UNITED STATES
NUCLEAR REGULATORY COMMISSION
REGION IV
611 RYAN PLAZA DRIVE, SUITE 400
ARLINGTON, TEXAS 76011-4005

May 1, 2006

James M. Levine, Executive
Vice President, Generation
Mail Station 7602
Arizona Public Service Company
P.O. Box 52034
Phoenix, AZ 85072-2034

SUBJECT: PALO VERDE NUCLEAR GENERATING STATION - REVISED REDACTED VERSION OF RESPONSE TO INFORMATION REQUEST DATED FEBRUARY 15, 2005

Dear Mr. Levine:

Arizona Public Service (APS) Company's letter (102-05213-DMS/SAB/GAM) and affidavit dated February 15, 2005, submitted your staffs response to an information request in NRC Special Inspection Report 05000528/2004014; 05000529/2004014; 05000530/2004014. In this letter, APS requested that the information in Enclosure 2 and its attachment (except Attachment 2-F) to the letter 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, dated July 5, 2005, that was suitable for public release. The redacted version of the submittal was subsequently posted on the NRC's public website (ADAMS assession number ML053480465).

We have carefully reviewed both the original February 15, 2005, letter and the redacted version. 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 attachment to this letter provides a revised redacted version of the July 5, 2005, 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 you in an NRC letter dated January 24, 2006, (ML060250548) 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,

Troy W. Pruett, Chief
Project Branch D
Division of Reactor Projects

Dockets: 50-528
50-529
50-530
Licenses: NPF-41
NPF-51
NPF-74

Attachment:

cc w/attachment:
Steve Olea
Arizona Corporation Commission
1200 W. Washington Street
Phoenix, AZ 85007

Douglas K. Porter, Senior Counsel
Southern California Edison Company
Law Department, Generation Resources
P.O. Box 800
Rosemead, CA 91770

Chairman
Maricopa County Board of Supervisors
301 W. Jefferson, 10th Floor
Phoenix, AZ 85003

Aubrey V. Godwin, Director
Arizona Radiation Regulatory Agency
4814 South 40 Street
Phoenix, AZ 85040

Craig K. Seaman, General Manager
Regulatory Affairs and
Performance Improvement
Palo Verde Nuclear Generating Station
Mail Station 7636
P.O. Box 52034
Phoenix, AZ 85072-2034

Hector R. Puente
Vice President, Power Generation
El Paso Electric Company
310 E. Palm Lane, Suite 310
Phoenix, AZ 85004

Jeffrey T. Weikert
Assistant General Counsel
El Paso Electric Company
Mail Location 167
123 W. Mills
El Paso, TX 79901

John W. Schumann
Los Angeles Department of Water & Power
Southern California Public Power Authority
P.O. Box 51111, Room 1255-C
Los Angeles, CA 90051-0100

John Taylor
Public Service Company of New Mexico
2401 Aztec NE, MS Z110
Albuquerque, NM 87107-4224

Thomas D. Champ
Southern California Edison Company
5000 Pacific Coast Hwy, Bldg. D1B
San Clemente, CA 92672

Robert Henry
Salt River Project
6504 East Thomas Road
Scottsdale, AZ 85251

Brian Almon
Public Utility Commission
William B. Travis Building
P.O. Box 13326
1701 North Congress Avenue
Austin, TX 78701-3326

Karen O'Regan
Environmental Program Manager
City of Phoenix
Office of Environmental Programs
200 West Washington Street
Phoenix, AZ 85003

Electronic distribution by RIV:
Regional Administrator **(BSM1)**
DRP Director **(ATH)**
DRS Director **(DDC)**
DRS Deputy Director **(RJC1)**
Senior Resident Inspector **(GXW2)**
Branch Chief, DRP/D **(TWP)**
Senior Project Engineer, DRP/D **(GEW)**
Team Leader, DRP/TSS **(RLN1)**
RITS Coordinator **(KEG)**
Dale Thatcher **(DFT)**
DRS STA **(DAP)**
William Maier, RSLO **(WAM)**
Stephen O'Connor, OEDO RIV Coordinator **(TEB)**

SUNSI Review Completed: __TWP_ ADAMS: √ Yes ☐ No Initials: TWP______
√ Publicly Available ☐ Non-Publicly Available ☐ Sensitive √ Non-Sensitive

R:_REACTORS\PV\2006\PV redacted response 2-15-05.wpd

TWPruett	KSFuller			
/RA/	/RA/			
3/8/06	4/28/06			

OFFICIAL RECORD COPY T=Telephone E=E-mail F=Fax

ATTACHMENT 1

Palo Verde Nuclear Generating Station

Gregg R. Overbeck
Senior Vice President
Nuclear

Tel (623) 393-5148
Fax (623) 393-6077
e-mail: GOVERBEC@apsc.com

Mail Station 7602
PO Box 52034
Phoenix, Arizona 85072-2034

102-05303-GRO/TNW/GAM
July 5, 2005

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Dear Sirs

Subject: Palo Verde Nuclear Generating Station (PVNGS)
Units 1, 2 and 3
Docket Nos. STN 50-528, 50-529, and 50-530
Redacted Version of Proprietary Submittal Dated February 15, 2005 Regarding Safety Significance Evaluation of ECCS Containment Sump Voided Piping

In letter no. 102-05213, dated February 15, 2005, Arizona Public Service Company (APS) submitted to the NRC the safety significance evaluation of emergency core cooling system (ECCS) containment sump voided piping. APS requested that Enclosure 2 and Attachments 2-A, 2-B, 2-C, 2-D, and 2-E of that submittal be withheld from public disclosure under 10 CFR 2.390(a)(4) because they contained information considered to be proprietary to APS. Since that time, NRC Region IV personnel have requested that APS submit redacted versions of Enclosure 2 and Attachments 2-A, 2-B, 2-C, 2-D, and 2-E of the February 15, 2005 submittal. The requested redacted versions of the enclosure and attachments are enclosed.

