UNITED STATES
NUCLEAR REGULATORY COMMISSION
REGION IV
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January 13, 2006

James M. Levine, Executive
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SUBJECT: PALO VERDE NUCLEAR GENERATING STATION - REVISED REDACTED VERSION OF RECIRCULATION SUMP VOID TESTING AND PROBABILISTIC RISK ASSESSMENT PRELIMINARY RESULTS DATED DECEMBER 27, 2004

Dear Mr. Levine:

Arizona Public Service (APS) Company's letter (102-05195-GRO/DGM/RAS) and affidavit dated December 27, 2004, submitted information regarding recirculation sump void testing and preliminary results from a probabilistic risk assessment. In this letter, APS requested that the information in Enclosure 2 to the letter related to special pump tests and a risk evaluation based on the test results be withheld from public disclosure pursuant to 10 CFR 2.390. At the request of the NRC staff, APS provided a redacted version of this submittal (letter 102-5208-SAB/GAM) on February 4, 2005, that was suitable for public release. The redacted version of the submittal was subsequently posted on the NRC's public website (ADAMS accession number ML050450353).

We have carefully reviewed the original December 27, 2004, letter, the February 4, 2005, redacted letter and the information contained in the request. We have concluded that some of the material that was redacted may be withheld in accordance with 10 CFR 2.390, but that certain other material should be released and placed in the Public Document Room (PDR). The enclosure to this letter provides a revised redacted version of the December 27, 2004, submittal which we believe meets the criteria of 10 CFR 2.390(a) for public withholding.

In accordance with 10 CFR 2.390(c)(2), this information was forwarded to Mr. Gregg Overbeck in an NRC letter dated on May 26, 2005, (ML051470260) as notice that the information would be placed in the Public Document Room fifteen (15) days from the date of that letter. No response was received from APS within the required fifteen (15) days.

In accordance with 10 CFR 2.390 of the NRC's "Rules of Practice," a copy of this letter, its enclosure, and your response (if any) will be made available electronically for public inspection in the NRC Public Document Room or from the Publicly Available Records (PARS) component of NRC's document system (ADAMS). ADAMS is accessible from the NRC Web site at http://www.nrc.gov/reading-rm/adams.html (the Public Electronic Reading Room).

Should you have any questions concerning this correction, we will be pleased to discuss them with you.

Sincerely,

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ENCLOSURE

Redacted Version of Preliminary Safety Significance Evaluation of ECCS Containment Sump Voided Piping

SIGNIFICANT CRDR 2726509
PRELIMINARY SAFETY SIGNIFICANCE EVALUATION OF ECCS CONTAINMENT SUMP VOIDED PIPING

1 Introduction

1.1 Background/Purpose of Report

In July, 2004, Engineering personnel determined that a section of Emergency Core Cooling System (ECCS) piping leading from the containment recirculation sump, in both ECCS trains in each of the three Palo Verde Units, was left in an unfilled condition during normal plant operation. The resultant air void could potentially be ingested into the ECCS pumps suction following a Recirculation Actuation Signal (RAS). A review of design basis information determined that this condition was not consistent with the design intent of the ECCS and not consistent with the analyses that demonstrate the ability of the ECCS to perform its design basis safety functions. Condition Report/Disposition Request (CRDR) 2726509 was initiated to document and evaluate the condition.

The purpose of this report is to describe and provide the preliminary results of a comprehensive testing and analysis program performed to determine the safety significance of this condition. The results of the evaluation are intended to be used in a risk assessment to determine the safety significance of the discovered condition.

1.2 Description of Condition

The Palo Verde ECCS design employs recirculation from the containment sump after the contents of the Refueling Water Tank (RWT) have been injected into the reactor vessel and containment building. Upon receipt of a RAS, automatic valve actuations result in suction of the ECCS pumps being transferred from the RWT to the containment sumps. Two completely redundant and separated ECCS trains are utilized. Figure 1-1 illustrates a typical ECCS suction piping and component layout.

