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AZ CORP COMMISSION
DOCKET CONTROL

IN THE MATTER OF THE APPLICATION OF ARIZONA PUBLIC SERVICE COMPANY FOR A HEARING TO DETERMINE THE FAIR VALUE OF THE UTILITY PROPERTY OF THE COMPANY FOR RATEMAKING PURPOSES, TO FIX A JUST AND REASONABLE RATE OF RETURN THEREON, TO APPROVE RATE SCHEDULES DESIGNED TO DEVELOP SUCH RETURN, AND TO AMEND DECISION NO. 67744.	DOCKET NO. E-01345A-05-0816
IN THE MATTER OF THE INQUIRY INTO THE FREQUENCY OF UNPLANNED OUTAGES DURING 2005 AT PALO VERDE NUCLEAR GENERATING STATION, THE CAUSES OF THE OUTAGES, THE PROCUREMENT OF REPLACEMENT POWER AND THE IMPACT OF THE OUTAGES ON ARIZONA PUBLIC SERVICE COMPANY'S CUSTOMERS.	DOCKET NO. E-01345A-05-0826
IN THE MATTER OF THE AUDIT OF THE FUEL AND PURCHASED POWER PRACTICES AND COSTS OF THE ARIZONA PUBLIC SERVICE COMPANY.	DOCKET NO. E-01345A-05-0827

NOTICE OF FILING

As required by Decision No. 69663, Arizona Corporation Commission Staff hereby files its report providing an update of the Palo Verde Unit 1 shutdown.

RESPECTFULLY SUBMITTED this 4th day of October, 2007.

Arizona Corporation Commission
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Palo Verde Unit 1 Shutdown Cooling Line Vibration Outage Review

October 3, 2007

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GDS ASSOCIATES, INC.

REVIEW OF PALO VERDE UNIT 1 SHUTDOWN COOLING LINE VIBRATION OUTAGE

EXECUTIVE SUMMARY

Palo Verde Unit 1 experienced extensive outages or periods of low power operation during the first half of 2006 due to excessive vibration levels in the Unit 1 Train A Shutdown Cooling (SDC) System suction line. The SDC suction line is used to remove residual heat from the reactor core when the reactor is shutdown for maintenance or refueling. Elevated vibration levels on the Unit 1 SDC Train A suction line were first identified in March 2001 during an engineering inspection conducted near the end of operating cycle 9 (1C9). Subsequent data taken from the vibration monitoring program indicated that the vibration level at 100% power was increasing from operating cycle to operating cycle. During startup from Refueling Outage 12 it was found that the SDC suction line vibration levels had increased dramatically and approached the established limit of 2.0 IPS at approximately 32% power. At this time the power level of the reactor was administratively limited. In March 2006, testing identified the potential for vibration levels to exceed the design limit if one reactor coolant pump were stopped. It was then decided to shutdown the unit until the final corrective actions, changing the location of the SDC suction line isolation valve, could be implemented.

APS conducted extensive investigations to determine the source of the SDC line vibrations and to determine the reasons for the increased vibration levels from operating cycle 9 following refueling outage 8 through operating cycle 13. APS concluded that the vibration was flow induced and was caused by coupling between an excitation source, vortex shedding in the SDC line tee, and an acoustic resonator. After evaluating many options, APS resolved the problem by moving the SDC suction isolation valve SI-651 nearer to the RCS hotleg. The new location of the SDC suction line isolation valve SI-V651 is 11 feet from the RCS nozzle compared to the original location which was approximately 50 feet from the nozzle.

GDS concludes that APS' response to the SDC suction line vibration issue was reasonable and prudent. The following information is presented in support of this conclusion of prudence:

1. The level of SDC suction line vibration that led to the outage could not have been anticipated.
2. APS conducted an extensive investigation to identify the source of the vibration, the cause of the increase in vibration over time, and the possible solutions.
3. APS' approach to implementation of a solution to the vibration problem was reasonable.
4. Relocating the SDC suction line isolation valve SI-651 was a complex and challenging modification requiring extensive engineering. Engineering and construction activities required to implement the modification were completed in a reasonable amount of time.
5. The original location of the SDC suction line isolation valve was a reasonable location based on maintenance and operational considerations.
6. The NRC was satisfied with APS actions to resolve the problem.
7. Relocating the SDC suction line valve was successful in resolving the problem and greatly reduced the level of vibration in the SDC suction line.