There are no commitments in this letter. Should you have any questions, please contact Mr. Thomas N. Weber at (623) 393-5764.

Sincerely,

Gregg R. Overbeck

GRO/TNW/GAM/ca

Enclosure: Redacted Versions of Proprietary Enclosure 2 and Attachments 2-A, 2-B, 2-C, 2-D, and 2-E of APS Letter No. 102-05213, dated February 15, 2005, Regarding Safety Significance Evaluation of ECCS Containment Sump Voided Piping

cc: T. W. Pruett	NRC Region IV	(w/ Enclosure)
B. S. Mallett	NRC Region IV Regional Administrator	(w/o Enclosure)
M. B. Fields	NRC NRR Project Manager	"
G. G. Warnick	NRC Senior Resident Inspector for PVNGS	"

Redacted Versions of Proprietary Enclosure 2 and Attachments 2-A, 2-B, 2-C, 2-D, and 2-E of APS Letter No. 102-05213, dated February 15, 2005, Regarding Safety Significance Evaluation of ECCS Containment Sump Voided Piping

ENCLOSURE 2

SAFETY SIGNIFICANCE EVALUATION OF ECCS CONTAINMENT SUMP VOIDED PIPING

~~(Proprietary)~~
REDACTED VERSION

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

Executive Summary

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 volume of air 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 results of a comprehensive testing and analysis program performed to evaluate the ECCS system response to the voided piping condition. The results of the evaluation are then used in a risk assessment to determine the safety significance of the discovered condition.

Scale model tests were performed at Fauske and Associates which simulated the system response during and following a RAS with the affected section of piping initially unfilled. The scale tests were conducted in phases. The purpose of the first phase (typically referred to as Phase 1) was to demonstrate the ability to simulate the transient and measure the important parameters such as void fraction, pressure, and flow rate. [

]

[ ]

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. 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, as defined by developed head and flowrate, was measured as a function of [redacted]

A series of thermal hydraulic analyses of the Palo Verde Reactor Coolant System and Containment were performed using the Westinghouse CENTS code and the EPRI MAAP code. These analyses established the expected reactor coolant and containment environment conditions that would exist at the time of RAS for a spectrum of Loss of Coolant Accident (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. [redacted]

[ ]

In addition to the testing program, a computer hydraulic transient analysis of the ECCS voided pipe condition was performed. [

]

Ultimately, the analysis results are compared to the testing program and shown to be complimentary.

Given the results of the tests and analyses, the risk significance was determined by making appropriate adjustments to the Palo Verde Probabilistic Risk Assessment (PRA) model. [

]

1 Introduction

1.1 Background/Purpose of Report

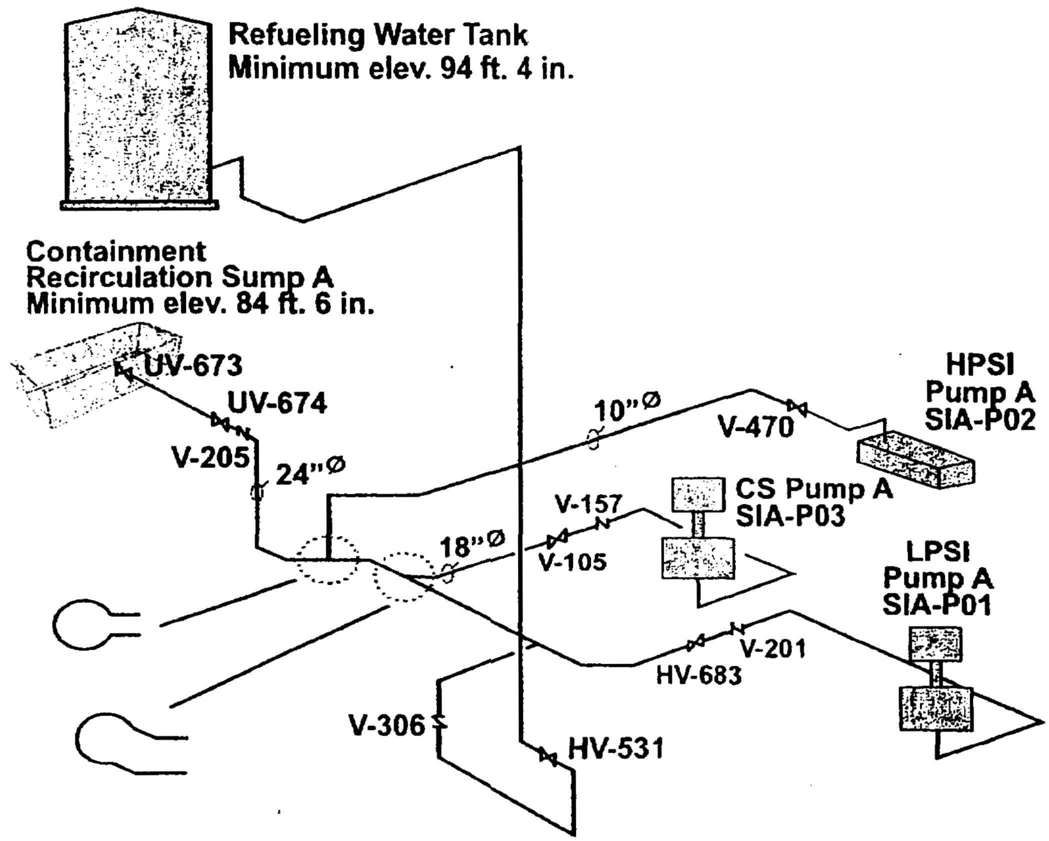
In July, 2004, Engineering personnel determined that a section of Emergency Core Cooling System (ECCS) piping leading from the containment recirculation sump, in both ECCS trains in each of the three Palo Verde Units, was left in an unfilled condition during normal plant operation. The resultant volume of air 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 results of a comprehensive testing and analysis program performed to evaluate the ECCS response to the voided piping condition. The results of the evaluation are then 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



-Not to scale-

Figure 1-1 Typical Palo Verde ECCS Suction Layout

As illustrated in Figure 1-1, the containment sump outlet 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 during plant operation.

