscale and in the plant, respectively. This relationship establishes that if it is desired to measure full-scale pressure fluctuations at subscale, the subscale system pressure would need to be raised by a_f^2/a_s^2 or by about 110% above the plant pressure, assuming air is used in the subscale facility.

Also, if subscale tests are contemplated, care should be exercised in test design to carry out the tests at as high a Reynolds number as practical, until it can be shown that the phenomenon to be investigated is insensitive over the Reynolds number ranges of interest. The

Reynolds number is defined here as the products of the steam density, steam velocity, and main steam line pipe diameter, divided by the absolute viscosity of steam or air. Since the absolute viscosity is only temperature dependent, and if acoustic phenomenon are to be examined (the velocities are fixed by Mach number scaling as discussed above), it is the product of the gas density times the diameter of the pipe that can be used to control the Reynolds number between scales. The important observation made here is that if a test is conducted where the diameter D is reduced from full scale to subscale by the scale factor s, it is advisable to increase the density of the gas by 1/s, or at least as much as practical. By conducting tests using air to replace 1000 psia steam and reducing the test rig by the scale factor s, the Reynolds number R_s of the subscale test to that of the plant R_f is

$$\frac{Re_s}{Re_f} \approx \frac{P_s}{P_f}\frac{L_s}{L_f} \tag{3.7}$$

where it has been assumed that steam can be analyzed by assuming it behaves as a perfect gas. The above relationship suggests again that subscale tests be conducted at high pressures, the higher the better. Preserving Reynolds number at subscale in general would require subscale pressures to exceed full scale pressures. Fortunately, previous testing has indicated that exact similitude of Reynolds number is not required.

Finally, it should be noted that Ziada [10] argued that while subscale tests must be used with care when inferring amplitudes, the onset of the resonance appears to be reasonably insensitive to scale. It is suspected that this observation is probably a result of the fact that onset infers infinitesimal motion, when nonlinear dissipative processes are not yet strong.

IV. Test Approach

The purpose of the testing effort is to confirm that the standpipes on the main steam lines are not excited at power levels between CLTP and EPU conditions. To do so, a 1.0/5.87 scaled test facility was constructed that represents two of the main steam lines at SSES, from the steam dome to past the standpipes. However, only one main steam line was tested at a time.

4.1 Test Design

An examination of the main steam line geometry enables evaluation of the most representative steam line at SSES. Previous work by Ziada [10] suggests that the Strouhal number is strongly dependent on the distance from the last upstream elbow to the standpipe. An examination of available SSES drawings provides the distance summary shown in Table 4.1. The closest standpipe at SSES is on main steam line B. For this reason the valves were positioned as if on this main steam line. A 1.0/5.87 scale model of main steam line B was developed principally from drawing numbers FCIP-51-2953-1 (MSL A), FCI-P51-2952 (MSL B), and FCIP-51-2951-1 (MSL C and D) previously supplied by Susquehanna, and is shown schematically in Figure 4.1.

From drawings, pictures, and additional information supplied by PPL, an approximate cross-sectional area of the Crosby valve – as a function of distance from the main steam line – was generated. This cross-section includes the Sweepolet inlet, standpipe length and diameter, mating flange to the valve, and internal valve geometry to the closed end of the valve. The scaled configuration is shown in Figure 4.2.

4.2 Pre-Test Predictions

An acoustic model of the standpipe/valve combination was used to make pre-test predictions of the excitation frequency (single standpipe/valve combinations). These predictions are shown in Table 4.2.

Table 4.1. Standpipe location summary at SSES.

Main Steam Line	Distances From Upstream Elbow (ft)
A	Dead-Headed Branch Line
B	3.33, 7.50, and 11.50
C	3.46, 7.63, and 12.86
D	Dead-Headed Branch Line

Table 4.2. Pre-test predictions of excitation frequency and onset velocity.

Configuration	Excitation Frequency (Hz)	Onset Velocity (ft/sec)
Crosby as built	217.3	253.7

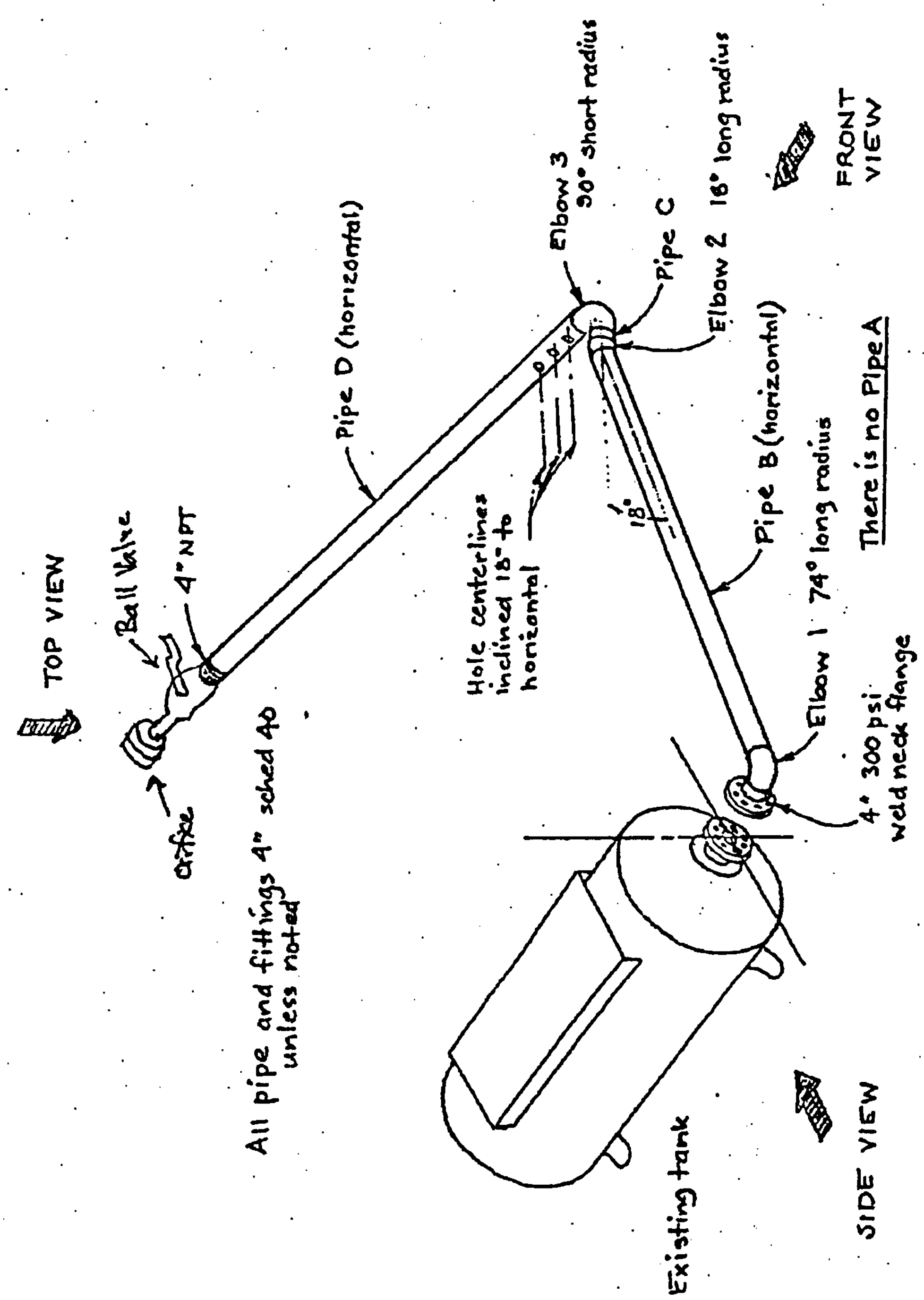


Figure 4.1. Schematic of SSES main steam line B. The tank is pressurized to 200 psig, then the ball valve is opened and flow ensues through the system. The orifice plate sets the Mach number in the pipe.

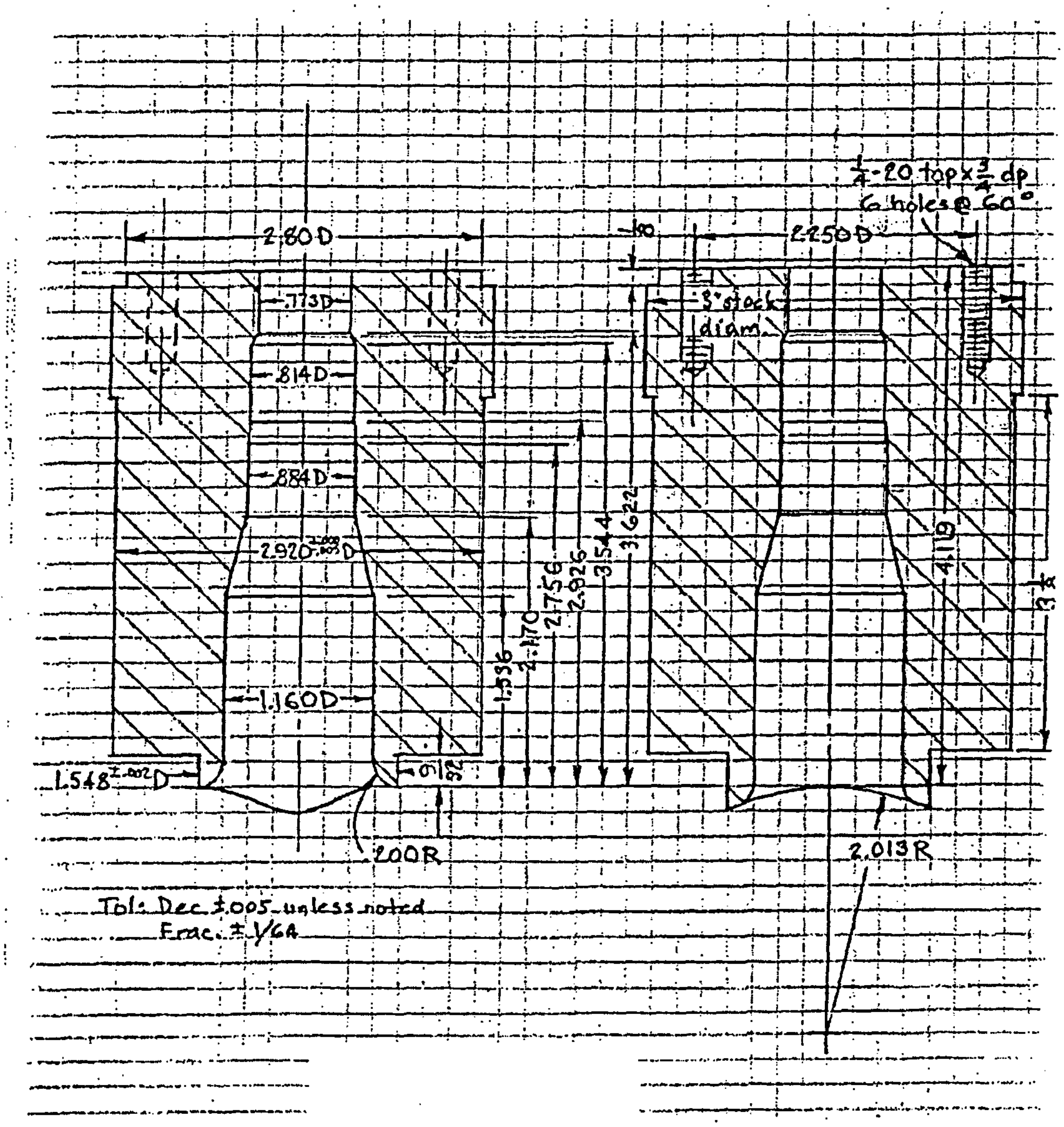


Figure 4.2. Cross-section of scaled standpipe and Crosby valve (all dimensions are in inches).

4.3 Dead-Headed Branch Lines

SSES main steam lines A and D position five standpipe/valves on dead-headed branch lines. To investigate FIV of this configuration, a second subscale steam line was constructed, as shown in Figure 4.3. Here the standpipe/valves were not expected to contribute significantly to the quarter wave frequency of the dead-headed branch line, and were therefore fabricated by pipes of the same diameter as the standpipes, but with a length that would recover the excitation frequency of the standpipe/valve combination as given in Table 4.2. As the branch lines are both approximately 24.0 feet in length (line A is 24.12 ft, while line B is 24.21 ft), the quarter standing wave frequency at full scale (Equation 3.2) is 16.6 Hz (for an acoustic speed of 1609 ft/sec). An acoustic circuit model of the dead-headed branch line with the five standpipes actually predicted a quarter standing wave frequency of 16.4 Hz. The purpose of testing is to determine if measured amplitudes in this line are a function of power level between CLTP and EPU operating conditions.