EMERGENCY CORE COOLING AND CONTAINMENT SPRAY SYSTEM
SUCTION PIPING - TRAIN A

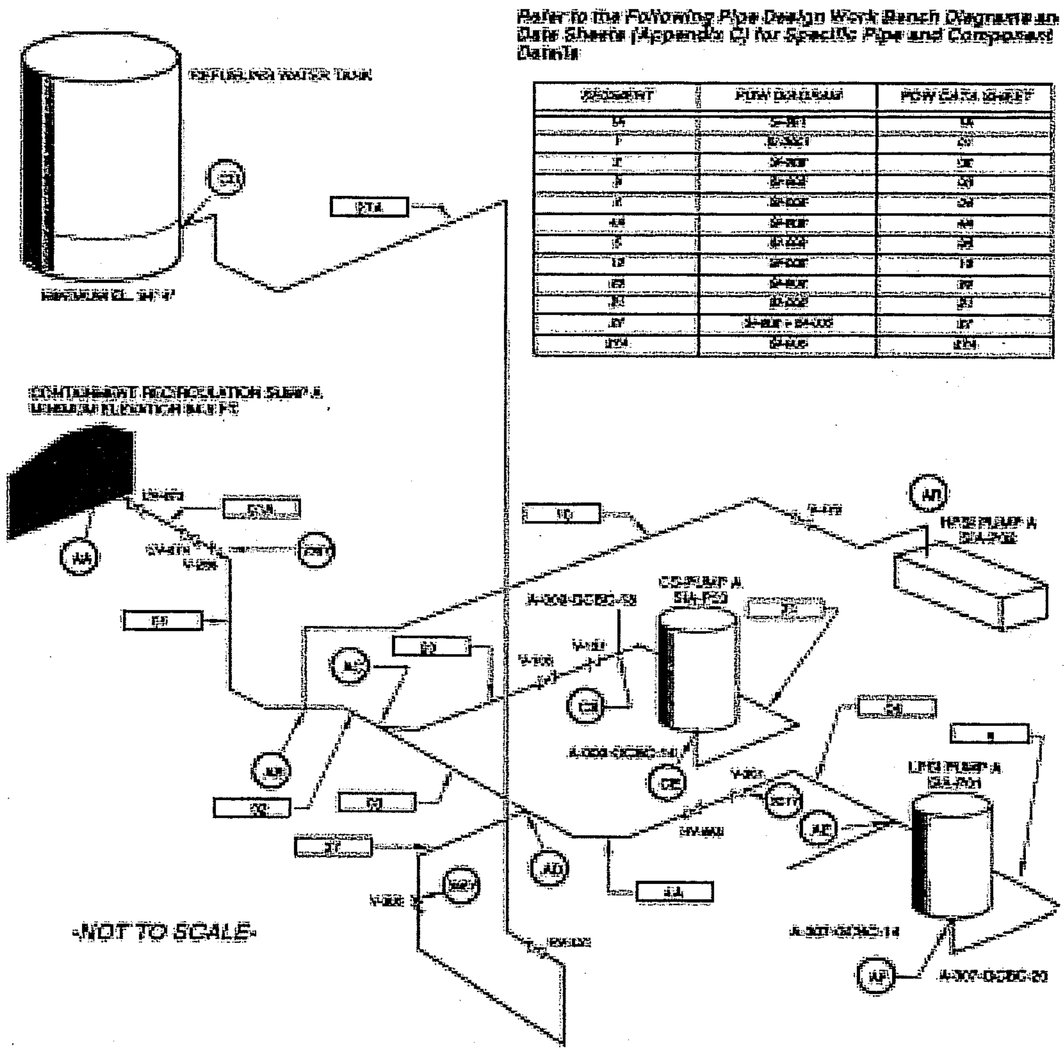

Figure 1-1 Typical Palo Verde ECCS Suction Layout

As illustrated in Figure 1-1, the containment sump suction pipe contains an in-board and an out-board containment isolation valve, and a downstream check valve. Engineering personnel determined that this section of the ECCS suction piping, between the two containment isolation valves and between the out-board valve and the downstream check valve, had been routinely left in an unfilled condition.

In the unlikely event of a Loss-of-Coolant Accident (LOCA), the contents of the Reactor Coolant System will leak into containment and flow into the containment sumps. Automatic ECCS actuation would occur causing the contents of the RWT to be injected into the RCS and the containment building to maintain core cooling and containment pressure and temperature control. Ultimately the basement of the containment building, including the containment sumps, would become flooded. Once the contents of the RWT are depleted, a RAS would be automatically generated causing both containment sump isolation valves to open, resulting in closure of the RWT isolation check valve. The RAS would also cause, by design, the Low Pressure Safety Injection pumps to be turned off. ECCS pump suction, consisting of a HPSI pump and a CS pump in each train, would thus be transferred to the containment sump.

With the containment sumps flooded and the section of containment sump piping voided, air would be trapped in the piping. As flow is initiated from the sump, this air could be entrained and/or transported into the ECCS suction piping and potentially into the ECCS pump inlets. Industry literature and operating experience indicates that pump performance could be severely degraded, or even result in air binding or pump failure, if the resultant air volume fraction ingested by the pump exceeds the pump's tolerance for air ingestion. Industry literature (Ref. 1 NUREG/CR 2792) indicates that a pump's tolerance for air ingestion varies by design and fluid conditions, but at air volume fractions above approximately 3%, pump degradation can be expected.