In the unlikely event of a Loss-of-Coolant Accident (LOCA), the contents of the Reactor Coolant System (RCS) 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 in each train to open, resulting in closure of the RWT isolation check valves. The RAS would also cause, by design, the Low Pressure Safety Injection (LPSI) pumps to be turned off. ECCS 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 not filled with water, 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 experienced.

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 inlet 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 scaled tests were conducted in 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 (typically referred to as Phase 1) 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 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 second 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 performance 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 EPRI MAAP 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. [redacted]

[

] For those system conditions in which the required head 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.

[ ]

[ ]

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. A complete report on the conduct and results of the Phase 1 test program is attached as Attachment 2-A to this report.

The test facility that was used was comprised of two tanks with water inventories, a centrifugal pump, piping, 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 $1/6^{th}$ geometric scaling factor. This geometric (lengths and diameters) scaling factor was maintained through out the Phase 1 tests to the extent possible.

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. As such, 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.

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 [ ] resulted in the identification of several phenomenological investigations that could be performed to provide

[ ]

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 <u>Phenomenological Testing Results and Observations</u>

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 facility for Phase 2 was similar to that of Phase 1[

]

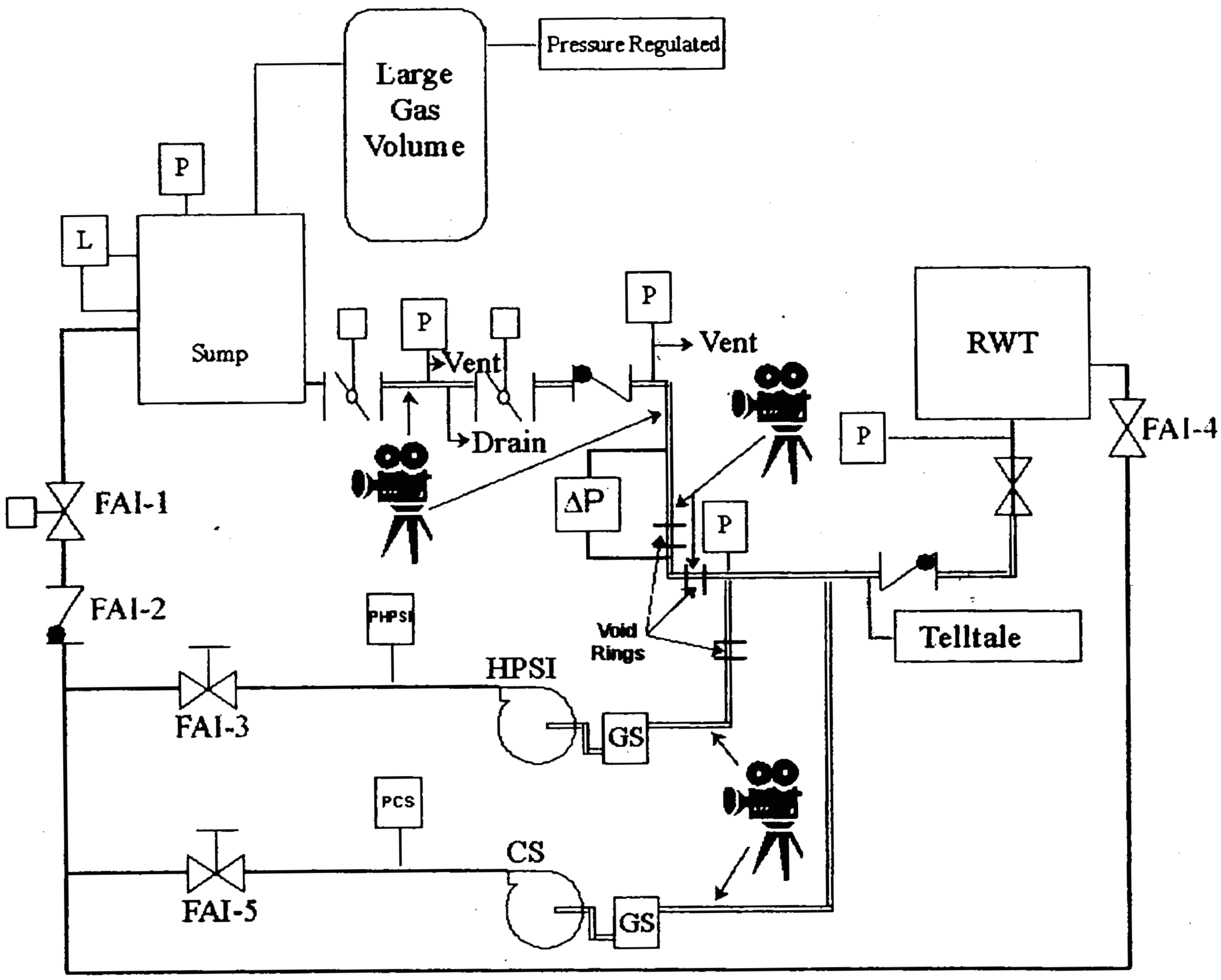


Figure 2-1 Phase 2 Test Arrangement.

[

] 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. LPSI start scenarios were also tested for a range of LPSI flow rates.

[ ]

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, CS, and LPSI pumps.