I. DESCRIPTION OF PROBLEM

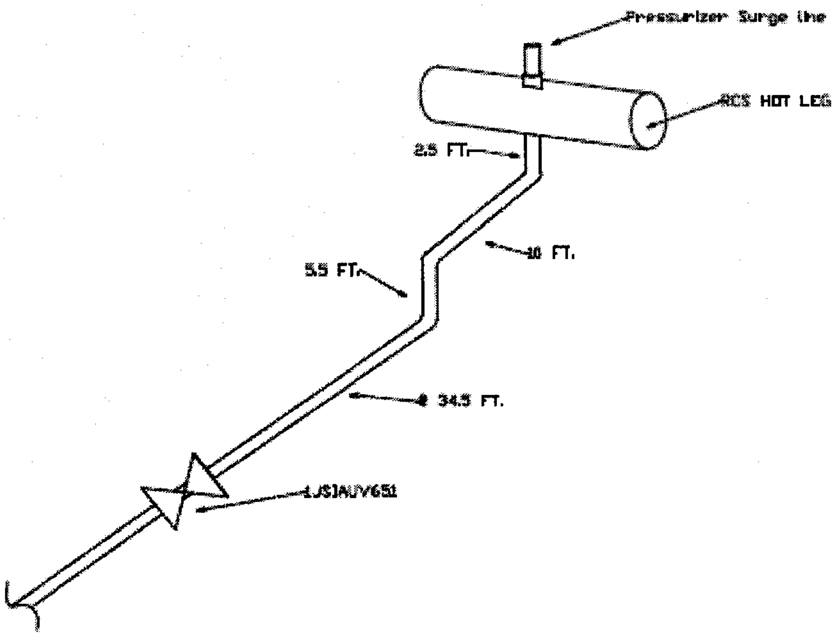
a. The Shutdown Cooling Line Vibration Outage

Palo Verde Unit 1 experienced extensive outages or periods of low power operation during the first half of 2006 due to excessive vibration levels in the Unit 1 Train A Shutdown Cooling (SDC) System suction line. These outages include operation at 25% to 32% power from December 27, 2005 to January 17, 2006, a plant outage from January 17 to January 21, 2006, operation at 25% power from January 21 to March 18, 2006, and another plant outage from March 18 to July 7, 2006. These outages and periods of reduced power operation for Palo Verde Unit 1 resulted in a capacity factor in 2006 of 42.3% versus the goal for 2006 of 97.6% and generation of only 4,868,234 net MWh compared to the 2006 generation goal of 11,261,906 net MWh.

b. Description of the Shutdown Cooling Line

APS identified vibration levels in the Unit 1 Train A Shutdown Cooling suction line that were determined to be above the levels at which the unit could safely operate. The Shutdown Cooling System is used to remove residual heat from the reactor core when the reactor is shutdown for maintenance or refueling activities. The Palo Verde plants each have two Shutdown Cooling suction lines identified as Train A and Train B. The Train A Shutdown Cooling suction line is a 16 inch line that is attached directly to the bottom of the 42 inch reactor coolant system hot leg as shown in the figure below.

Figure 1. Original Train A Shutdown Cooling Line Configuration



II. HISTORY OF SDC LINE VIBRATION

Elevated vibration levels on the Unit 1 SDC Train A suction line were first identified in March 2001 during an engineering inspection conducted near the end of operating cycle 9 (1C9). Vibration at the same frequency but substantially lower amplitude was also found on the Train A

Shutdown Cooling suction line of Units 2 and 3. The Unit 1 vibration levels were analyzed and found to be within acceptable limits for continued operation. A program to monitor the vibration levels was implemented to ensure that vibration levels stayed within acceptable limits.