Therefore, in order to determine the safety significance of this condition, the air volume fraction that could be ingested by the HPSI and CS pumps would need to be determined. Once the air volume fraction is determined, each pump's tolerance for the projected air ingestion can be assessed, and ultimately the impact on the ECCS safety functions.

1.3 Significance Determination Approach

The assessment of voided and two-phase fluid behavior is complex. A comprehensive scale-model testing program was employed to develop a full understanding of the system response to the void and the resulting air/fluid conditions that would be delivered to the pumps' suction inlet. The impact to pump performance was then assessed via full-scale testing, given the projected air/fluid conditions.

The scale model tests were performed at Fauske and Associates, and simulated the system response during and following a RAS with the affected section of piping initially voided. The scale tests were conducted in three phases. The first phase modeled the RWT and associated piping, and the sump and associated piping down through and including the long vertical run of pipe. The purpose of the first phase was to demonstrate the ability to simulate the transient and measure the important parameters such as void fraction, pressure, and flow rate. A series of tests were performed to test important scaling parameters to ensure the results of the test could be confidently applied to the full scale Palo Verde units. A series of phenomenological tests (the second phase) using a larger scale model was incorporated into the test plan to verify that the flow regime in the vertical section of the scaled piping configuration was representative of large pipe behavior.

The third phase extended the scale model to include the individual pump suction piping up to each pump inlet. An extensive series of tests under varying flow and pressure conditions were performed.

. These results established the inlet conditions for the subsequent full-scale pump performance tests.

Full-scale pump tests were performed at Wyle Labs utilizing a spare Palo Verde High Pressure Safety Injection (HPSI) pump and a representative Containment Spray (CS) pump to determine the impact on pump performance under the projected air ingestion conditions. The HPSI pump was of the same make and model as those installed at Palo Verde. A spare CS pump of the same make and model as the Palo Verde CS pumps was not readily available; therefore a spare CS pump from a cancelled WPSS plant was utilized for the test. This pump is the same make and model as the Palo Verde LPSI pumps and is very similar in design and size to the Palo Verde CS pumps. The impact on performance for equivalent fluid conditions is expected to be representative. Tests were performed for a spectrum of flow rates and air ingestion rates based on the results of the scale-model test program. Pump performance was measured as a function of air volume fraction. A maximum degraded pump performance curve was then constructed using the test results for the tests performed at maximum air volume fractions.

A series of thermal hydraulic analyses of the Palo Verde Reactor Coolant System and Containment were performed using the Westinghouse CENTS code and the

code. These analyses established the expected reactor coolant and containment environment conditions that would exist at the time of RAS for a spectrum of LOCA break sizes. Operator actions, as prescribed in the Palo Verde Emergency Operating Procedures (EOPs), to initiate a cool down and depressurize the RCS upon diagnoses of a LOCA were explicitly considered in the analyses. In this way, best-estimate parameters such as RCS and containment pressures at time of RAS were established.

For those conditions which do not exceed the degraded pump performance capability, continued degraded ECCS delivery (i.e. continued pump flow) is assumed until the air inventory available for ingestion into the pump is consumed, at which time restoration of full pump performance is assumed. For these conditions, maintenance of the ECCS safety function is assured.

2 Scale Model Testing

2.1 Phase 1 Test Program and Results

2.1.1 Experimental Objectives and Physical Arrangement

The objective of the Phase 1 testing was to investigate the potential for the air initially resident in the horizontal piping section from the containment sump to be forced into the vertical downward piping section. Phase 1 tests included the transient effects of switching the supply from the simulated RWT to the simulated containment sump by simultaneously opening the sump suction isolation valves. Clear piping was used for the horizontal and vertical segments of the simulated suction line to observe and record the flow pattern and the behavior of the initial air filled void.

The test facility that was used was comprised of two tanks with water inventories, a centrifugal pump, piping, and valves and associated instrumentation. The piping and valves used to establish and visualize the flow pattern development from the initial location between the valves and into the downcomer piping were all 4 inch in diameter. Clear plastic piping facilitated observation of the initial air inventory behavior during the opening of the motor operated valves. The vertical segment was also clear plastic piping that allowed for the observation [ ] in the downward vertical flow. [ ]

2.1.2 Scaling Considerations

As indicated, 4 inch diameter piping was used to simulate the sump horizontal and vertical downward sections of piping. Since actual Palo Verde piping is 24 inch in diameter, this results in a 1/6th geometric scaling factor. This geometric (lengths and diameters) scaling factor was maintained through out the Phase 1 tests to the extent possible.