[ ]

[ ]

In this horizontal orientation, the principal scaling parameter has been well established previously (References 3 and 4) to be the Froude number which is a ratio of the inertial and buoyancy forces, i.e.

$$N_{Fr}^2 = \frac{\rho_w U^2}{gD\left(\rho_w - \rho_g\right)} \qquad \text{Eq. (1)}$$

where:

- D is the diameter of the horizontal piping,
- g is the acceleration of gravity,
- U is the one-dimensional velocity of the flow in this line,
- ρ_g is the air density, and
- ρ_w is the water density.

Since $\rho_w >> \rho_g$, this reduces to the familiar form

$$N_{Fr} = \frac{U}{\sqrt{gD}} \qquad \text{Eq. (2)}$$

[ ]

[ ]

[ ]

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 [
]

[ ]

With a 1/6th linear scale, the respective volumes are determined by the cube of this linear scale, i.e. the scaled up quantities are defined by the volume multiplied by 216. More simply put, the area is scaled by the square of the diameter times the length. Thus six cubed equals 216. Since mass is directly proportional to volume at a given pressure and temperature, mass quantities are also scaled by a factor of 216.

[ ]

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 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 full-scale pump tests. [

]

[ ]

3 Hydraulic Transient Analysis

3.1 Description of Analysis and Computer Model

A hydraulic computer model of a typical Palo Verde ECCS system was developed [

]

3.2 Analysis Results

[ ]

[ ]

[ ]

3.3 Hydraulic Transient Analysis Conclusions

[

]

4 Pump Performance Testing With Air Ingestion

4.1 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.

[ ]

4.2 Test Conduct

A series of tests were conducted at each base case flow rate. The base case flow rates of 600 gpm, 900 gpm, and 1310 gpm were selected 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 4-1 illustrates the final test for the 900 gpm base case. [
]

[ ]

Figure 4-1 Air Injection and Air Volume Fraction for Final 900 gpm Series Test

During every test, the duration of air injection was specified to assure that the total volume of air [ ] 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.

4.3 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 scaling of 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 [

] 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.

[ ]

[ ]

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 4-5 is taken from Reference 32 as cited in the NUREG.

SULZER RESEARCH NUMBER 1970

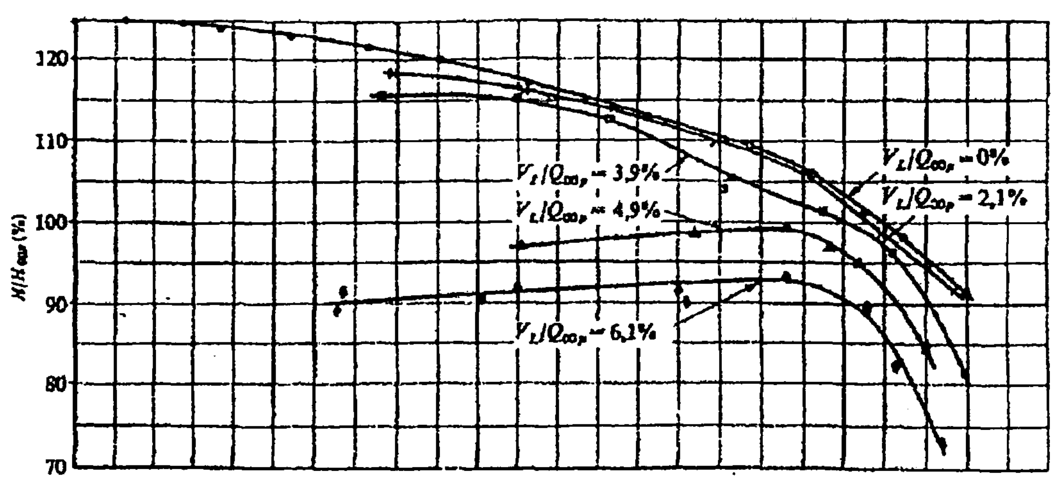
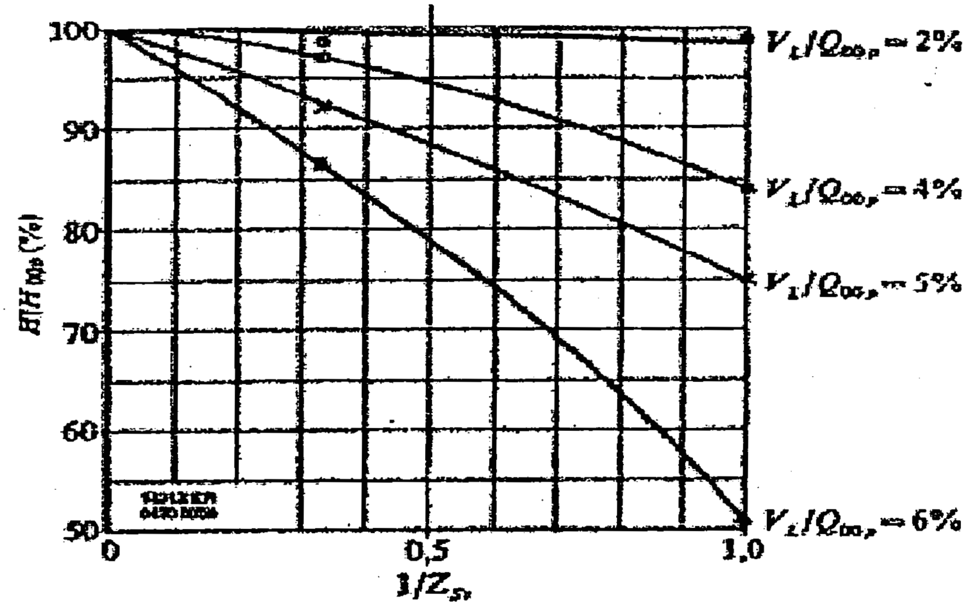


Figure 4-5 Degrading Pump Performance as a Function of Air Volume Fraction

A maximum bounding degraded pump curve is then constructed as shown in Figure 4-6. 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.