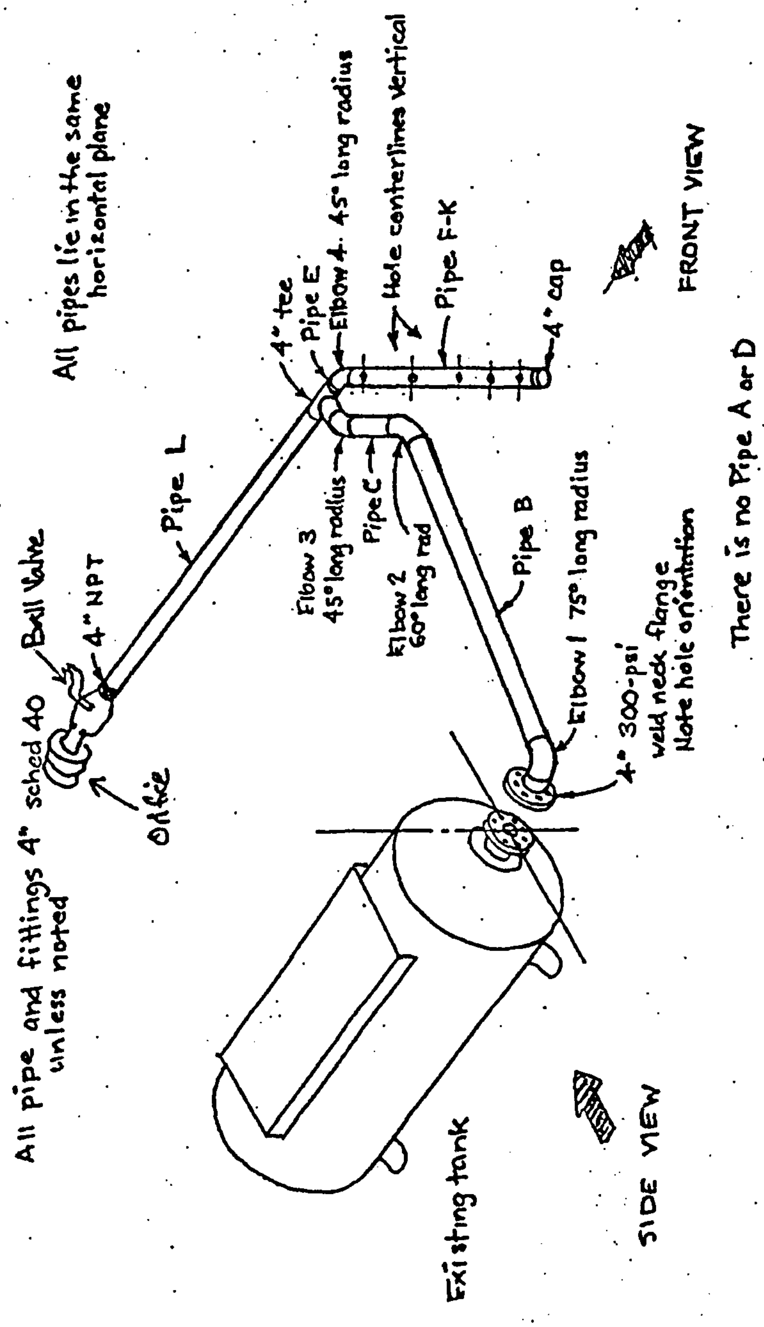


Figure 4.3. Schematic of SSES main steam lines A and D. The tank is pressurized to 200 psig, then the ball valve is opened and flow ensues through the system. The orifice plate sets the Mach number in the pipe.

V. Test Apparatus and Instrumentation

Test apparatus for the PPL testing program (Figure 5.1) consists of a pressure tank, a system of pipes to model full scale steam lines, a set of interchangeable model pressure relief valves, a ball valve, and a set of interchangeable orifices.

5.1 Experimental Facility

The test apparatus was assembled in the C.D.I. laboratory (Figures 5.2 and 5.3). The tank is a 250 gallon steel pressure vessel that was hydro tested to 300 psig. The piping is 4 inch Schedule 40 steel pipe with welded seams, flanged to the tank. The valve models were fabricated from PVC blocks, to replicate the standpipe and the valve geometry tested. A cross-sectional sketch of the subscale standpipe/valve configuration used in the study was shown previously in Figure 4.2.

The sizes on the orifices were selected so as to achieve the Mach numbers desired in the test (see Section 5.2). CLTP and EPU specific plant conditions correspond to main steam line Mach numbers of 0.0872 and 0.0999, respectively.

The system is charged from a Champion MNPL30A two-stage compressor, 10 HP, 250 psig maximum, with 37.3 CFM displacement.

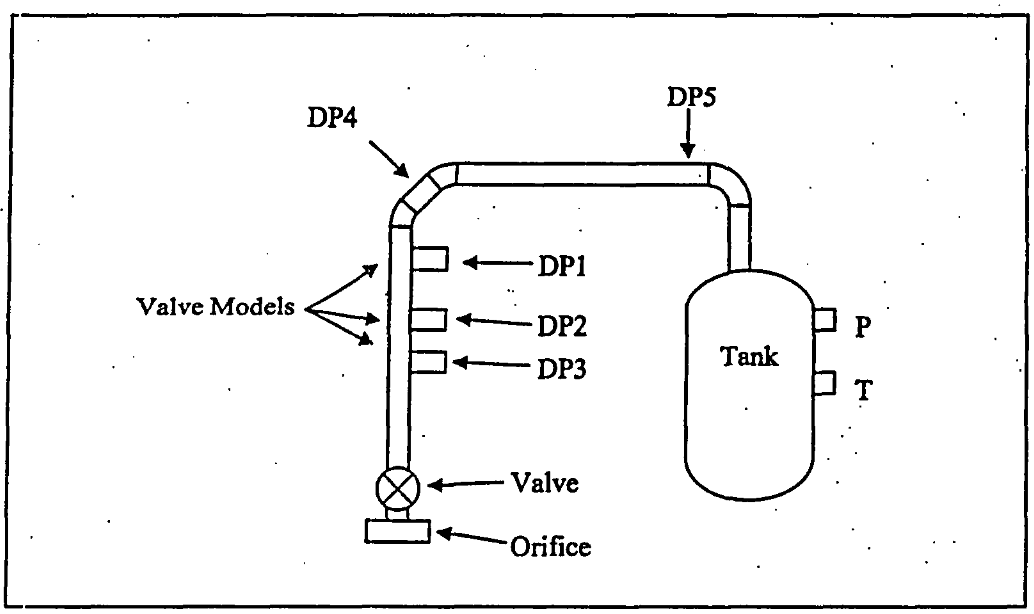
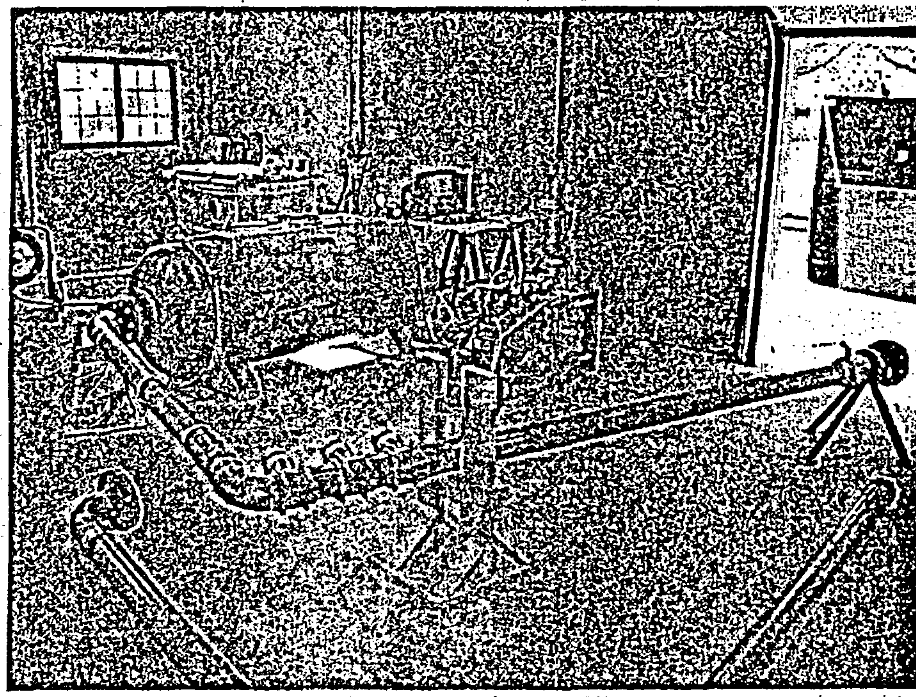


Figure 5.1. Schematic of test apparatus, where P is static pressure, T is temperature, and DP1 to DP5 are unsteady pressure transducers.



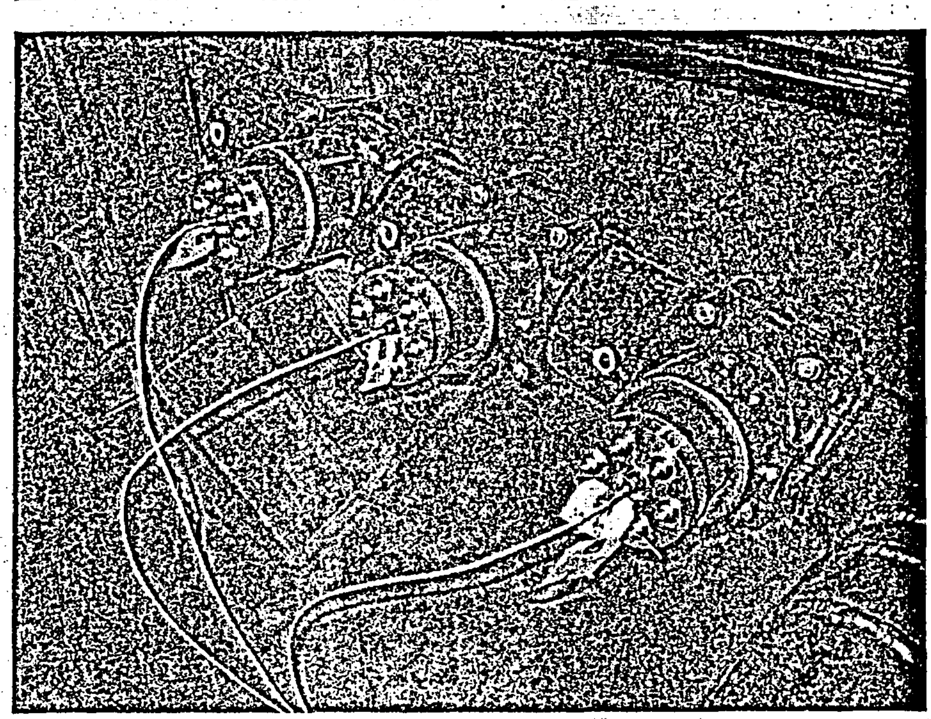


Figure 5.2. Photographs of the SSES blowdown facility: entire scaled main steam line B (top); the three standpipe locations (bottom).

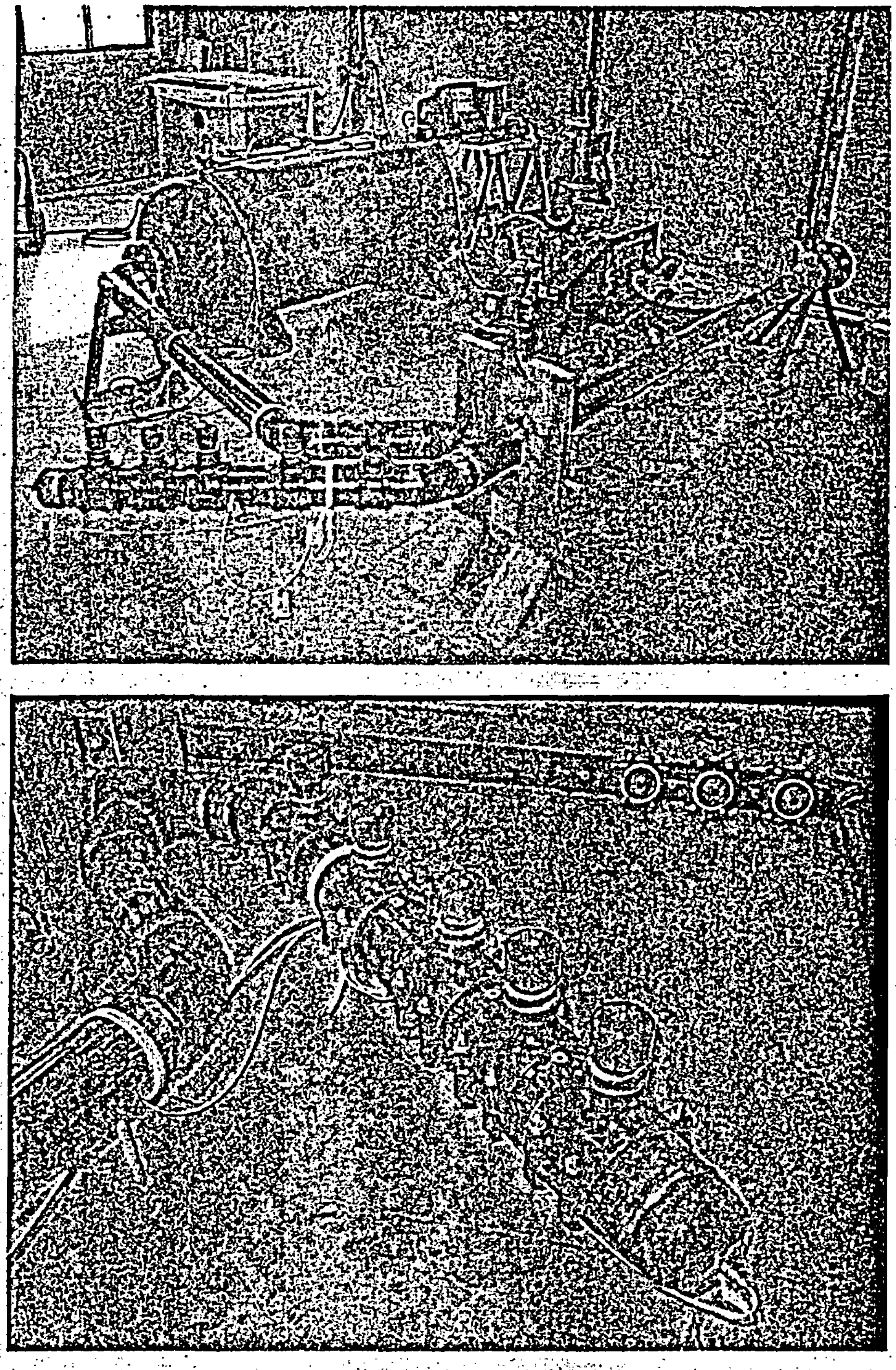


Figure 5.3. Photographs of the SSES blowdown facility: entire scaled main steam lines A and D (top); the dead-headed branch line (bottom).