Data taken from the vibration monitoring program indicated that the vibration level at 100% power was increasing from operating cycle to operating cycle. During the cycle 10 continuous breaker-to-breaker run from May 2001 to September 2002, vibration levels trended upward from 1.0 inches per second (IPS) to 1.2 IPS during the final 3 months. At the end of operating cycle 10, the SDC suction isolation valve 1JSIAUV0651 failed to open. The failure was attributed to loosening of fasteners within the valve actuator. The root cause was determined to be inadequate torque on the fasteners during reassembly in conjunction with a sustained high level of vibration during operating cycle 10. Corrective actions included hardening of the valve actuator by securing the internal fasteners with Loctite, addition of an inspection port on the valve actuator, and addition of vibration and temperature monitoring equipment. An additional pipe support was installed in an attempt to reduce SDC line vibration. However, a significant increase in vibration amplitude was observed and power ascension was stopped at 70% power when the amplitude reached 1.90 IPS. The new pipe support was removed and the vibration levels returned to the levels experienced at the end of Cycle 10.

During Cycle 11, Unit 1 was forced to shutdown due to a pin-hole leak on branch drain line socket weld. Elevated vibration levels were identified as a contributor to this leak. During Cycle 12, the vibration level was approximately 1.60 IPS.

The steam generators at Palo Verde Unit 1 were replaced during refueling outage 12, and during startup from this refueling outage it was found that the SDC suction line vibration levels had increased dramatically and approached the established limit of 2.0 IPS at approximately 32% power. At this time the power level of the reactor was administratively limited. In March 2006, testing identified the potential for vibration levels to exceed the design limit if one reactor coolant pump were stopped. At this time it was decided to shutdown the unit until the final corrective actions, changing the location of the SDC suction line isolation valve, could be implemented.

III. CAUSE OF THE SDC LINE VIBRATION

APS conducted extensive investigations to determine the source of the SDC line vibrations and to determine the reasons for the increased vibration levels from operating cycle 9 following refueling outage 8 through operating cycle 13. Two sources of the energy for the vibratory motion, or forcing function, were identified as mechanical action by rotating equipment or reactor coolant system flow induced vibration. Mechanical action by rotating equipment as an excitation source was investigated and rejected as tests provided no evidence of a forcing function attributed to the reactor coolant pumps or any other rotating equipment. Many types of excitation by various reactor coolant flow phenomena were investigated but were not supported by the evidence. Significant evidence was found to support the existence of coupling between vortex shedding in the SDC tee and the acoustic frequency of the SDC suction line configuration.

APS concluded that the vibration was flow induced and was caused by coupling between an excitation source, vortex shedding in the SDC line tee, and an acoustic resonator. The excitation source is the pressure disturbance resulting from the flow of reactor coolant across the tee joining the SDC suction line to the RCS hot leg. The acoustic resonator is the SDC suction line itself which forms a deep cavity bounded by the RCS hotleg on one end and the SDC suction isolation valve (1JSIAUV0651) on the other, a length of more than 50 feet. Facts supporting this determination include:

- The vibration amplitude is related to hot-leg flow and independent of the particular pump combination used to establish the specific flow rate:
- Scaled model testing demonstrated the potential for acoustic amplification due to coupling in a configuration equivalent to the SDC suction line;
- A review of work done during Refueling Outage 8 did not identify any maintenance or modifications that would indicate that the increased vibration experienced during operating cycle 9 was caused by reduced damping, increased stiffness or changes to structural natural frequencies.

- Pressure pulsation and other data recorded in Unit 1 during operating cycle 13 demonstrated that the vibration was driven by acoustic excitation.

The root cause of the SDC suction line vibration was determined by APS to be a latent design weakness in that the configuration of the SDC suction line creates a resonator with a fundamental frequency close to the pressure disturbance at the SDC suction line tee.