[ ]



$Q = Q_{00} = 100\%$ $\quad v_1 = 1.18$
P_1 abs ≥ 2.5 atm abs $\quad R = 29.3$ (m/°K)

8 Influence of number of stages Z_{St}.

Figure 4-7 Influence of Number of Stages on Performance Degradation (from NUREG/CR-2792)

5 Safety Function Impact

5.1 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 EPRI MAAP4 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 CENTS and MAAP codes were used to mutually develop the conclusions associated with the LOCA scenarios. Summary descriptions of the two codes are presented, followed by descriptions of application of the HPSI and CS pump test data in the transient results. Detailed descriptions of the codes and their applications and limitations are within References [redacted]. These references also provide detailed descriptions of the individual transient results.

5.1.1 MAAP4 Analysis Code Description

MAAP is a computer code that simulates light water reactor system response to accident initiation events. The Modular Accident Analysis Program (MAAP), an integral systems analysis computer code for assessing severe accidents, was initially developed during the industry-sponsored IDCOR Program. At the completion of IDCOR, ownership of MAAP was transferred to Electric Power Research Institute (EPRI). Subsequently, the code evolved into a major analytical tool (MAAP 3B) for supporting the plant-specific Individual Plant Examinations (IPEs) requested by NRC Generic Letter 88-20. Furthermore, MAAP 3B was used as the basis to model the Ontario Hydro CANDU designs. As the attention of plant-specific analyses was expanded to include accident management evaluations, the scope of MAAP (its design basis) was expanded to include the necessary models for accident management assessments. MAAP4 is the first archived code that contains a graphical representation of the reactor and containment response. MAAP4, like MAAP 3B, is currently being maintained by Fauske & Associates, LLC (FAI) for EPRI and the MAAP User's Group (MUG).

MAAP4 is an accident analysis code that provides results with confidence in all phases of severe accident studies, including accident management, for current PWR reactor/containment designs and for ALWRs. MAAP4 includes models for the important accident phenomena that might occur within the primary system, in the containment, and/or in the auxiliary/reactor building. For a specified reactor and containment system, MAAP4 calculates the progression of the postulated accident sequence, including the disposition of the fission products, from a set of initiating events to either a safe, stable state or to an impaired containment condition (by overpressure or over-temperature) and the possible release of fission products to the environment.

Since the beginning of the MAAP code development, the codes have represented all of the important safety systems such as emergency core cooling, containment sprays, residual heat removal, etc. MAAP4 allows operator interventions and incorporates these in a flexible manner, permitting the user to model the operator response and the availability of the various plant systems in a general way.

The user can represent operator actions by specifying a set of values for variables used in the code and/or events, which are the operator intervention conditions. There is a large set of actions that the operator can take in response to the intervention conditions.

MAAP4 has been developed under the FAI Quality Assurance Program, in conformance with 10CFR50 Appendix B and with the International ISO 9000 Standard. Furthermore, the new software has been subjected to review by a Design Review Committee, comprised of senior members of the nuclear community, in a manner similar to that exercised for MAAP 3B.

MAAP4 has been benchmarked against plant experience and large-scale integral experiments and also against one integral computer code. Most of the plant experience and experiment benchmarks are documented in the MAAP4 User's Manual [EPRI, 2003a].

The USNRC reviewed and approved MAAP 3.0B for support of probabilistic risk assessment (PRA) activities at licensed power reactors in the U.S., particularly the IPE's that occurred in the late 1980's and early 1990's. While MAAP4 has not undergone a formal review process by the NRC, the code owner, EPRI, Fauske & Associates, and the MAAP User's Group previously engaged in MAAP4 familiarization activities with the NRC when MAAP4 was first released. Recently, a MAAP4 Information Exchange between these parties has been undertaken in view of the expanding scope of MAAP4 application and MAAP4-supported submittals to the NRC.

MAAP4 has been used previously for safety analyses outside of the risk arena with NRC approval. For example, an NRC Safety Evaluation Report (SER) was written for the D.C. Cook plant in its assessment of minimum safe sump level in the containment recirculation sump during a small LOCA event. This assessment involved small LOCA scenarios that are similar to those in the present analysis for PVNGS.

The MAAP4 RCS model uses momentum equation selectively for sub-models that demand a momentum equation for model integrity. One of the aspects for which a full-fledged momentum equation is not implemented is water flow. Consequently, MAAP4 cannot void the core by reversing flow from the core to the downcomer and loop piping during a large LOCA event. However, small breaks of the size being analyzed for this analysis do not engage in such significant flow reversal, so this limitation is not relevant to this analysis.

The MAAP4 containment model can accommodate most physical phenomena that would occur. However, since it does not entrain pre-existing liquid and condensate from heat sink surfaces, it does not mechanistically bring suspended water droplets into the containment atmosphere (although the model could accommodate droplets if such liquid entrainment was added). Consequently, it conservatively predicts excess gas-phase superheat and pressurization during the blowdown stage of a large LOCA event. Since small breaks of the size being analyzed for this analysis do not engage in this phenomenon, this limitation is not relevant to this analysis. Documented containment benchmarks are testament to the adequacy of the containment model for predicting short-term and long-term containment pressurization under small and medium LOCA conditions, which is necessary for an accurate depiction of containment spray actuation signal (CSAS) timing in this analysis.

The latest MAAP4 archived revision, MAAP 4.0.5 [EPRI, 2003b], was used with the latest PVNGS-specific plant model (a.k.a., parameter file). [

]

[ ]

[ ]

[ ]

[ ]

[ ]

The analyses provide three key results. The first result is the RCS pressure that would exist at the time of RAS for various size breaks. These results are provided in Figure 5-1.