Flow rates were scaled in the Phase 1 tests so as to maintain the same dimensionless Froude Number parameter as would exist in the Palo Verde units. Previous tests and experiments described in the literature have demonstrated that maintenance of the Froude number, particularly for horizontal flow regimes, will result in prototypical behavior in scaled experiments.

2.1.3 Phase 1 Results and Observations

A series of twelve tests were performed with varied [ ]

[ ]

2.2 Phenomenological Testing Program

2.2.1 Experimental Objective and Physical Arrangement

Design reviews conducted before and after the Phase 1 tests and an independent review by Dr. M. Ishii of Purdue University, an expert in two-phase modeling and experiments, resulted in the identification of several phenomenological investigations that could be performed to provide additional perspective and assurance on proper scaling of the full plant condition to the 1/6th scale model. The phenomenological investigations included:

[ ]

The test arrangement also provided the opportunity to observe the flow patterns and influence of the HPSI and CS branch connections off the lower header piping.

2.2.2 Phenomenological Testing Results and Observations

An extensive series of tests using the [ ] scale test apparatus were performed. Key observations from these tests were

[ ]

2.3 Phase 2 Test Program and Results

2.3.1 Experimental Objectives and Physical Arrangement

The test facilitv for Phase 2 was similar to that of Phase 1,

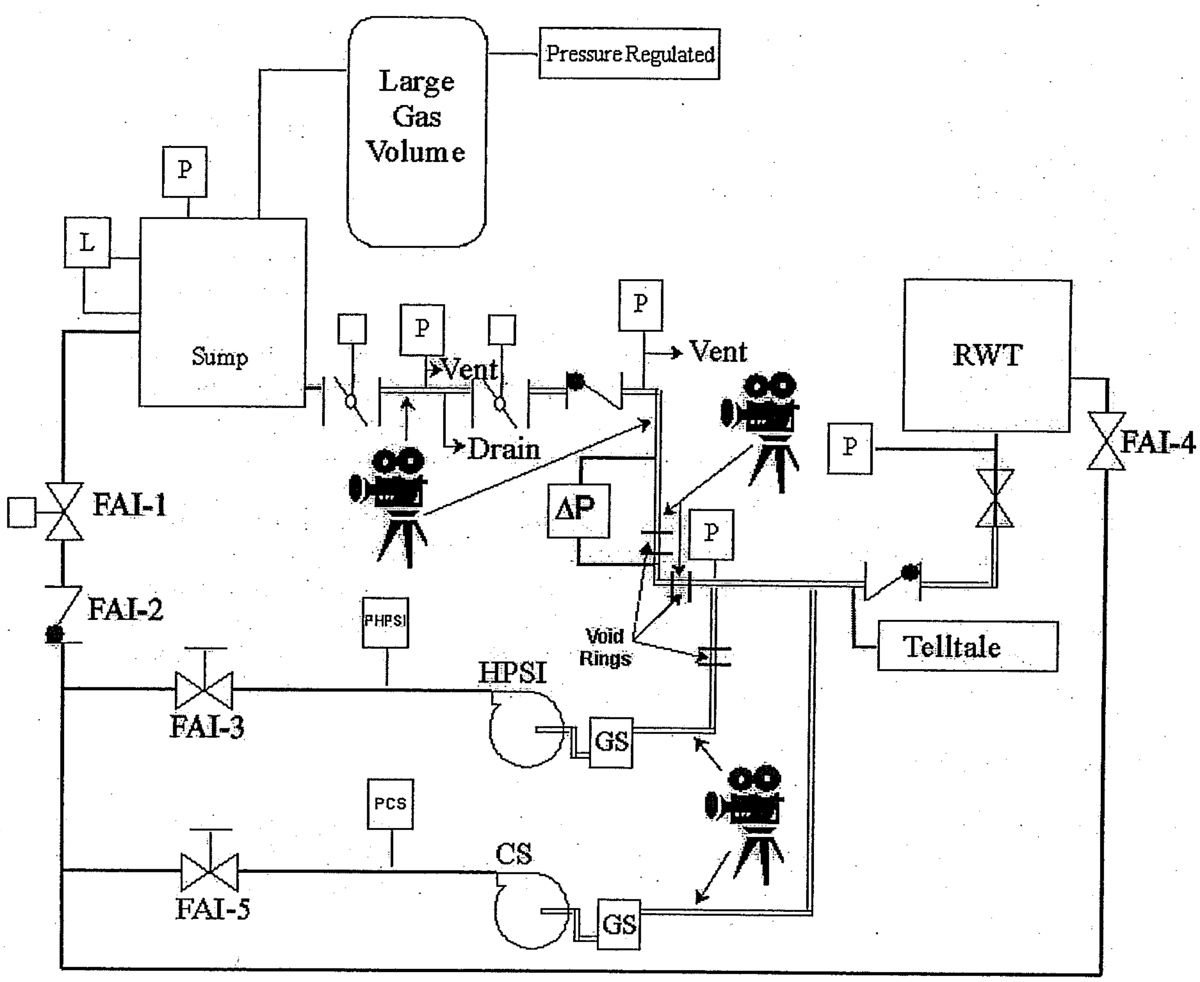

Figure 2-1 Phase 2 Test Arrangement.

[ ]

[ ] In the plant system under accident conditions, air transported through the HPSI line would influence the pump performance and cause a decrease in the flow rate being pumped. Reduced flow rate would cause a corresponding reduction in the rate of air ingestion. Thus, the air intrusion rate deduced from these scaled experiments provides a conservative representation of the plant response.

The test instrumentation is also illustrated in Figure 2-1. A computer with a CIO-DAS008 data acquisition card was used to collect the data. Key pieces of instrumentation included

[ ]

- Various pressure , level, and flow meters

[ ]

During the Phase 2 tests, the flow rate through the CS pump was again held constant at the maximum predicted flow rate equivalent to 4885 gpm, except for several tests in which CS flow was set to zero to simulate a HPSI flow only scenario. HPSI flow rate was varied ranging from the equivalent to 200 gpm to an equivalent maximum run-out flow of 1310 gpm.

[ ]

2.3.2 Scaling Considerations

The same 1/6th geometric scaling used in Phase 1 was used for the Phase 2 experiments. Flow rates were scaled to maintain the same Froude number that would exist at Palo Verde. The Froude number relationship was maintained for both the total flow and the individual flow rates to the simulated HPSI and CS pumps.

[ ]

[ ]

2.3.3 Phase 2 Results and Observations