5.2 Orifice Size

When the pressure in the tank is sufficiently high, the flow will be choked at the orifice and the Mach number in the pipe can be determined by using an assumption of compressible isentropic flow. It may be shown [14] that

$$\frac{A}{A^*}=\frac{1}{M}\left[\left(\frac{2}{\gamma+1}\right)\left(1+\frac{\gamma-1}{2}M^2\right)\right]^{\frac{\gamma+1}{2(\gamma-1)}} \tag{5.1}$$

where A is the area of the pipe, A* is the effective area of the orifice, M is the Mach number, and γ is the ratio of specific heats, equal to 1.4 for air. The effective area of the orifice is equal to the discharge coefficient C_D times the actual orifice area. The value of C_D for the present effort is 0.85 [15], so that $A^* = C_D A_a$, where A_a is the actual area of the orifice.

The relationship between orifice diameter and Mach number is shown in Figure 5.4. The Mach numbers at CLTP and EPU (0.0872 and 0.0999, respectively) were obtained from specific plant conditions supplied by PPL at these two full-scale power settings, with an acoustic speed of 1609 ft/sec.

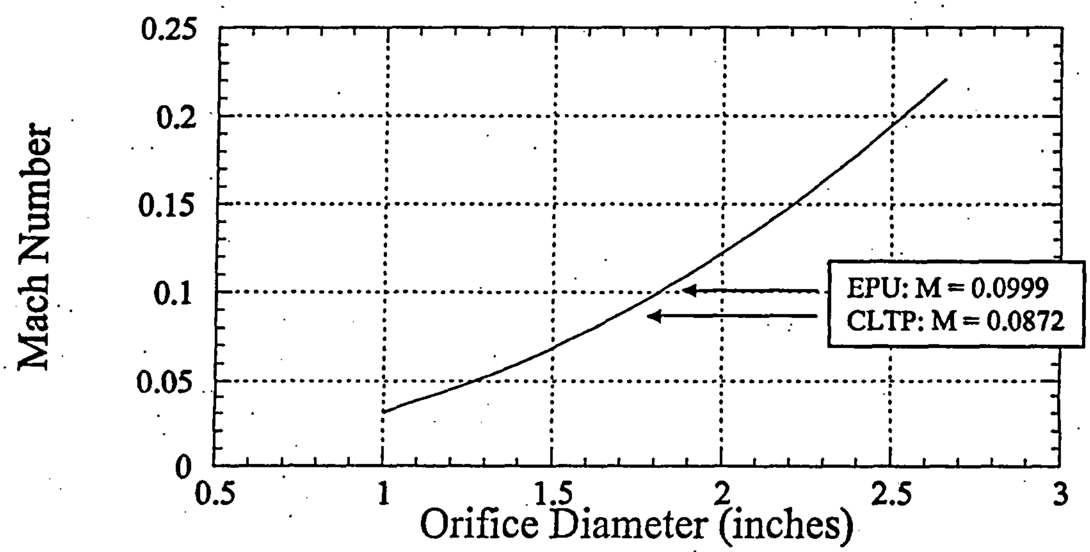


Figure 5.4. Behavior of Mach number with orifice size.

Table 5.1 tabulates the physical orifice diameters tested, steam line Mach numbers, and plant power levels as a percentage of EPU power.

Table 5.1. Plant power and main steam line (MSL) Mach numbers, where the CLTP Mach number = 0.0872 and the EPU Mach number = 0.0999.

Orifice Diameter (inch)	MSL Mach Number	% EPU Power
1.003	0.0302	30.2
1.270	0.0487	48.7
1.390	0.0585	58.6
1.510	0.0690	69.1
1.630	0.0805	80.6
1.724	0.0901	90.2
1.812	0.0996	99.7
1.854	0.1044	104.5
1.899	0.1096	109.7
2.000	0.1218	121.9
2.087	0.1329	133.0
2.187	0.1462	146.3
2.400	0.1772	177.4
2.657	0.2194	219.6

5.3 Instrumentation and Data Acquisition

The test apparatus is fitted with transducers to measure static pressure in the tank, temperature in the tank, unsteady pressure at the three valve locations, and unsteady pressure at two additional locations directly on the line. A typical wiring diagram is shown in Figure 5.5.

Voltage signals from the various instruments are sampled by a Cyber Research CMF 3202DA A/D board. The board resides in an eMachines T3882 PC running Microsoft Windows XP and a custom A/D application.

Static pressure measurements are provided by an Omega PX302-200GV pressure transducer (CDI 0568) powered by an Omega PSS-10 10 volt power supply. The output voltage is fed to a differential channel on the A/D system.

Temperature is measured by an Omega thermocouple (CDI 0545) powered by an Omega High Performance Temperature Indicator DP41-TC display unit (CDI 0544). The display unit samples and conditions the thermocouple signal and produces a voltage suitable for a differential channel of the A/D system. Since the sampling rate of the display unit is less than the sampling rate of the A/D system, a trace of the temperature signal captured by the A/D system displays a "staircase" effect during blowdown when the temperature changes rapidly.

Unsteady pressures, whether measured at the top of the model valves or directly on the piping system, are provided by Kistler Piezotron Pressure Transducers Model 211B4 (CDI 0011, 0012, 0013, 0014, and 0015), via a four-channel Kistler Power Supply/Signal Conditioner Type 5134 (CDI 0495) and a Sunstrand Piezotron Coupler signal conditioner (CDI 0024).

Connections between the A/D system and the pressure transducer, the temperature display, and the unsteady pressure signal conditioners are configured the same way for all tests. Connections between the unsteady pressure transducers and their signal conditioners vary according to valve installation.

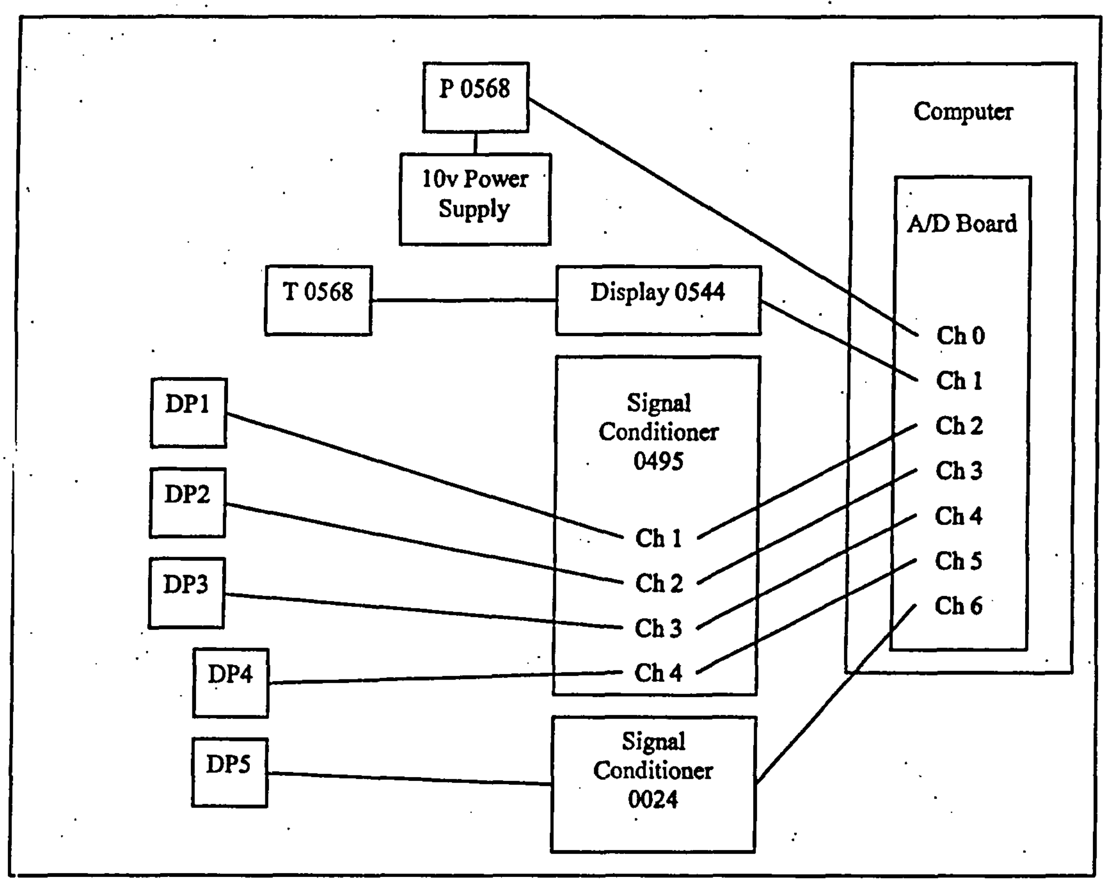


Figure 5.5. Schematic of data acquisition system with five DP transducers

VI. Test Matrix

The test matrix is summarized in Table 6.1.

Table 6.1. Test matrix. Main steam line B/C tests are identified by three letters (X, Y, Z), where X corresponds to the upstream valve, Y corresponds to the middle valve, and Z corresponds to the downstream valve (see Figure 5.1). Main steam line A/D tests are identified by two pressure transducers on the dead-headed branch line. Terminology: CR = Crosby valve; DPE = pressure transducer at the end of the dead-headed branch line; DPM = pressure transducer at the middle of the dead-headed branch line.

Test	Date	Orifice (inch)	Notes
BC Test 1	12/15/05	1.510	CR, CR, CR
BC Test 2	12/15/05	1.510	CR, CR, CR
BC Test 3	12/15/05	1.854	CR, CR, CR
BC Test 4	12/15/05	1.854	CR, CR, CR
BC Test 5	12/15/05	1.854	CR, CR, CR
BC Test 6	12/15/05	1.854	CR, CR, CR
BC Test 7	12/15/05	2.657	CR, CR, CR
BC Test 8	12/15/05	2.657	CR, CR, CR
BC Test 9	12/15/05	1.630	CR, CR, CR
BC Test 10	12/15/05	1.724 (1)	CR, CR, CR
BC Test 11	12/15/05	1.812 (2)	CR, CR, CR
BC Test 12	12/15/05	2.000	CR, CR, CR
BC Test 13	12/15/05	2.087	CR, CR, CR
BC Test 14	12/15/05	2.187	CR, CR, CR
BC Test 15	12/15/05	2.400	CR, CR, CR
AD Test 1	12/22/05	2.657	DPE, DPM
AD Test 2	12/22/05	1.003	DPE, DPM
AD Test 3	12/22/05	1.003	DPE, DPM
AD Test 4	12/22/05	1.854	DPE, DPM
AD Test 5	12/22/05	1.854	DPE, DPM
AD Test 6	12/22/05	1.854	DPE, DPM
AD Test 7	12/22/05	1.510	DPE, DPM
AD Test 8	12/22/05	1.630	DPE, DPM
AD Test 9	12/22/05	1.812 (2)	DPE, DPM
AD Test 10	12/22/05	2.000	DPE, DPM
AD Test 11	12/22/05	2.087	DPE, DPM
AD Test 12	12/22/05	2.187	DPE, DPM
AD Test 13	12/22/05	2.400	DPE, DPM
AD Test 14	12/22/05	2.657	DPE, DPM

Tests denoted with (1) indicate an orifice size approximating CLTP conditions.
Tests denoted with (2) indicate an orifice size approximating EPU conditions.

VII. Test Procedure

7.1 Data Collection

For each run, the tank is pressurized with air to a static pressure of approximately 200 psig. A custom computer program for A/D collection is started and commands the A/D board inside to begin collecting data for a period of 15 seconds. Signals on all connected channels are collected at a rate of 4000 samples/second/channel and stored in a disk file. Immediately following the start of data collection, the ball valve near the orifice is opened quickly, and the pressurized air in the tank and the piping system escapes through the orifice until equilibrium with atmospheric pressure is achieved. The pressure time history data are stored in a data file for subsequent analysis.