Break Size	RCS Pressure at RAS (psia) Discharge Leg Breaks	RCS Pressure at RAS (psia) Suction Leg Breaks
1"	1386	1384
2"	546	438
3"	222	233
4"	213	155
5"	132	148
6"	102	79
7"	77	74
8"	47	53
9"	49	46
10"	37	38

Table 5-1 RCS Pressure at RAS for Various Break Sizes from CENTS

This parameter is used in the following section to [ ] assess ECCS performance (i.e. HPSI flow) under the maximum predicted air ingestion conditions.

The second result from these analyses is that break sizes of 2" diameter or smaller [

] alternate method of core cooling is available should the HPSI pump fail due to air ingestion. The current PVNGS Emergency Operating Procedures fully implement this recovery strategy.

[ ]

5.2 Determination of Degraded HPSI Flow

[ ]

[ ]

The resulting HPSI system performance or operating points, given the degraded pump performance and the system resistance curves developed above, can be determined and illustrated graphically as shown in Figure 5-2. The developed head and flow rate of the degraded pump is determined by the intersection of the system curves and the degraded pump curves.

[ ]

As indicated in Figure 5-2, 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.

For break sizes 2" diameter and larger, Figure 5-2 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. [ ]

5.3 HPSI Pump (Emergency Core Cooling) Safety Function Impact 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 [ ] until the air inventory available to be ingested is exhausted, at which time pump performance can be assumed to return to normal. The analyses performed using the CENTS and MAAP codes determined that for the full spectrum of

[ ]

5.4 Containment Spray Safety Function 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 during the period of air ingestion, and 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.

6 Other Considerations

6.1 Waterhammer

The ECCS voided piping condition did not present any negative impacts stemming from waterhammer. Numerous analyses and experiments (References 12 through 14) have been performed to evaluate the influence of air in a system during a strong hydraulic transient such as a pump start. As stated by Martin (Ref. 12):

The effect of the presence of entrapped air on transient pressures of a liquid pipeline can either be beneficial or detrimental, depending on the amount of air, the two-phase flow regime of the mixture (whether homogeneous or slug), and the nature and cause of the transient.

Of particular importance are those situations which could be detrimental to the piping system. Generally these are conditions in which a significant coherent gas volume has formed on the discharge side of the pump. Significant means a volume that is comparable to or larger than the integrated volumetric flow discharged from the pump during the time that it comes up to speed. Given these conditions the pump can accelerate to essentially runout flow conditions with the only resistance being the frictional forces generated by the moving water column between the pump discharge and the air pocket. Subsequent to this, the moving water column will begin to compress the air volume and the gas pressure will increase dramatically as volume is reduced.

For example, under these conditions, the gas bubble pressure more than doubles when the gas volume is reduced by one half and similarly more than doubles again when it is reduced again by one half, etc. Hence, with a low pressure gas volume on the discharge side of the pump, the compression of the gas bubble will eventually absorb the kinetic energy of the water column. For this to occur, the gas volume pressure can increase to values much greater than the maximum pump discharge pressure.

Conversely, if the air volume is on the suction side of the pump such as in the case of the Palo Verde ECCS voided piping, [

]

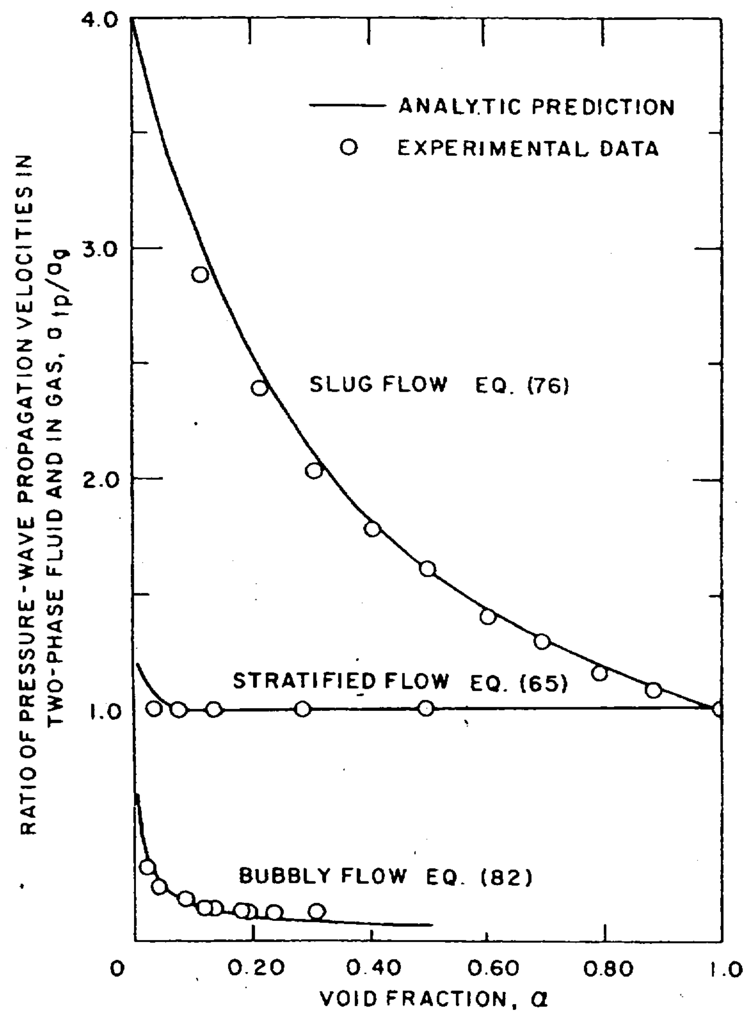


Figure 6-1: Comparison of the ratio of the two-phase propagation velocities to the water sonic velocity for selected flow patterns (taken from Henry, Grolmes and Fauske, 1971).