A series of twenty-eight tests were initially performed with varied flow rates, containment level, and containment pressure conditions. Additional tests were later performed to investigate the air transport process during potential LPSI pump start scenarios. Key observations from the tests were:

[ ]

Flow Patterns

Digital movie cameras were used to record the flow patterns in all the Phase 2 tests. Each test was initiated by simultaneously opening the sump containment isolation valves. As the valves open, water is seen to enter the initially voided horizontal piping segment and induce mixing of the water and air. The air is swept out of the horizontal segment and into the vertical piping segment.

[ ]

HPSI Air Ingestion Rates

[ ]

[ ]

These results show that the air flow ingestion rates increase to their maximum value within approximately [ ] seconds for the scaled experiments and then subsequently decay towards zero as the air inventory in the horizontal suction header becomes insufficient to enter the HPSI line. Similar evaluations for scaled HPSI flow rates [ ] were also performed.

The air ingestion rate information was then scaled up to determine the air ingestion rates that could have been experienced at Palo Verde under postulated accident conditions. Since the Phase 2 tests were conducted on a $1/6^{th}$ linear scale, the mass flow rates were increased by six cubed (216) and the time interval increased by the square root of six (2.44) to develop the conditions that would have been experienced at Palo Verde and for use as input into the full scale pump performance tests. Using the results from the Phase 2 tests, these scale factors are applied and the results illustrated in Figure 2-4 for the case of a full HPSI flow rate of 1310 gpm. As shown, the meaningful delivery period for the air flow is approximately [ ]

[ ]

Since Reference 1, and other pump performance tests described in the literature, indicates that pump performance is typically assessed as a function of air volume fraction, the peak mass flow rate data obtained during the Phase 2 tests was converted to air volume fractions for use in the subsequent full-scale pump tests.

[ ]

3 Pump Performance Testing With Air Ingestion

3.1 Description of Test Facility

The pump performance tests were conducted at Wyle Labs in Huntsville AL. The test facility consisted of two closed pump loops each drawing suction from, and discharging to, a common 30,000 gallon pressure vessel. One loop was constructed to provide for testing of the spare HPSI pump. Suction and discharge pipe sizes were selected to correspond to the actual pipe sizes at Palo Verde. The specific suction piping configuration leading into the HPSI suction nozzle was explicitly reproduced. The second loop was provided for testing of the representative CS pump.

[ ]

3.2 Test Conduct

A series of tests were conducted at each base case flow rate. The base case flow rates were selected to produce the same dimensionless Froude number as the cases tested in the Phase 2 scale model tests, and were meant to span the range of flow rates that could be expected at the time of RAS during a postulated LOCA.