Once the cause of the SDC suction line vibration had been found, APS initiated actions to determine the reasons that the vibration had increased over time and to identify corrective actions to reduce the vibration level to within acceptable limits. APS evaluated numerous possible causes for changes in hot leg flow that could result in increased vibration. The potential causes for increasing vibration include:

<u>Physical Structural Changes</u>

- The snubber reduction modification;
- Modification to the SDC suction isolation valve to address pressure locking;
- Physical changes to SDC train A branch lines;
- Changes in the contour of the SDC line tee from the vortex breaker modification;
- Physical changes to pipe supports;
- Physical changes to structural steel;
- Reactor Coolant Pump impeller changes;
- Steam Generator replacement;

<u>Changes Internal to the Reactor Pressure Vessel</u>

- Possible repositioning of the Core Support Barrel when it was removed and reinstalled for inservice inspection during 1R8.
- Changes to fuel assembly design and manufacture;
- Changes to core design;

<u>Leakage Mechanisms</u>

- Cold leakage flow into the SDC suction line;
- Hot leakage flow out of the SDC suction line;

<u>Component Degradation or Damage</u>

- Degraded performance of one or more pipe supports;
- Degradation of the upper guide structure flow alignment plate sleeves or plugs
- Degradation of the fuel alignment plate sleeves;
- Degradation of the Core Support Barrel lower keys or keyways;
- Degradation of the RPV flow skirt (flow baffle);
- Degradation of the reactor coolant pumps;
- Degradation of other RPV flow pathways;
- Increased bowing of fuel assemblies causing core flow changes;
- Steam Generator tube plugging or other degradation.

Changes to Operating Procedures and / or Parameters

- Hot/Cold leg temperature changes;
- Stretch Power / Power Uprate;
- Changes in post outage reactor coolant pump starting sequence;
- Changes to pressurizer spray / surge line operations.

Each of these potential causes for the observed increase in vibration level was investigated and evaluated. While some of the causes listed above could explain certain observed increases in vibration level, no single cause was identified that could be responsible for all of the observed increases in vibration level.

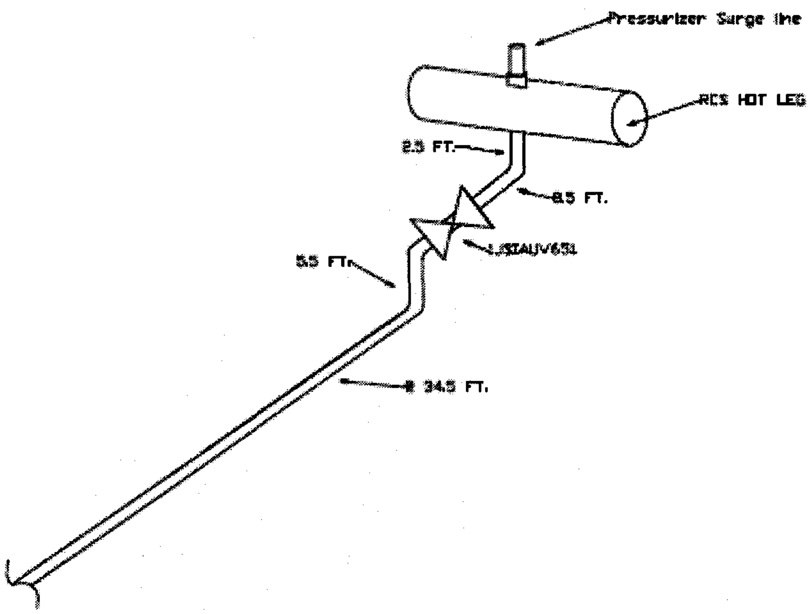
IV. CORRECTIVE ACTIONS

In parallel with the efforts to identify the source of the vibration and the reasons for the observed increase in vibration levels, APS also worked to develop corrective actions that would reduce the vibration level to acceptable levels. APS retained a consultant and an EPRI expert panel to assist in development of the corrective actions. The approach was predicated on the flow-induced vibration hypothesis. Initial attempts at reducing the vibration level by adding mass dampening devices to the SDC suction line and by heating the SDC suction line were unsuccessful. Following these unsuccessful attempts, proposed modifications were designed to de-couple the acoustic process by shifting the vortex shedding frequency or shifting the acoustic frequency. Modifications to affect structural resonance were not considered. Modifications to affect the vortex shedding and acoustic frequency were evaluated by scale model testing. Eleven variations of nozzle modifications were tested and the effects of valve relocation were quantified.