As illustrated, for stratified flow the pressure wave propagation velocity was reduced by a factor of four while bubbly mixtures experienced a reduction of as much as two-orders of magnitude. Consequently, a uniformly distributed gas volume will slow the response to transients, i.e. stabilize the flow. This is consistent with the example calculations provided by Martin (Ref. 12).

In summary, if a large air bubble exists in the pump discharge piping, the pump start transient can experience pressure surges with peak values well in excess of the pump shutoff head. The extent of the pressure increase is determined by the gas volume, pump runout flow, etc. For those conditions with air on the suction side of a pump, the air flow rate will be determined by the pressure difference from the pump header to the pump inlet, the dispersed air flow will have a greatly reduced volume in the discharge piping and will slow (stabilize) the hydraulic response of the piping network.

6.2 Net Positive Suction Head

NUREG/CR-2792 (Ref. 1) provides discussion and guidance regarding the affect of pump air ingestion on NPSH considerations. For example, Section 3.2.3 states that "the presence of air at the inlet.....increases the limiting NPSH required for satisfactory operation. The increased degradation at the pump inlet, as inlet NPSH or pressure is lowered, results from the increased volumetric expansion of air between the pump inlet flange and the impeller inlet. Thus pumps operating with air ingestion will have higher NPSH requirements than those required in single-phase operation."

Section 4.2 goes on to establish an "arbitrary relationship" for the purpose of minimizing this volumetric expansion that occurs between the inlet and the impeller eye. The relationship is:

$NPSHR_{air/water} = NPSHR_{water} + (1 + 0.5\ AF)$

Where AF is the air volume fraction in percent. It is noted that this relationship is only intended for use with air volume fractions less than 2%

[redacted]

[ ]

7 Probabilistic Risk Assessment

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. Consideration was also given to small LOCA events that are induced through the lifting of a PSV and the subsequent failure to reseat. An estimate of the risk increase due to small LOCAs resulting from seismic events was also calculated. 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.

Engineering Study 13-NS-C074, Revision 0 (Attachment 2-F) calculated the increase in risk associated with the unfilled containment sumps suction lines. The following table shows the overall impact of loss of High Pressure Recirculation (HPSR) for break sizes of two inches or less.

Initiator	Delta-CDF (per year)
Small LOCA	4.5E-6
PSV – Internal Events Plus Fire	2.0E-6
Seismic	4.7E-7
Total	**7.0E-6**

Table 7-1 Over-all Risk Associated with Loss of HPSR

The above described model adjustments were applied to the entire range of small break LOCA events (i.e. 2.3 " diameter and smaller). The pump testing and analysis program described in the previous sections of this report demonstrate that continued functionality of the HPSI pump for the upper end of the SBLOCA range (those breaks approaching 2" in diameter and larger) would be expected. For the small end of the SBLOCA range of approximately 0.5" in diameter or less, analyses using the CENTS and MAAP code demonstrate that complete depressurization of the RCS to shutdown cooling conditions would be achieved prior to RAS. Therefore, no additional risk is associated with the breaks on the small end of the SBLOCA range. Therefore, the above result provided in Table 7-1 is considered to be a conservative estimate of the incremental risk associated with the ECCS voided piping condition.

8 Conclusions

A comprehensive testing and analysis program was conducted to conservatively estimate the risk significance of the ECCS voided piping condition. The scale model testing program simulated bounding conditions and parameters to provide high confidence the air ingestions rates obtained from the tests exceeded the air ingestion rates the ECCS pumps would have actually experienced had an accident requiring containment recirculation actually occurred. Subsequent pump performance tests were conducted under conditions considered to be more severe than would have been experienced during an actual emergency. The results of the pump performance tests were then used in a set of thermal hydraulic analyses of the Palo Verde Reactor Coolant System and Containment. The analyses determined that performance of the ECCS and containment and temperature control functions would have been maintained. For most postulated accidents scenarios, the ECCS safety function would have been maintained by the HPSI pumps. For a subset of SBLOCA scenarios, the ECCS function would have been maintained by the use of any available CS or LPSI pump following RCS cooldown and depressurization by the Plant Operators, if the HPSI pumps were to have failed due to air ingestion. Utilizing the results of the testing and analysis program in a conservative manner, the incremental risk associated with the ECCS voided piping condition is estimated to be 7.0×10^{-6}.

9 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. Ishii, M. et.al., 1989 "The Three-Level Scaling Approach With Application to the Purdue University Multi-Dimensional Integral Test Assembly (PUMA), "Nuclear Engineering and Design, 186, pp. 177-211

4. Wallis, G.B. "Conditions for a Pipe to Run Full When Discharging Liquid into a Space Filled With Gas, "Transactions for the ASME, Journal of Fluids Engineering, June 1977, pp. 405-413

[ ]

6. Wallis, G.B., 1969. <u>One Dimensional Two-Phase Flow</u>, McGraw-Hill, New York.

[ ]

12. Martin, C. S., 1976, "Entrapped Air in Pipelines," Second Int'l Conf. on Pressure Surges, Sept. 22-24, London, England, pp. F2-15 to F2-28.

13. Chaiko, M. A. and Brinckman, K. W., 2002, "Model for Analysis of Waterhammer in Piping with Entrapped Air," Transactions of the ASME, Journal of Fluids Engineering, 124, pp. 194-204.

14. Lee, N. H. and Martin, C. S., 1999, "Experimental and Analytical Investigations of Entrapped Air in a Horizontal Pipe," Proceedings of the Third ASME/JSME Joint Fluids Engineering Conference, July 18-23, San Francisco, California.