For each base case, tests were performed at incrementally increasing air injection mass flow rates. The resulting air volume fraction, defined as the ratio of volumetric air flow rate to total volumetric air flow rate, was then determined. [

] Figure 3-1 illustrates the final test for the [ ] base case.

[ ]

During every test, the duration of air injection was specified to assure that the total volume of air injected exceeded the total volume of air predicted by the scale model tests. Pump performance data was taken during each test for subsequent assessment of the air ingestion on pump performance. Visual observations, and digital camera recordings, were made for all HPSI test cases.

3.3 Test Results

Visual observations through the clear spool piece on the HPSI suction line confirmed similar in nature to that observed during the scale model Phase 2 tests. The visual observations confirmed the proper scale up from the Phase 2 tests and gives reasonable confidence that the Phase 2 and Phase 3 tests closely approximate the full-scale plant conditions. Pump performance data was taken using a data acquisition system that recorded each data point 10 times per second. The recorded data was then inserted into Excel spreadsheets to facilitate calculation of pump developed

a typical pump curve graph as shown in Figures 3-2 through 3-4. The data represents the calculated developed head (TDH) from the recorded pump inlet and outlet pressure data taken every 0.1 seconds, and the corresponding flow rates as measured on the pump discharge line. The data represents that obtained over a specific time period during which the air injection rate was at its maximum steady state value and the corresponding peak air volume fractions were obtained. The data points, as expected, fall along the test loop system curve.

[ ]

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[ ]

As illustrated in the preceding three figures, and as would be expected, pump performance progressively degrades as inlet air volume fraction increases. This progressive degradation is consistent with data reported in NUREG/CR 2792 (Reference 1). The following figure 3-5 is taken from Reference 32 as cited in the NUREG.

SULZER RESEARCH NUMBER 1970

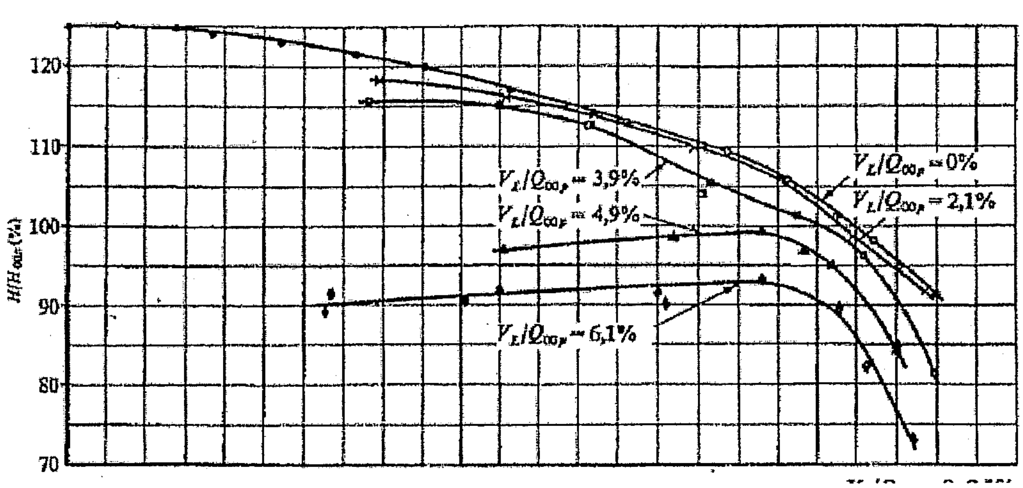
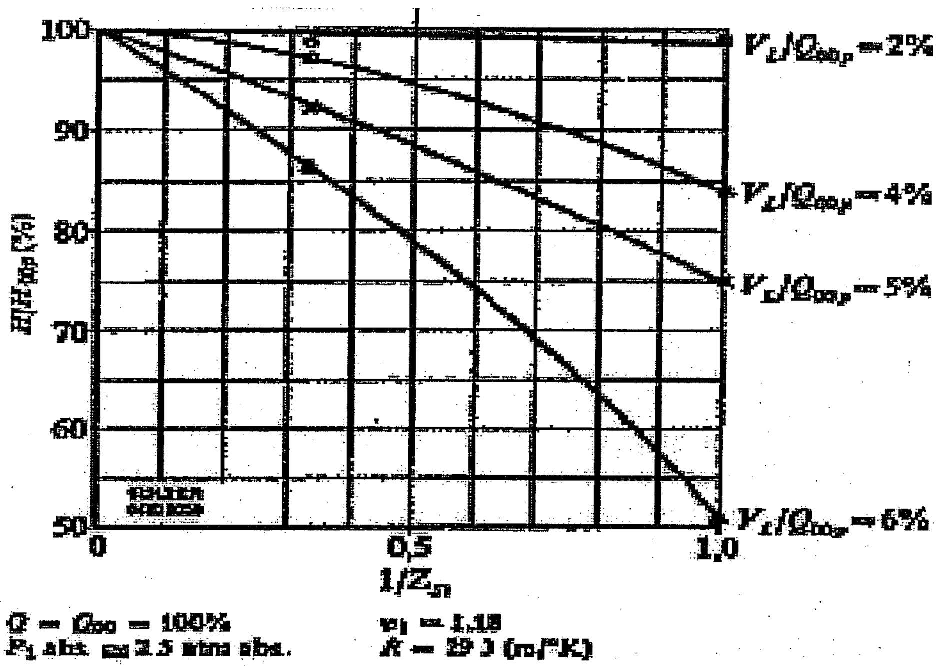