The model testing demonstrated that moving the SDC suction line isolation valve would solve the problem. However, this modification was a complicated and lengthy process that involved significant engineering and procurement. Another promising approach was to modify the SDC suction line tee by installation of a grid plate. Scale model testing demonstrated that installation of a grid plate would be effective in reducing the acoustic pressure at the nozzle and the chosen design would not impact the functionality of the SDC system. The grid plate was installed during refueling outage 12. However validation testing following the refueling outage showed significant increases in surface vortexing and air entrainment which would make certain desirable modes of plant operation not feasible. Therefore, the grid plate was removed. With the failure of the grid plate modification, APS concluded that the best solution was to relocate the SDC suction line isolation valve.

Relocation of this valve was proposed by the consultants and the EPRI expert panel. Scale model testing showed a significant reduction in pressure amplitude and the acoustic frequency was shifted away from the vortex shedding and resonant pipe frequencies. The new location of the SDC suction line isolation valve SI-V651 is 11 feet from the RCS nozzle compared to the original location which was approximately 50 feet from the nozzle. This resulted in a higher acoustic frequency of 61 Hz compared to 25 Hz for the original location. The new configuration resulted in no significant coupling with the vortex shedding modes and no evidence of other significant excitation sources was identified. The new location is consistent with the location in some similar Korean System 80 plants. Most importantly, the modification was a success. No vibration issues were identified and vibration of the SDC suction line was well within acceptable limits. The new valve location approximately 11 feet from the hot leg is shown in Figure 2 below:

Figure 2. Relocated SDC Suction Line Isolation Valve



While conceptually changing the location of the SDC isolation valve does not appear to be a major undertaking, in fact relocating the valve to the new location required extensive engineering to develop the physical plant changes and supporting engineering analyses including:

Physical Changes

- Relocate Shut Down Cooling Valve SI-V651 from outside the Steam Generator compartment to inside;
- Re-route the 3-inch Reactor Coolant System Hot Leg Injection piping;
- Add on Missile Shield;
- Add one pipe whip restraint;
- Add several pipe supports;
- Relocate conduit;
- Install platforms;

Design Basis Analysis and Evaluations

- Equipment Environmental Qualification;
- Jet impingement evaluation;

- Missile evaluation;
- ASME Class I piping analysis;
- Hydraulic evaluation of piping;
- Motor Operated Valve Locking / Thermal Binding analysis;
- Safety analysis for boron dilution.

APS completed these designs and analyses expeditiously to allow completion of the project by mid-2006.

V. REGULATORY REVIEW

The NRC closely monitored APS' activities to resolve the SDC line vibration problem. Previously, the NRC had identified concerns with problem identification and resolution by the Palo Verde staff. NRC inspection reports discussed instances in which root cause evaluations by APS were too narrowly focused. The NRC monitored APS to ensure that the problem identification and resolution activities related to the SDC line vibration problem were thorough and comprehensive.

On March 18, 2006, vibration testing was being performed to gather data related to the SDC line vibration problem. The data revealed that stopping one reactor coolant pump (RCP) in loop 2 with all four RCPs operating resulted in vibration levels at the SDC line suction isolation valve SI-V651 which exceeded the design vibration limit. On March 31, 2006, APS submitted a request for an amendment to the Unit 1 operating license under exigent circumstances to allow operation of the unit during a one-time 12-hour period to collect SDC suction line vibration data. The NRC granted this request on April 6, 2006. On May 11, 2006, APS made a presentation to the NRC entitled "A Presentation on the Physical Modification of PVNGS Unit 1 SDC Suction Line to Eliminate High-Level Vibration." This presentation provided a detailed description of the SDC line vibration problem, the efforts APS had made to ensure that the cause of the problem was identified and the planned modification to resolve the problem.