7.2 Data Reduction

The data reduction procedure to reduce measured pressured fluctuations to normalized power spectral density (PSD) results is now described. Raw pressure measurements from pressure transducers in the standpipes are high-pass filtered to remove the slow transient associated with the change in system (total) pressure. A third-order Butterworth filter with cutoff frequency of 2 Hz is used here. The data are processed using a forward-reverse filtering technique resulting in zero phase shift and sixth-order roll-off characteristics in the stop band. The filtered pressure fluctuations are normalized by the dynamic pressure at CLTP, which is derived from measurement in the reservoir (total) pressure and the flow Mach number. The total pressure is low-pass filtered, with cutoff frequency of 2 Hz, to remove high frequency noise, using a similar technique for the standpipe pressure sensors. Time histories of normalized pressure fluctuations are used to estimate the PSD for each transducer, which is determined using Welch's averaged periodogram method. The normalized pressure fluctuations are separated into 400-point (100-msec) overlapping blocks that are de-trended and windowed using a Hanning weighting to reduce side-lobe leakage in the PSD estimate. This approach provides PSD estimates with frequency resolution of 10 Hz with maximum Nyquist frequency of 2000 Hz (sampling rate was 4000 Hz). A MatLab (Version 6.5 Release 13, from The MathWorks, Inc.) program is used for data reduction.

A typical pressure time history in the tank is shown in Figure 7.1. Resulting normalized PSD plots for all tests are shown in Appendix A.

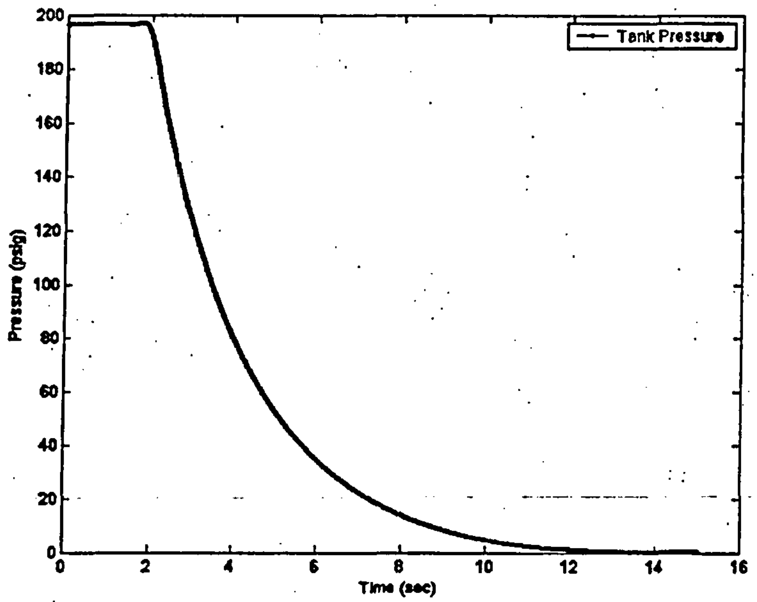


Figure 7.1. Stagnation pressure time history.

VIII. Results

The purpose of the PPL study was to characterize the behavior of the standpipe/valve combination currently at SSES. To this end, the results of the numerous tests conducted by C.D.I. may be examined with regard to excitation frequency, Mach number, onset velocity, and dead-headed branch line effects.

8.1 Excitation Frequency

A comparison of measured excitation frequencies (frequencies where peaks in the PSDs are recorded in the subscale experiments) with pre-test predictions (from Table 4.3) is shown in Table 8.1. The predicted excitation frequency is based on a single standpipe/valve, while the full-scale excitation frequency is obtained by averaging all measured excitation frequency data taken for the standpipe/valve combinations tested, as summarized in Table 6.1, and scaling to full scale (by multiplying the measured excitation frequency by 0.2478). These results suggest a close agreement between experimental results and theoretical predictions.

Table 8.1. Comparison between predicted and measured excitation frequencies for SSES.

Configuration	Predicted Excitation Frequency (Hz)	Measured Excitation Frequency (Hz)	Full-Scale Excitation Frequency (Hz)
Crosby as built	217.3	875.2	218.1

8.2 Mach Number

The PSD results shown in Appendix A provide a good indication of peak response for standpipe/valve behavior at specific Mach numbers. However, a better metric is the root mean square (RMS) of the recorded signal. This parameter was determined by integrating the PSD from 100 to 1000 Hz, then taking the square root to recover the RMS pressure level. These results will now be examined.

The subscale tests swept Mach number by changing orifice size (increasing orifice size to increase Mach number as seen in Figure 5.4). The effect of Mach number on maximum normalized RMS pressure may be seen in Figure 8.1. The curve shown here includes (for Mach numbers between 0.07 and 0.15) a double vortex mode, followed (for Mach numbers between 0.15 and above) by a single vortex mode (vortex mode nomenclature is discussed in [11]). The double vortex mode is reminiscent of the Strouhal curve, shown in Figure 3.2. It may be seen that the EPU Mach number (0.1050) is near the peak pressure for the double vortex mode excitation of the standpipe/valve.

The double vortex mode peaks at a Mach number of approximately 0.11. It has been suggested in [12] that the peak pressure in the double vortex mode should be at least one order of magnitude lower than the peak pressure in the single vortex mode. Figure 8.1 shows that the single vortex mode peak was not reached in the tests, although the figure does suggest that the double vortex mode peak will be at least a factor of eight smaller that the single vortex mode peak. It would appear prudent for PPL to check whether any pressure oscillations in the main steam lines were observed at frequencies above 200 Hz, at or above CLTP conditions.

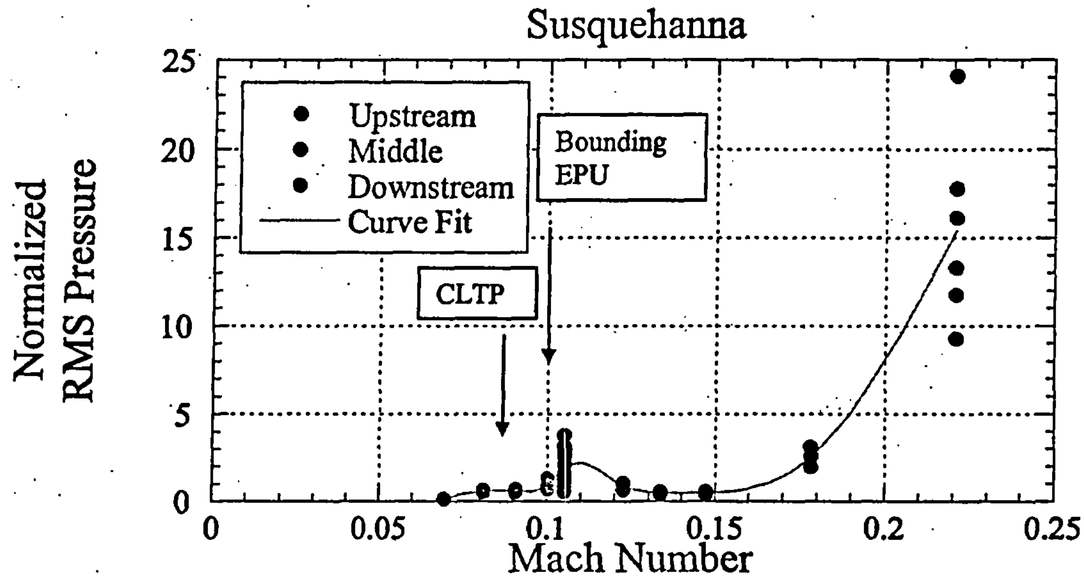


Figure 8.1. Normalized RMS pressure for all B/C tests: upstream refers to the pressure at the upstream standpipe/valve; middle refers to the pressure at the middle standpipe/valve; and downstream refers to the pressure at the downstream standpipe/valve. A cubic spline curve fit to all data is shown by the green curve.

8.3 Onset Velocity

If onset is defined as the point at which the normalized RMS pressure is ten percent of the maximum normalized RMS pressure measured (in this case 24.0 from Figure 8.1), a Mach number of 0.18 should be near onset (even though the pressure curve peak was not measured in the subscale tests). Table 8.2 compares the predicted and measured onset velocities based on these assumptions.

Table 8.2. Comparison between predicted and measured onset velocities for SSES.

Configuration	Predicted Onset Velocity (ft/sec)	Measured Onset Velocity (ft/sec)
Crosby as built	253.7	289.6

8.4 Dead-Headed Branch Line Effects

The dead-headed branch line results are also shown in Appendix A. These results suggest that the dead-headed branch line will contribute a source in the main steam line, specifically above a Mach number of 0.0810 (Figure 8.2). This figure indicates that the normalized RMS pressures between CLTP and EPU conditions are increasing slowly with Mach number. Therefore, in this frequency range, pressure fluctuations are anticipated to increase as the square of the flow velocity between CLTP and EPU conditions. The frequency comparison is shown in Table 8.3.

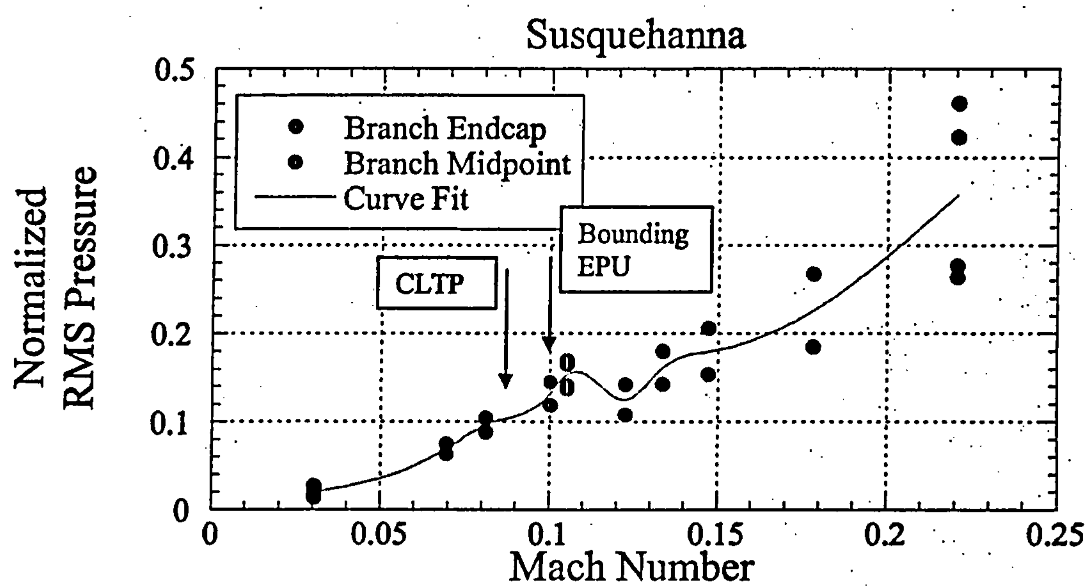


Figure 8.2. Normalized RMS pressure for all A/D tests: branch endcap refers to the pressure at the end of the dead-headed branch line; and branch midpoint refers to the pressure at the middle of the dead-headed branch line. A cubic spline curve fit to all data is shown by the green curve.

Table 8.3. Comparison between predicted and measured excitation frequency for the dead-headed branch lines for SSES.

Configuration	Predicted Excitation Frequency (Hz)	Measured Excitation Frequency (Hz)	Full-Scale Excitation Frequency (Hz)
Dead-headed branch lines as built	16.4	60.0	15.0

IX. Conclusions

Normalized acoustic RMS pressures from dead-headed branch lines and from standpipes for the Crosby safety valves do not increase in amplitude as power is increased from CLTP to EPU conditions in the SSES plant. It is therefore anticipated that unsteady dryer loads are expected to increase from CLTP to EPU conditions as the flow velocity squared. Curiously, the plant is currently operating at CLTP, where FIV is anticipated from the relief valve standpipes at a frequency of 218 Hz. In-plant measurements if undertaken should be sampled at a high enough digitization rate to determine whether this load is present.

X. Quality Assurance

All quality-related activities will be performed in accordance with the C.D.I. Quality Assurance Manual, Revision 13 [16]. Quality-related activities are those activities which will be directly related to the planning, execution, and objectives of the test program. Supporting activities, such as test apparatus design, fabrication, and assembly, are not controlled by the C.D.I. Quality Assurance Manual. C.D.I.'s Quality Assurance Program provides for compliance with the reporting requirements of 10 CFR Part 21. All instrument certifications, calibrations, test procedures, data reduction procedures, and test results will be contained in a Design Record File kept on file at C.D.I. offices.

XI. References

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Appendix A: Normalized PSD Results

Appendix A provides the normalized PSD traces for the pressure time histories taken during the test program. Here, normalized PSD is obtained by normalizing unsteady pressure by the dynamic pressure at CLTP, then constructing the PSD from the Fast Fourier transform.

The nomenclature on the B/C test plots (Figures A.1 to A.15) are:

Upstream	Unsteady pressure recorded at the valve end of the upstream standpipe/valve
Middle	Unsteady pressure recorded at the valve end of the middle standpipe/valve
Downstream	Unsteady pressure recorded at the valve end of the downstream standpipe/valve

The nomenclature on the A/D test plots (Figures A.16 to A.29) are:

Branch Midpoint	Unsteady pressure recorded at the center of the dead-headed branch line
Branch Endcap	Unsteady pressure recorded at the closed end of the dead-headed branch line

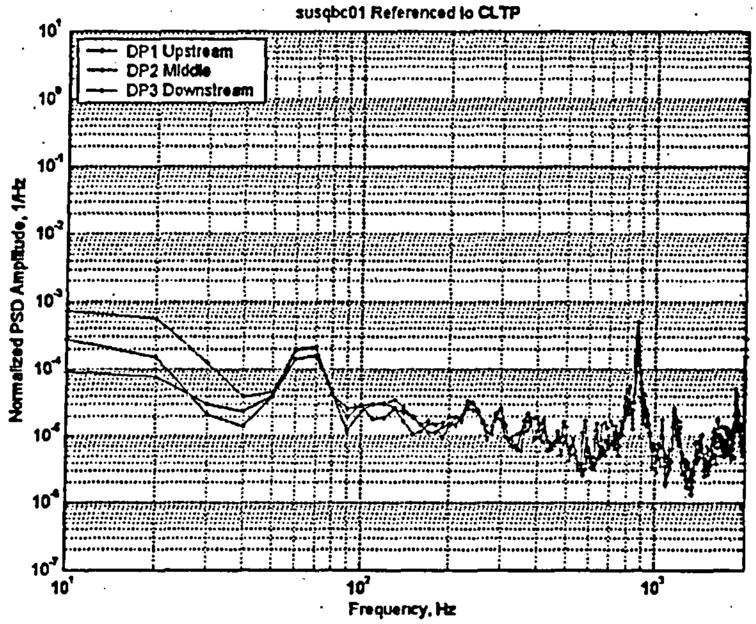

Figure A.1. Normalized PSD for B/C Test 1: Mach number = 0.0690.