Figure 3-5 Degrading Pump Performance as a Function of Air Volume Fraction

A maximum bounding degraded pump curve is then constructed as shown in Figure 3-6. As illustrated, the maximum degraded pump curve conservatively bounds all recorded data for the peak air volume fraction cases tested. The use of this maximum degraded pump curve results in additional conservatism since the Phase 3 tests conditions in some cases exceeded the specified air volume fraction from the Phase 2 scale model tests.

The eight-stage HPSI pump demonstrated a very high tolerance for air ingestion. This is consistent with the limited data in the literature regarding multi-stage pumps under air ingestion conditions. The following figure (Figure 3-7) is a reproduction of Figure 3-8 from NUREG/CR-2792. As reported in the NUREG, performance degradation for a multi-stage pump is much less pronounced. The author of the test report cited in the NUREG (Reference 32 of the NUREG) attributes this to the fact that air is raised to a higher pressure (i.e. compressed) at each stage and has less effect on the performance of the next stage.



8 Influence of number of stages Z_{st}.

Figure 3-7 Influence of Number of Stages on Performance Degradation (from NUREG/CR-2792)

4 Safety Function Impact

4.1 Thermal Hydraulic Analysis of Spectrum of LOCA Break sizes

A series of thermal hydraulic analyses of the Palo Verde ECCS system were performed using the Westinghouse CENTS code and the . code. These analyses established the expected reactor coolant system and containment environment conditions that would exist at the time of RAS for a spectrum of LOCA break sizes. Operator actions as prescribed in the Palo Verde Emergency Operating Procedures (EOPs) to initiate a cool down and depressurization of the RCS upon diagnosis of a LOCA were explicitly considered in the analyses. In this way, best-estimate parameters such as RCS and containment pressures at time of RAS were established.

The analyses provide two key results. The first is that break sizes of 2" diameter or smaller

alternate method of core cooling is available. The current PVNGS Emergency Operating Procedures fully implement this recovery strategy.

The second result is the RCS pressure that would exist at the time of RAS for various size breaks. These results are provided in Figure 4-1.

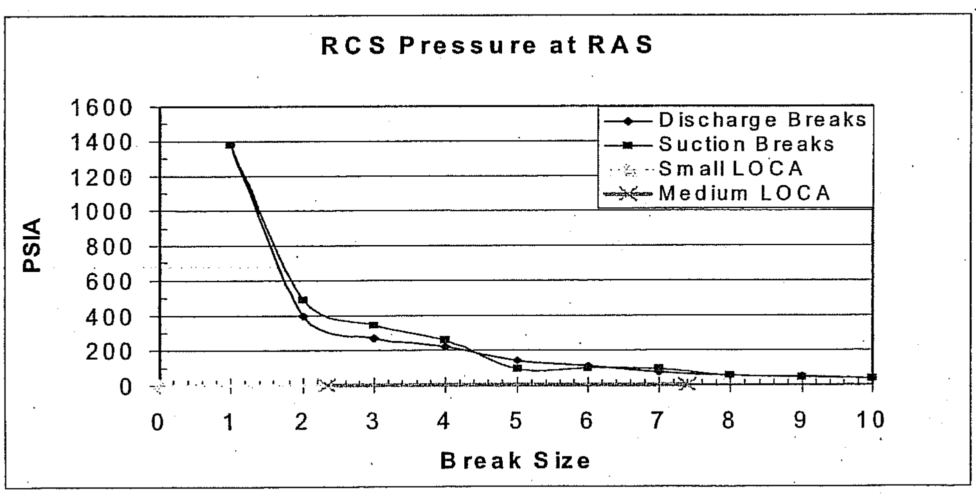


Figure 4-1 RCS pressure at the time of RAS for various break sizes from CENTS analyses

This parameter is used in the following section to construct system resistance curves and subsequent assessment on ECCS performance (i.e. HPSI flow) under the maximum predicted air ingestion conditions.