On July 24, 2006, the NRC issued Palo Verde Nuclear Generating Station Integrated Inspection Report 05000528/2006003. In the report section that addresses permanent plant modifications, the NRC inspection focused on the SDC suction line modification. The inspection report states:

> The primary focus of this inspection effort was the modification package to relocate the shutdown cooling isolation valve (SI-651) to reduce the magnitude of vibration on the shutdown cooling line. The inspectors reviewed the analyses, calculations, proposed post-modification testing, and the requirements for returning the system to operation.
>
> Issues and Findings
>
> No findings of significance were identified. The inspectors found that the licensee's engineers had adequately addressed engineering requirements and had developed a modification that could reduce the vibrations. While a root cause was not definitively identified, the inspectors found that the licensee personnel had done extensive assessment and investigation to identify several contributing causes and develop corrective actions to significantly reduce vibrations. The inspectors noted that the initial vibration levels were lower than the levels allowed by the ASME code by an order of magnitude.

The NRC found that APS had conducted extensive assessment and investigation of the problem and had developed corrective actions to significantly reduce the vibration level in the SDC suction line.

VI CONCLUSIONS

GDS concludes that APS' response to the SDC suction line vibration issue was reasonable and prudent. The following information is presented in support of this conclusion of prudence:

1. The level of SDC suction line vibration that led to the outage could not have been anticipated.
2. APS conducted an extensive investigation to identify the source of the vibration, the cause of the increase in vibration over time, and the possible solutions. APS retained qualified experts to assist in these analyses and evaluations.

3. APS' approach to implementation of a solution to the vibration problem was reasonable. Faster and less complex alternative solutions than relocating the SDC suction line isolation valve were identified and attempted but did not solve the problem.
4. Relocating the SDC suction line isolation valve SI-651 was a complex and challenging modification requiring extensive engineering. Engineering and construction activities required to implement the modification were completed in a reasonable amount of time.
5. The original location of the SDC suction line isolation valve was a reasonable location based on maintenance and operational considerations.
6. The NRC was satisfied with APS actions to resolve the problem.
7. Relocating the SDC suction line valve was successful in resolving the problem and greatly reduced the level of vibration in the SDC suction line.
8. APS is taking action to ensure that Units 2 and 3 will not experience the same problem.

While a lengthy outage such as that described above is clearly costly and undesirable, APS' actions in determining the cause of the problem and identifying and implementing a solution were reasonable and prudent.

APPENDIX A

REFERENCES

1. APS response to Data Request PB 1.1
2. Palo Verde CRDR Number 2859071 High Level Vibration on U1 SDC Line Limits Power Operation dated 11/13/2006.
3. Palo Verde CRDR Number 2818682 Potential Relationship Between SI651 Vibration, SIP390P Repressurization Rates and Containment Temperature.
4. Palo Verde Study 13-MS-B045 "Experimental Investigation of Acoustic Coupling of the PVNGS Unit 1 SDC Suction Line dated May 29, 2006
5. Fauske & Associates Report No. FAI/05-93 Test Report for Palo Verde Shutdown Cooling (SDC) System Hot Leg Nozzle Vortex Testing dated September 2005
6. Palo Verde Report entitled "Basis Paper for System Modifications to Reduce High Level Vibration on the PVNGS Shutdown Cooling Suction Line" Revision 0 dated 05/29/2006
7. APS presentation to the Nuclear Regulatory Commission on May 11, 2006 entitled "A Presentation on the Physical Modification of PVNGS Unit 1 SDC Suction Line to Eliminate High-Level Vibration."
8. NRC Integrated Inspection Report 05000528/2006003.
9. Electric Power Research Institute Report entitled "EPRI Review of Palo Verde Unit 1 Shutdown Cooling Line Vibration Problem" dated August 25, 2004.
10. Electric Power Research Institute Report entitled "EPRI Review of Palo Verde Unit 1 Acoustic Pressure Suppression Device Modification dated September 28, 2005