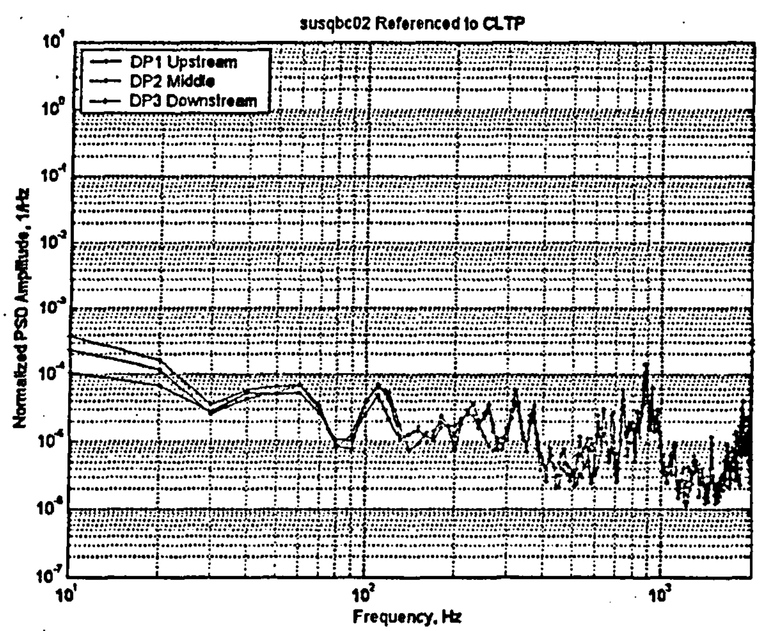

Figure A.2. Normalized PSD for B/C Test 2: Mach number = 0.0690.

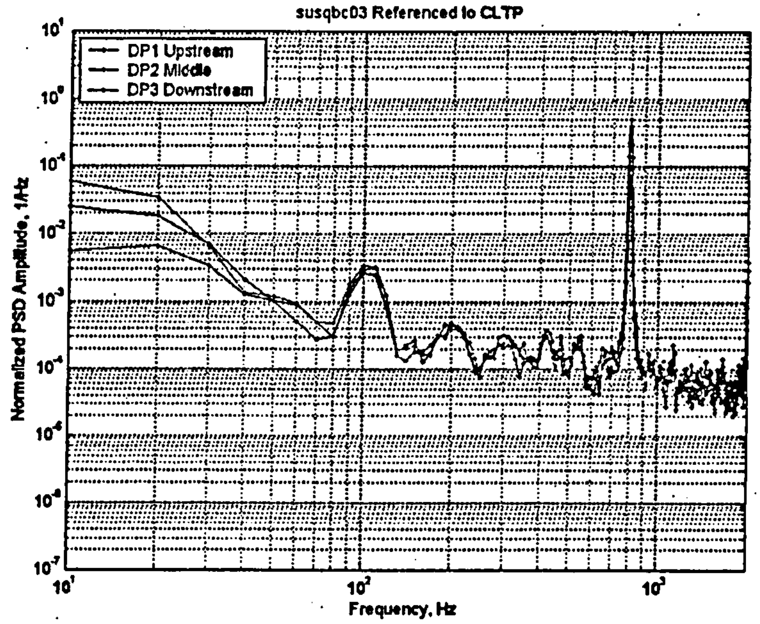

Figure A.3. Normalized PSD for B/C Test 3: Mach number = 0.1044.

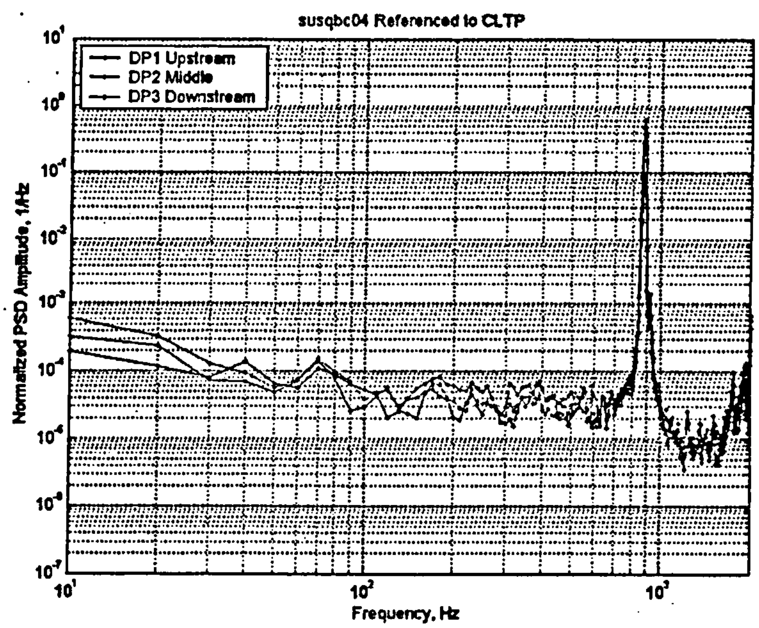

Figure A.4. Normalized PSD for B/C Test 4: Mach number = 0.1044.

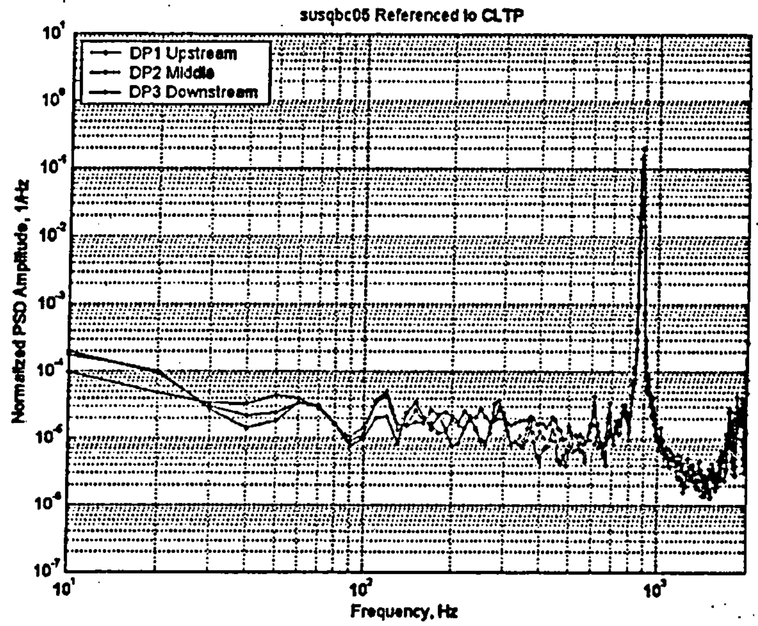

Figure A.5. Normalized PSD for B/C Test 5: Mach number = 0.1044.

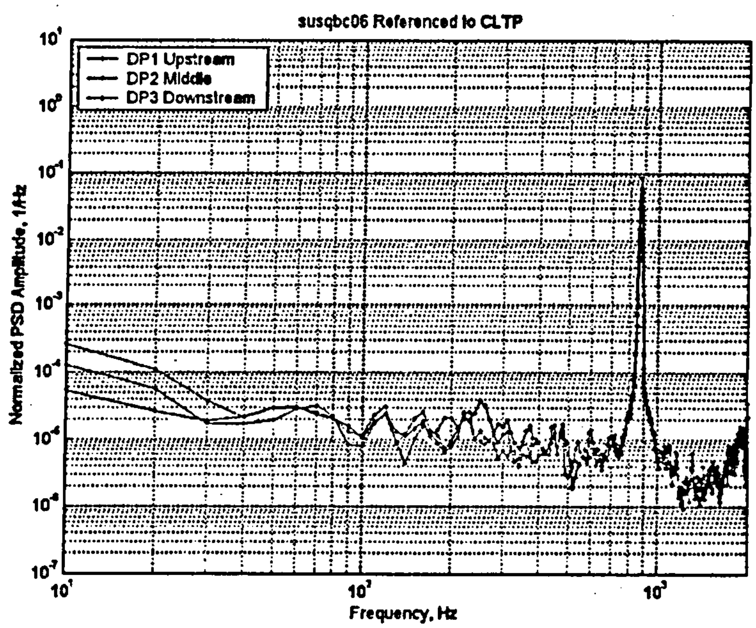

Figure A.6. Normalized PSD for B/C Test 6: Mach number = 0.1044.

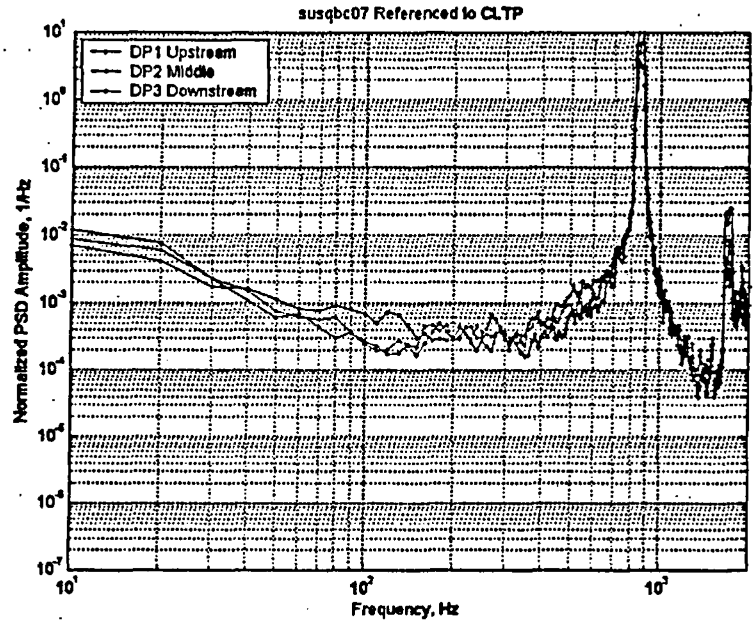

Figure A.7. Normalized PSD for B/C Test 7: Mach number = 0.2194.

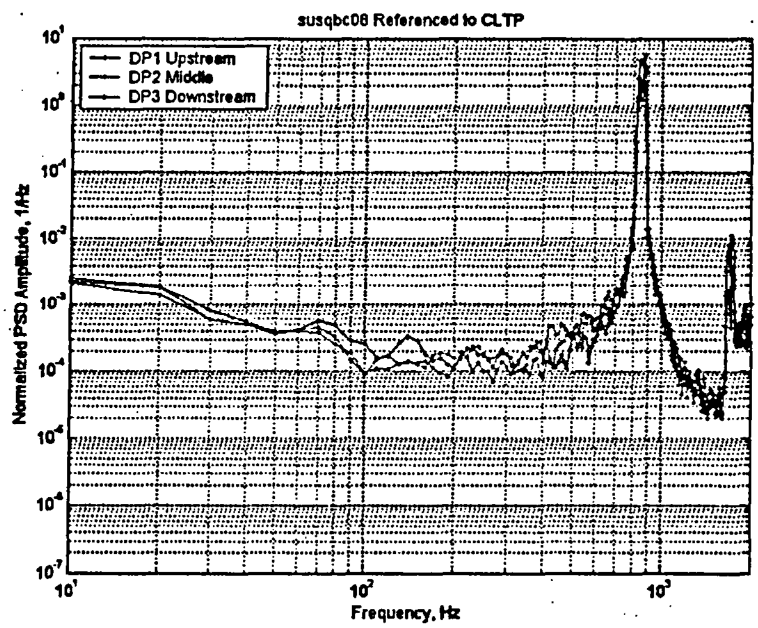

Figure A.8. Normalized PSD for B/C Test 8: Mach number = 0.2194.