4.2 Determination of Degraded HPSI Flow

Considering the RCS pressure at RAS for the various break sizes described in Figure 4-1, system resistance curves can then be developed using the following relationship:

$$TDH = \frac{144}{\rho}(P_{RCS} - P_{CONT}) + (Z_{RCS} - Z_{SUMP}) + C_{sys}Q^2$$

The elevation ot the RCS is assumed to be the centerline of the cold legs at . The elevation of the sump is taken as the minimum flood level elevation of . Containment pressure is assumed to be equal to be . The system resistance curves are then developed as shown in Figure 4-2.

The resulting HPSI system performance or operating points, given the degraded pump performance and the system resistance curves developed above, can be determined from the extended Bernoulli energy equation:

$$\left(\frac{144}{\rho}Pcont + Zcont + \frac{V^2}{2g}\right) - C_{sys}Q^2 + THD = \left(\frac{144}{\rho}PRCS + ZRCS + \frac{V^2}{2g}\right)$$

The results can be depicted graphically as shown in Figure 4-3.

As indicated in Figure 4-3, the static head associated with the 1" diameter small break LOCA at the time of RAS is well above the developed head of the degraded HPSI pump under maximum air ingestion. It is assumed that the degraded HPSI pump would be unable to deliver flow to the RCS.

For break sizes 2" diameter and larger, Figure 4-3 indicates the degraded HPSI pump has sufficient developed head to continue delivering ECCS flow to the RCS for the short time until the volume of air originally resident in the voided piping is exhausted. After the total air volume is ingested, the Phase 3 pump performance tests demonstrated the HPSI pump would recover and return to its normal non-degraded performance.

4.3 HPSI Pump Test Conclusion

From the Phase 3 pump performance tests under air ingestion, a bounding degraded HPSI pump performance curve was developed. The bounding degraded performance curve envelopes the maximum predicted air volume fractions ingested by the HPSI pump, based on Phase 2 scale-model testing. This study then compared the resulting degraded pump performance with the calculated system resistance that would exist at the time of RAS, for the spectrum of break sizes. The comparison indicates the degraded HPSI pump would develop sufficient discharge head to maintain flow to the RCS for all break sizes except for the smallest breaks less than 2". The degraded flow rate delivered to the RCS would only exist for [.] until the air inventory available to be ingested is exhausted, at which time pump performance can be assumed to return to normal.

4.4 Containment Spray Pump Test Conclusion

Tests were conducted on the representative CS pump by injecting air at rates up to approximately [ ] air volume fraction. This air volume fraction conservatively bounds the amount of air predicted by scale model testing for all scenarios tested. The pump experienced a reduction in flow of approximately [ ] during the period of air ingestion, then returned to normal baseline performance after air injection was suspended. It is concluded that the voided pipe condition does not have a significant impact on Containment Spray pump functionality.

4.5 Probabilistic Risk Assessment Conclusion

From the CENTS thermal-hydraulics analyses and the Phase 3 pump performance tests, modifications to the Palo Verde Probabilistic Risk Assessment (PRA) model were made to assess the risk significance of the voided pipe condition. The Palo Verde model contains an event tree for small break LOCAs of 2.3 inch diameter and smaller. The model was revised by inserting a failure of the HPSI pumps at RAS (failing the high pressure recirculation function) for small-break LOCA due to air binding and modeling the subsequent plant cool down and depressurization and LPSI alignment for low pressure recirculation. Since the pump performance tests indicate that for breaks 2 inches in diameter and larger failure of the HPSI pump is not likely, medium and large LOCA events were unaffected by the voided condition. Thus the small LOCA event would be the dominant contributor to the risk increase due to the voided pipe condition. Some sensitivity studies related to this analysis are currently in progress and no analysis of the impact on Large Early Release Frequency has been performed at this time.

With the above described change made to the PRA model, the increase in CDF is about **3E-6/yr**.

5 References

1. NUREG/CR-2792 "An Assessment of Residual Heat Removal and Containment Spray Pump Performance Under Air and Debris Ingesting Conditions". Published September 1982.
2. Paranjape, S. S. et al. 2003. "Interfacial Structures in Downward Two-Phase Bubbly Flow". 11th International Conference on Nuclear Engineering (ICONE11). Tokyo, Japan.
3. Wallis, G.B., 1969. One Dimensional Two-Phase Flow, McGraw-Hill, New York.