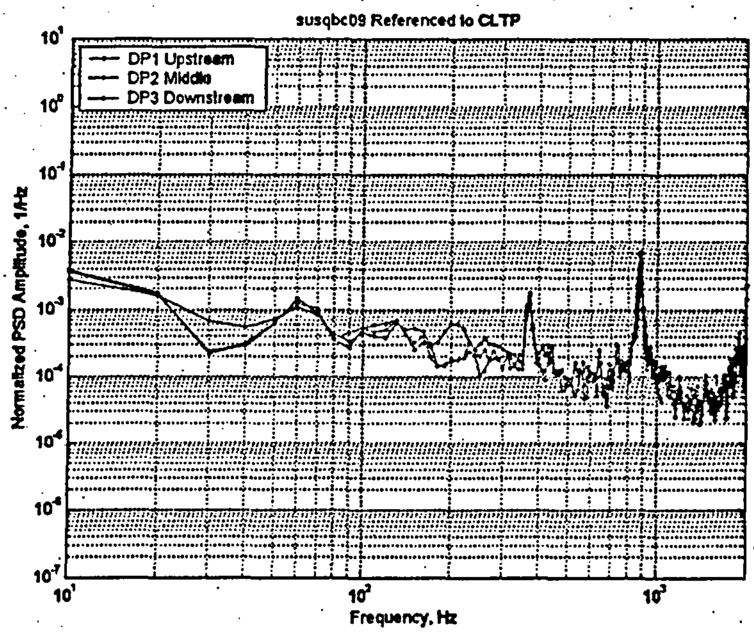

Figure A.9. Normalized PSD for B/C Test 9: Mach number = 0.0805.

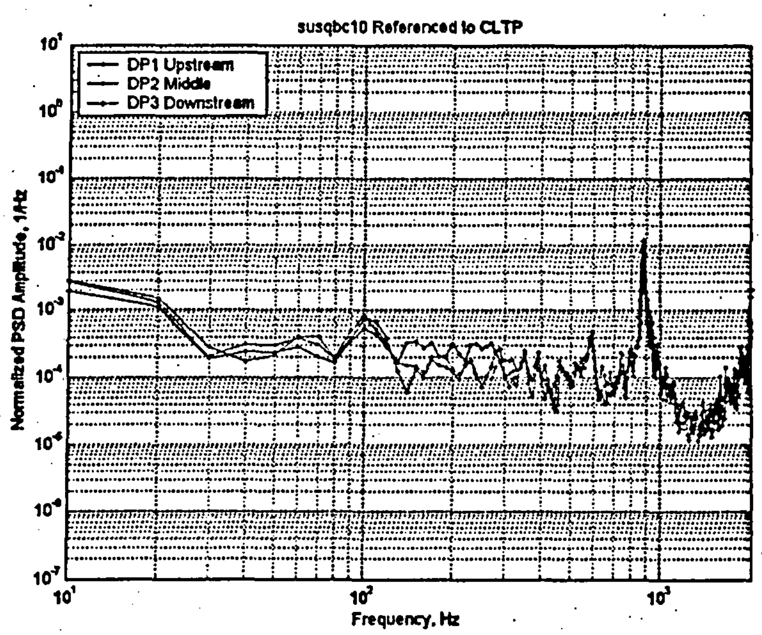

Figure A.10. Normalized PSD for B/C Test 10: Mach number = 0.0901.

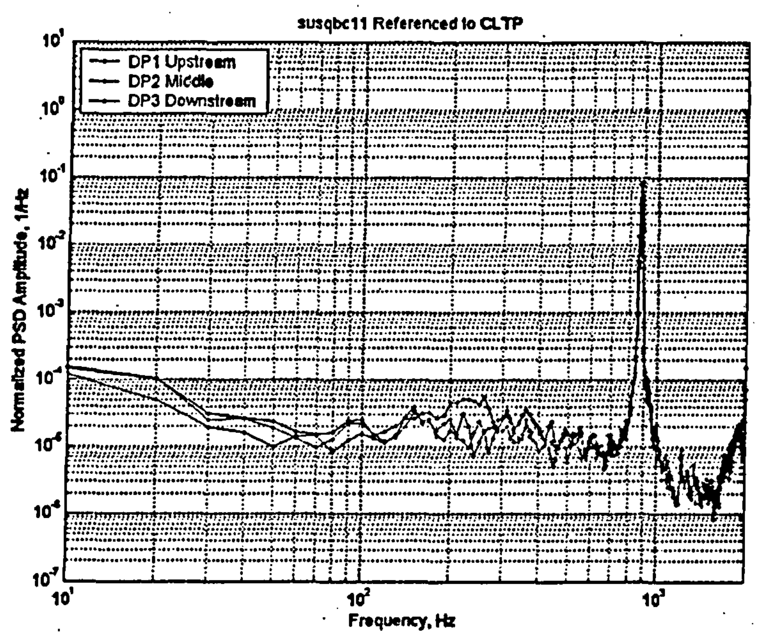

Figure A.11. Normalized PSD for B/C Test 11: Mach number = 0.0996.

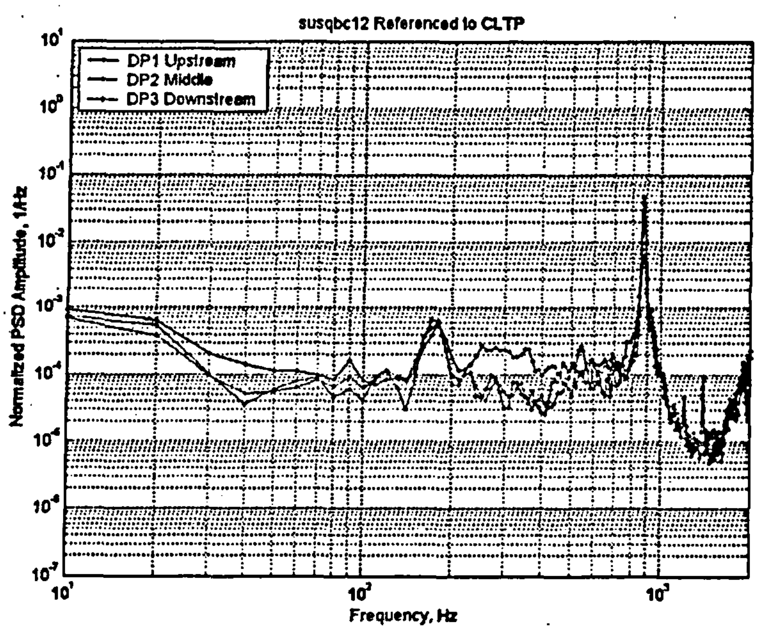

Figure A.12. Normalized PSD for B/C Test 12: Mach number = 0.1218.

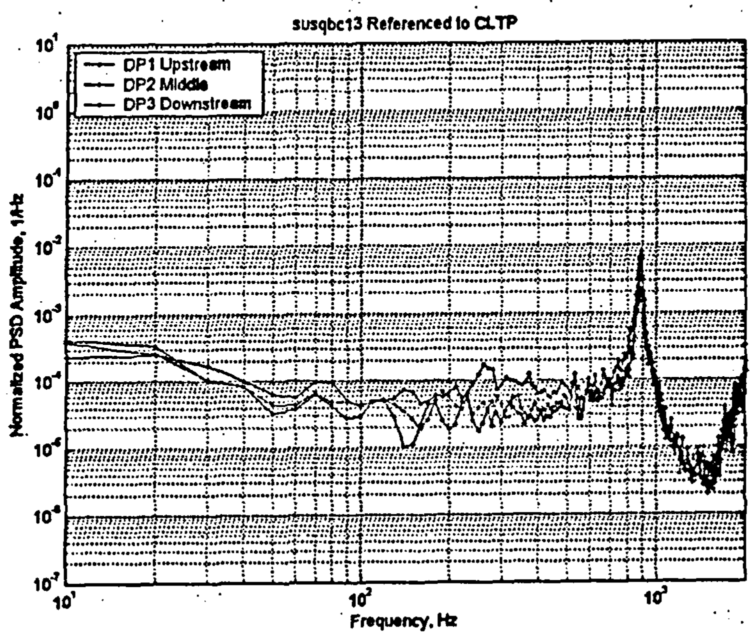

Figure A.13. Normalized PSD for B/C Test 13: Mach number = 0.1329.

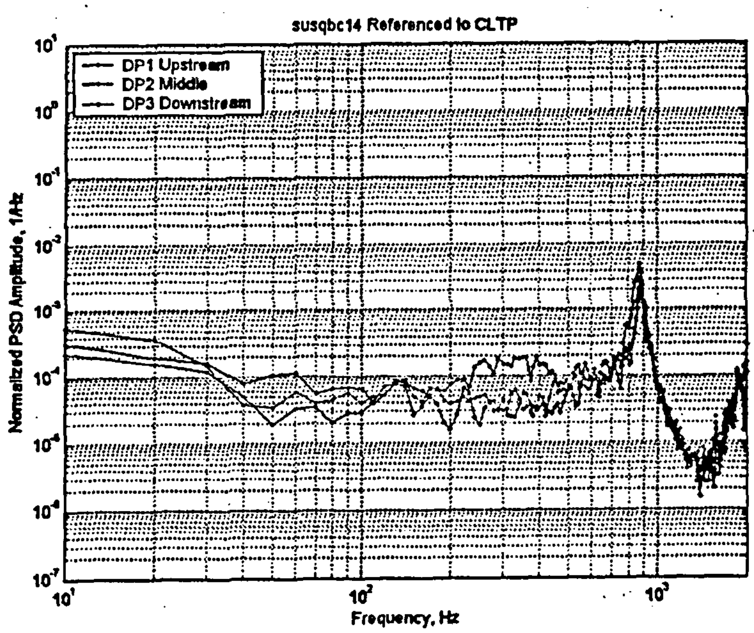

Figure A.14. Normalized PSD for B/C Test 14: Mach number = 0.1462.

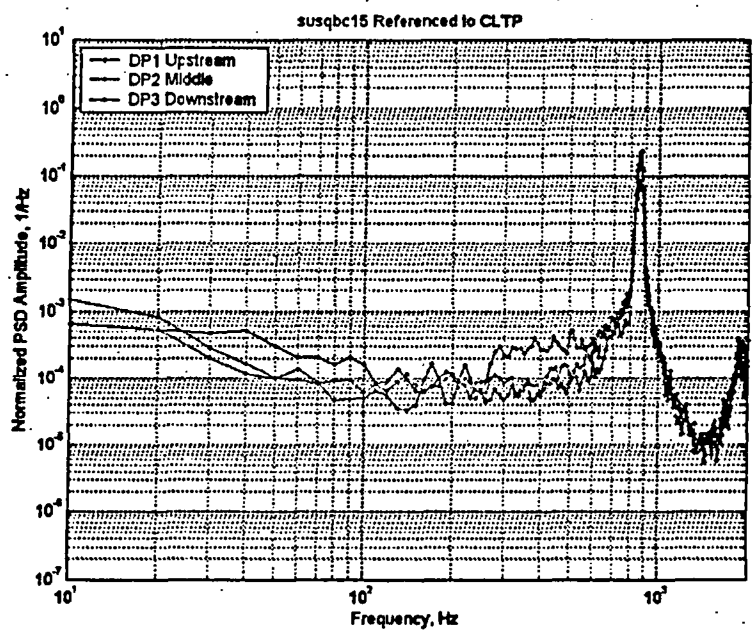

Figure A.15. Normalized PSD for B/C Test 15: Mach number = 0.1772.

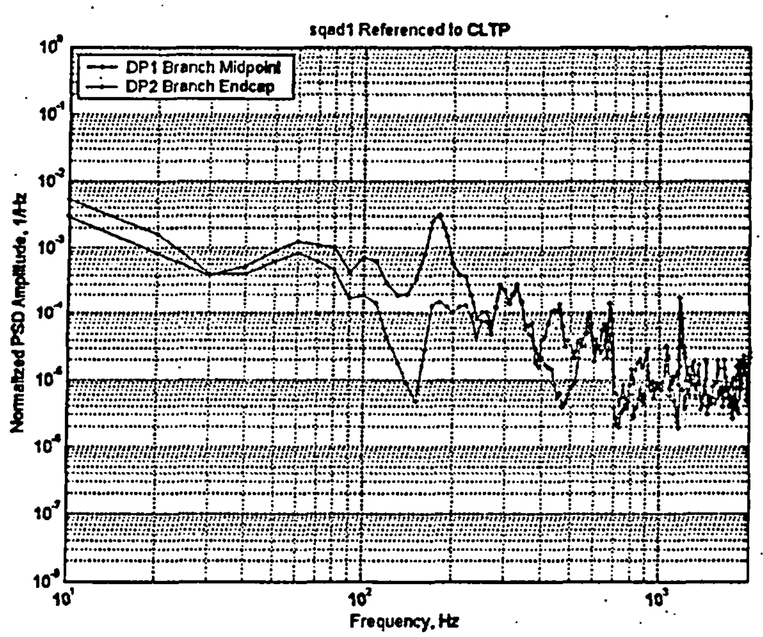

Figure A.16. Normalized PSD for A/D Test 1: Mach number = 0.2194.

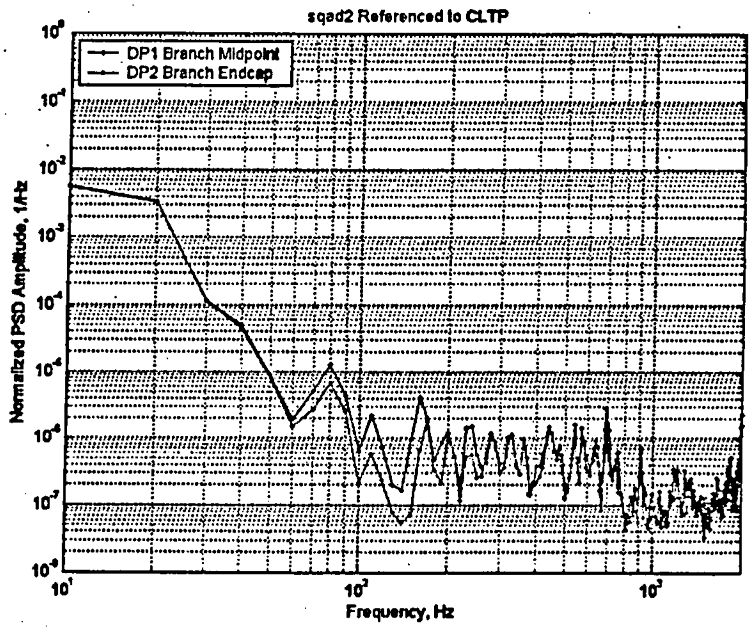

Figure A.17. Normalized PSD for A/D Test 2: Mach number = 0.0302.

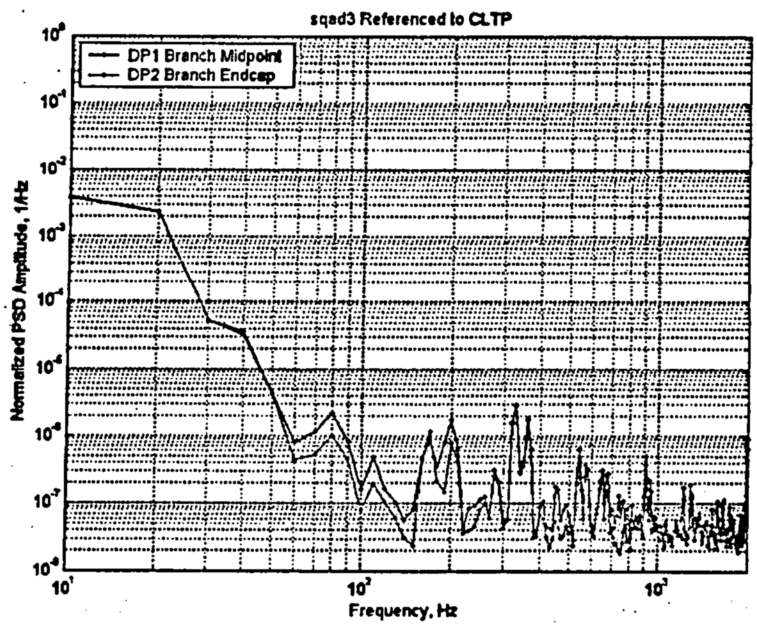

Figure A.18. Normalized PSD for A/D Test 3: Mach number = 0.0302.

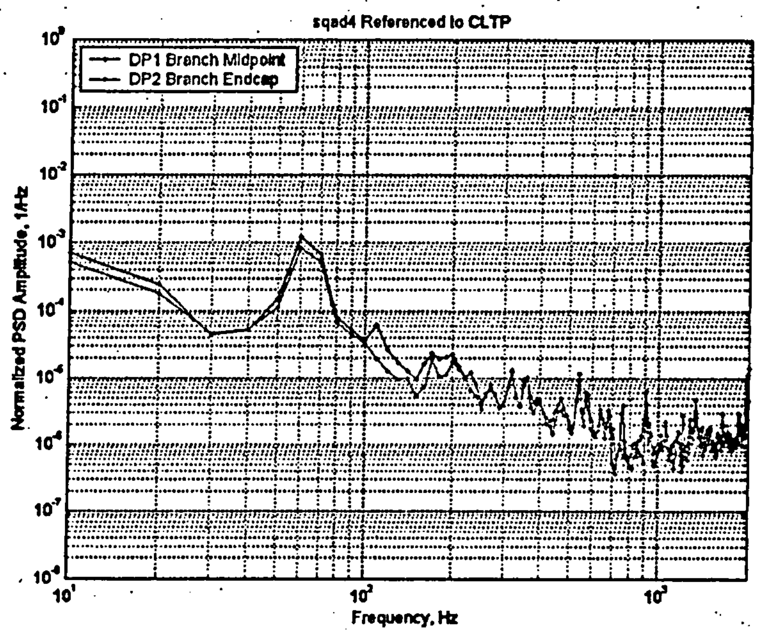

Figure A.19. Normalized PSD for A/D Test 4: Mach number = 0.1044.

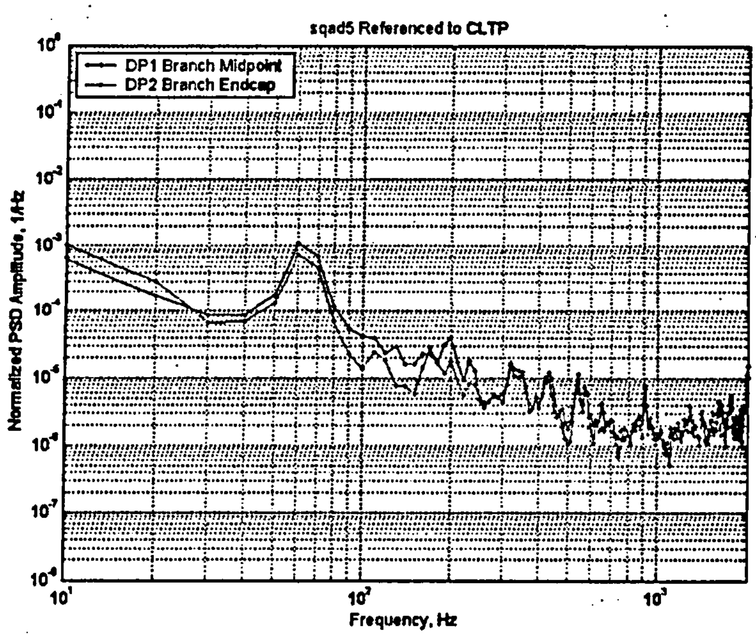

Figure A.20. Normalized PSD for A/D Test 5: Mach number = 0.1044.

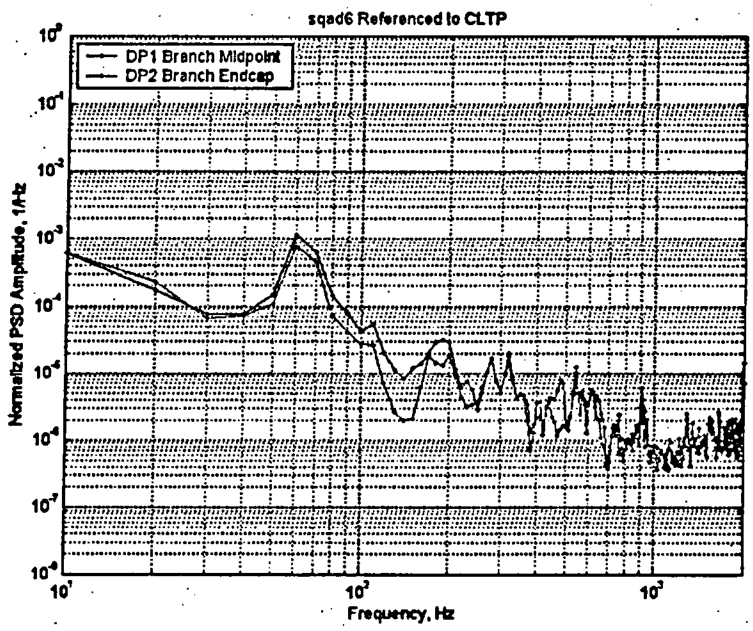

Figure A.21. Normalized PSD for A/D Test 6: Mach number = 0.1044.

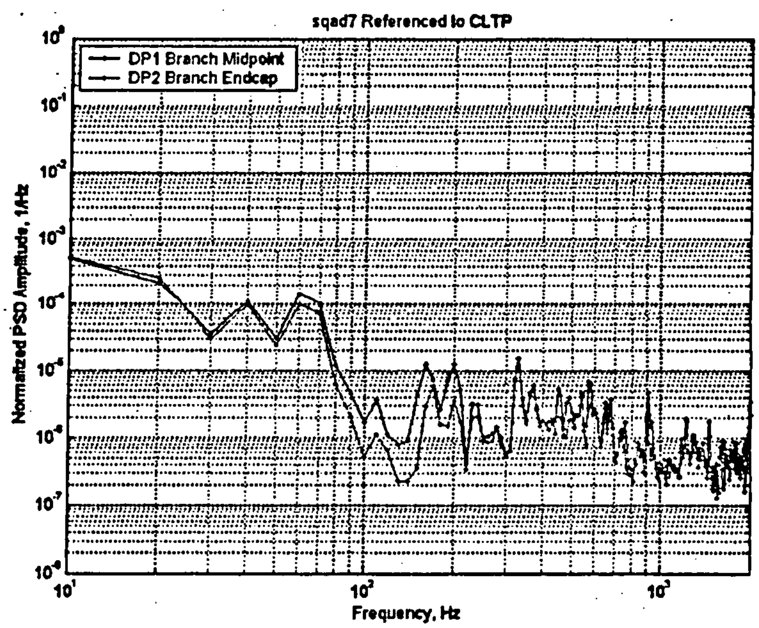

Figure A.22. Normalized PSD for A/D Test 7: Mach number = 0.0690.

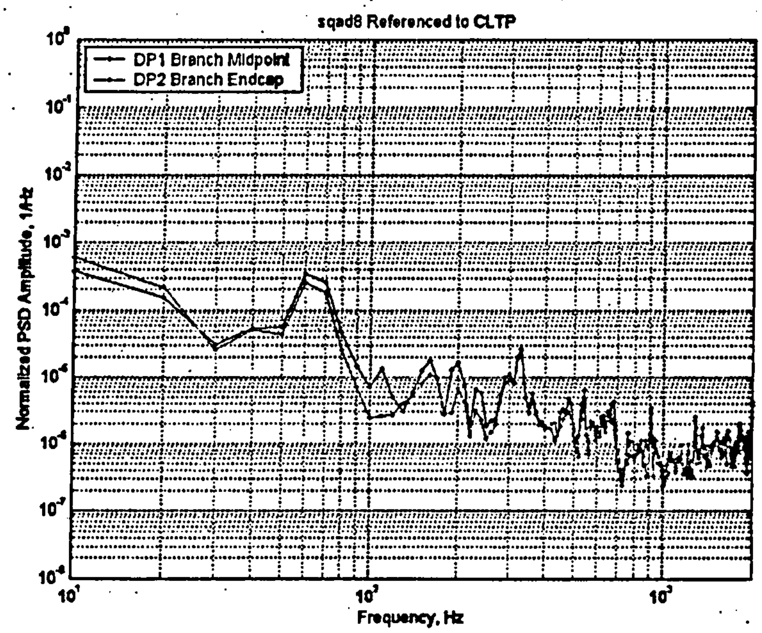

Figure A.23. Normalized PSD for A/D Test 8: Mach number = 0.0805.

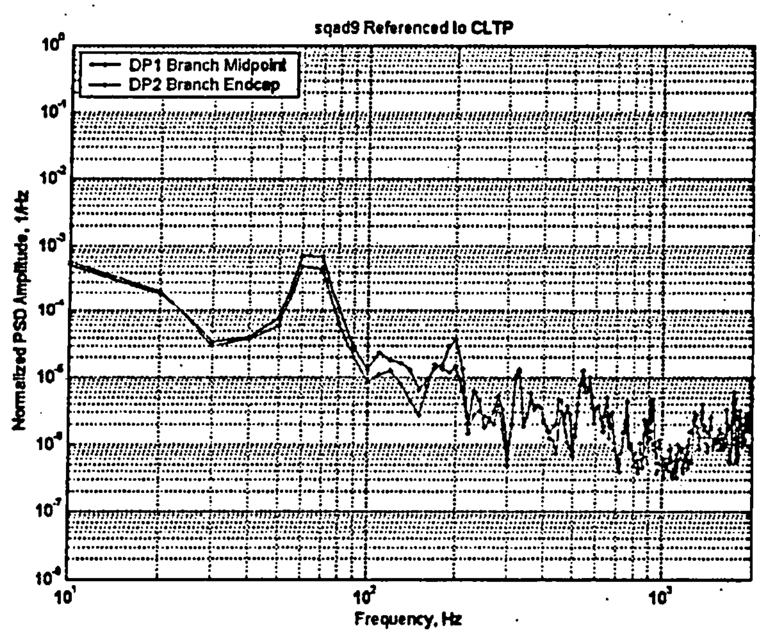

Figure A.24. Normalized PSD for A/D Test 9: Mach number = 0.0996.

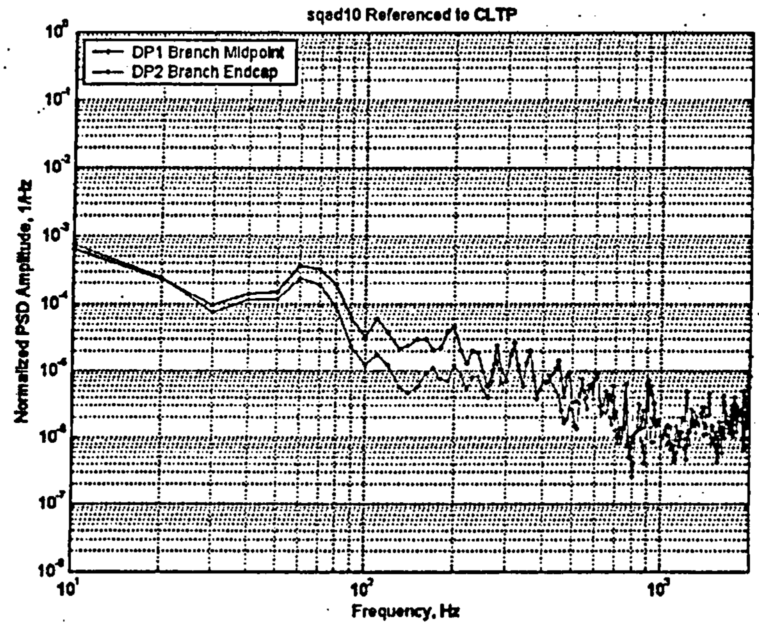

Figure A.25. Normalized PSD for A/D Test 10: Mach number = 0.1218.

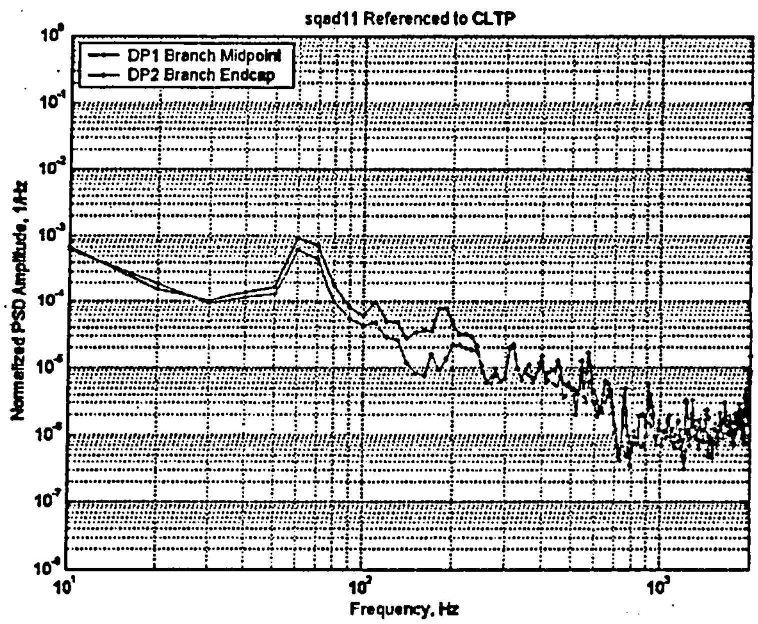

Figure A.26. Normalized PSD for A/D Test 11: Mach number = 0.1329.

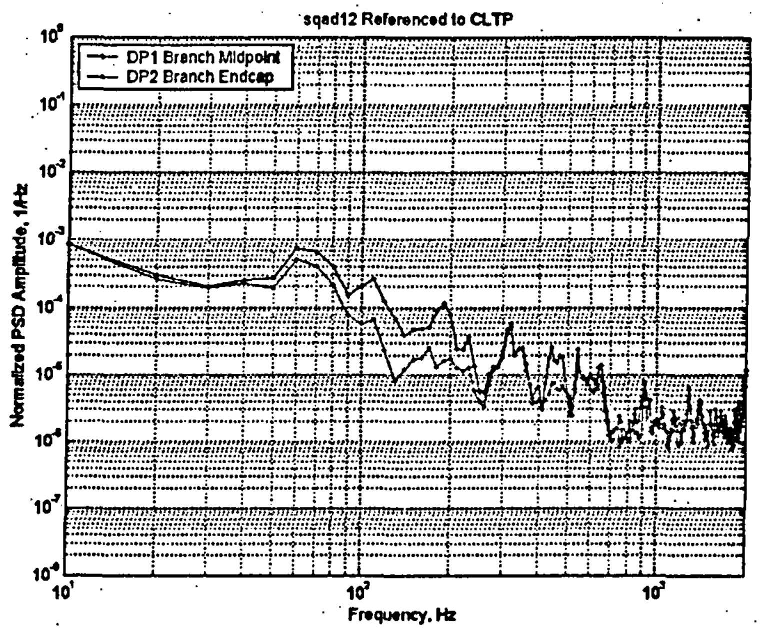

Figure A.27. Normalized PSD for A/D Test 12: Mach number = 0.1462.

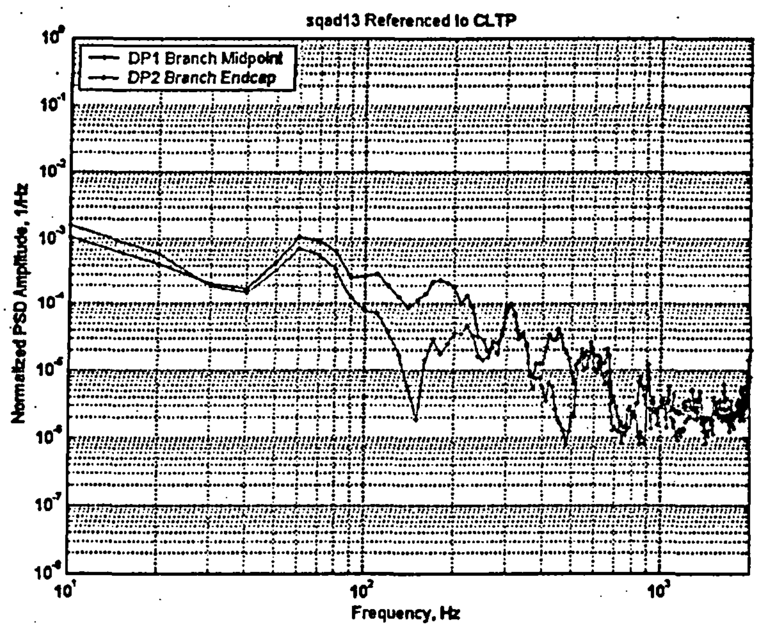

Figure A.28. Normalized PSD for A/D Test 13: Mach number = 0.1772.

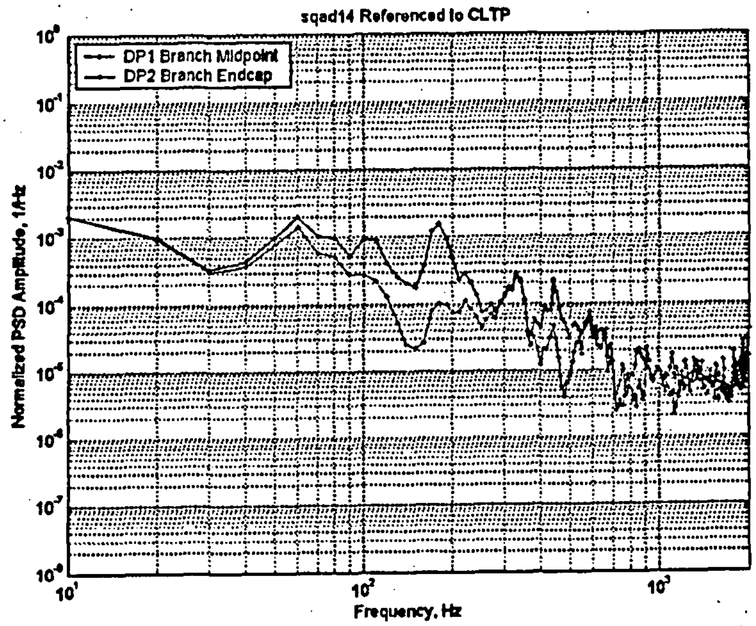

Figure A.29. Normalized PSD for A/D Test 14: Mach number = 0.2194.

Attachment 5 to PLA-6002

GE & Framatome Affidavits

AFFIDAVIT

I, George B. Stramback, state as follows:

(1) I am Manager, Regulatory Services, General Electric Company ("GE") and have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is GE proprietary information contained in PPL Susquehanna LLC License Amendment Request, Attachment 4 to PLA-6002, *Susquehanna Steam Electric Station Units 1 and 2 Safety Analysis Report For Constant Pressure Power Uprate*, dated March 2006. The proprietary information is delineated by a double underline inside double square brackets. Figures and large equation objects are identified with double square brackets before and after the object. In each case, the superscript notation {3} refers to Paragraph (3) of this affidavit, which provides the basis for the proprietary determination.

(3) In making this application for withholding of proprietary information of which it is the owner, GE relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4), and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10 CFR 9.17(a)(4), and 2.390(a)(4) for "trade secrets" (Exemption 4). The material for which exemption from disclosure is here sought also qualify under the narrower definition of "trade secret", within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975F2d871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704F2d1280 (DC Cir. 1983).

(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by General Electric's competitors without license from General Electric constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product;

c. Information which reveals aspects of past, present, or future General Electric customer-funded development plans and programs, resulting in potential products to General Electric;

d. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a, and (4)b, above.

(5) To address 10 CFR 2.390 (b) (4), the information sought to be withheld is being submitted to NRC in confidence. The information is of a sort customarily held in confidence by GE, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GE, no public disclosure has been made, and it is not available in public sources. All disclosures to third parties including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Access to such documents within GE is limited on a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist or other equivalent authority, by the manager of the cognizant marketing function (or his delegate), and by the Legal Operation, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside GE are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information identified in paragraph (2), above, is classified as proprietary because it contains detailed results and conclusions from evaluations of the safety-significant changes necessary to demonstrate the regulatory acceptability for the power uprate of a GE BWR, utilizing analytical models, methods and processes, including computer codes, which GE has developed, obtained NRC approval of and applied to perform evaluations of the GE Boiling Water Reactor ("BWR"). The development and approval of these system, component, and models and computer codes was achieved at a significant cost to GE, on the order of several million dollars.

The development of the underlying evaluation process along with the interpretation and application of the analytical results is derived from the extensive experience database that constitutes a major GE asset.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GE's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GE's comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC-approved methods.

The research, development, engineering, analytical and NRC review costs comprise a substantial investment of time and money by GE.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

GE's competitive advantage will be lost if its competitors are able to use the results of the GE experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to GE would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive GE of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing these very valuable analytical tools.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information, and belief.

Executed on this 28th day of March 2006.

George B. Stramback
George B. Stramback
General Electric Company

General Electric Company

AFFIDAVIT

I, George B. Stramback, state as follows:

(1) I am Manager, Regulatory Services, General Electric Company ("GE") and have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is GE proprietary information contained in PPL Susquehanna LLC License Amendment Request, Attachment 10 to PLA-6002, PPL *Susquehanna, LLC Extended Power Uprate Steam Dryer Evaluation,* dated March 2006. The proprietary information is delineated by a double underline inside double square brackets. Figures and large equation objects are identified with double square brackets before and after the object. In each case, the superscript notation{3} refers to Paragraph (3) of this affidavit, which provides the basis for the proprietary determination.

(3) In making this application for withholding of proprietary information of which it is the owner, GE relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4), and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10 CFR 9.17(a)(4), and 2.390(a)(4) for "trade secrets" (Exemption 4). The material for which exemption from disclosure is here sought also qualify under the narrower definition of "trade secret", within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975F2d871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704F2d1280 (DC Cir. 1983).

(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by General Electric's competitors without license from General Electric constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product;

c. Information which reveals aspects of past, present, or future General Electric customer-funded development plans and programs, resulting in potential products to General Electric;

d. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a., and (4)b, above.

(5) To address 10 CFR 2.390 (b) (4), the information sought to be withheld is being submitted to NRC in confidence. The information is of a sort customarily held in confidence by GE, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GE, no public disclosure has been made, and it is not available in public sources. All disclosures to third parties including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Access to such documents within GE is limited on a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist or other equivalent authority, by the manager of the cognizant marketing function (or his delegate), and by the Legal Operation, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside GE are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information identified in paragraph (2), above, is classified as proprietary because it contains detailed design and analysis information related to the BWR Steam Dryer. Development of this information and its application for the design, procurement and analysis methodologies and processes for the Steam Dryer Program was achieved at a significant cost to GE, on the order of approximately two million dollars.

The development of the evaluation process along with the interpretation and application of the analytical results is derived from the extensive experience database that constitutes a major GE asset.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GE's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GE's

comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC-approved methods.

The research, development, engineering, analytical and NRC review costs comprise a substantial investment of time and money by GE.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

GE's competitive advantage will be lost if its competitors are able to use the results of the GE experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to GE would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive GE of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing these very valuable analytical tools.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information, and belief.

Executed on this 28th day of March 2006.

George B. Stramback
General Electric Company

AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Jerald S. Holm. I am Manager, Product Licensing, for AREVA NP Inc. ("AREVA NP"), and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by AREVA NP to determine whether certain AREVA NP information is proprietary. I am familiar with the policies established by AREVA NP to ensure the proper application of these criteria.

3. I am familiar with the AREVA NP information contained in the PPL report entitled "Safety Analysis Report for Susquehanna Steam Electric Station Units 1 and 2 Constant Pressure Power Uprate", and referred to herein as "Document." Information contained in this Document has been classified by AREVA NP as proprietary in accordance with the policies established by AREVA NP for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by AREVA NP and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure.

6. The following criteria are customarily applied by AREVA NP to determine whether information should be classified as proprietary:

(a) The information reveals details of AREVA NP's research and development plans and programs or their results.

(b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.

(c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for AREVA NP.

(d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for AREVA NP in product optimization or marketability.

(e) The information is vital to a competitive advantage held by AREVA NP, would be helpful to competitors to AREVA NP, and would likely cause substantial harm to the competitive position of AREVA NP.

7. In accordance with AREVA NP's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside AREVA NP only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. AREVA NP policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

Jerald L. Holm

SUBSCRIBED before me this 27th day of March, 2006.

Susan K. McCoy

Susan K. McCoy
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 1/10/2008

SUSAN K. McCOY
COMMISSION EXPIRES
NOTARY
PUBLIC
1-10-08
STATE OF WASHINGTON