15. Henry, R. E., Grolmes, M. A. and Fauske, H. K., 1971, "Pressure Pulse Propagation in Two-Phase One- and Two-Component Mixtures," Argonne National Laboratory Report, ANL-7792.

ATTACHMENT 2-A

FAI/04-65, Revision 0
Test Report for Phase 1 of Experimental Investigation of Post RAS Air Intrusion into ECCS Suction Piping for Palo Verde Nuclear Generating Station
~~(Proprietary)~~

REDACTED VERSION

FAUSKE & ASSOCIATES, INC.

CALCULATION NOTE COVER SHEET

SECTION TO BE COMPLETED BY AUTHOR(S):

Calc-Note Number FAI/04-65 Revision Number 0

Title Test Report for Phase 1 of Experimental Investigation of Post RAS Air Intrusion Into ECCS Suction Piping for Palo Verde Nuclear Generating Station

Project Arizona Public Service (APS) Project Number or Shop Order APS003

Purpose: This report documents the scaled experiments that were conducted to investigate a past plant operability question regarding the possibility of any of the air initially residing in the horizontal segment of the sump suction line being swept into the vertical downcomer and subsequently into the ECCS pumps. The nature of the two phase flow pattern produced in the vertical segment was also investigated.

Results Summary: A range of containment overpressure and system flow rates were investigated. The set of conditions that would be expected for a large break LOCA event were found to result in the air being relocated from the horizontal segment into the vertical segment. The two-phase flow pattern in the vertical segment was seen to be liquid continuous with dispersed air bubbles.

References of Resulting reports, Letters, or Memoranda (Optional)

Author(s): Name (Print or Type)	Signature	Completion Date
R. J. Hammersley	Robert J. Hammersley	September 17, 2004

SECTION TO BE COMPLETED BY VERIFIER(S):

Verifier(s): Name (Print or Type)	Signature	Completion Date
W. E. Berger	WEBerger	September 24, 2004

Method of Verification: Design Review ____, Independent Review or Alternate Calculations X, Testing ____

Other (specify) ____

SECTION TO BE COMPLETED BY MANAGER:

Responsible Manager: Name (Print or Type)	Signature	Approval Date
R. E. Henry	Robert E. Henry	September 24, 2004

CALC NOTE NUMBER FAI/04-65 PAGE 2

CALCULATION NOTE METHODOLOGY CHECKLIST

CHECKLIST TO BE COMPLETED BY AUTHOR(S) (CIRCLE APPROPRIATE RESPONSE)

1. Is the subject and/or the purpose of the design analysis clearly stated?.. YES NO
2. Are the required inputs and their sources provided? .... YES NO N/A
3. Are the assumptions clearly identified and justified? .... YES NO N/A
4. Are the methods and units clearly identified? .... YES NO N/A
5. Have the limits of applicability been identified? .... YES NO N/A
(Is the analysis for a 3 or 4 loop plant or for a single application.)
6. Are the results of literature searches, if conducted, or other background data provided? .... YES NO N/A
7. Are all the pages sequentially numbered and identified by the calculation note number?.. YES NO
8. Is the project or shop order clearly identified? .... YES NO
9. Has the required computer calculation information been provided? .... YES NO N/A
10. Were the computer codes used under configuration control?.......................... YES NO N/A
11. Was the computer code(s) used applicable for modeling the physical and/or computational problems identified? .... YES NO N/A
(i.e., Is the correct computer code being used for the intended purpose.)
12. Are the results and conclusions clearly stated?.................................... YES NO
13. Are Open Items properly identified .... YES NO N/A
14. Were approved Design Control practices followed without exception? ....YES NO N/A
(Approved Design Control practices refers to guidance documents within Nuclear Services that state how the work is to be performed, such as how to perform a LOCA analysis.)
15. Have all related contract requirements been met? .... YES NO N/A

NOTE: If NO to any of the above, Page Number containing justification ______

FAI/04-65

Test Report for Phase 1 of Experimental Investigation of Post RAS Air Intrusion Into ECCS Suction Piping for Palo Verde Nuclear Generating Station

Prepared For:

Palo Verde Nuclear Generating Station

Arizona Public Service

Prepared By:

Fauske & Associates, LLC

16W070 West 83rd Street

Burr Ridge, Illinois 60527

TEL: (630) 323-8750

FAX: (630) 986-5481

September, 2004

ABSTRACT

This report documents the scaled experiments that were conducted to investigate a past plant operability question regarding the possibility of any of the air initially residing in the horizontal segment of the sump suction line being swept into the vertical downcomer and subsequently into the ECCS pumps. The nature of the two phase flow pattern produced in the vertical segment was also investigated.

A range of containment overpressure and system flow rates were investigated. The set of conditions that would be expected for a large break LOCA event were found to result in the air being relocated from the horizontal segment into the vertical segment. The two-phase flow pattern in the vertical segment was seen to be liquid continuous with dispersed air bubbles.

PURPOSE

The purpose of this report is to document the Phase 1 test conditions and results for the APS experimental investigation of the post RAS air intrusion into ECCS suction piping.

INPUT DATA AND ASSUMPTIONS

The Phase 1 experiments were configured and conducted per the approved test plan (FAI, 2004). The initial conditions, major components, and key dimensions for these tests are described in the test plan.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 PHASE 1 TEST OBJECTIVES

1.1 Technical Issue

The Palo Verde Nuclear Generating Station (PVNGS) has identified a concern that their sump recirculation flow paths to the Emergency Core Cooling System (ECCS) pumps contain a pocket of air trapped between the sump isolation Motor Operated Valves (MOVs) and check valve that could potentially be forced into the operating pump suction upon an initiation of a Recirculation Actuation Signal (RAS) during a design basis event. PVNGS has requested analysis of this concern to determine:

(1) If any volume of air between the inboard sump isolation valve and the downstream check valve could be forced into the suction of the operating High Pressure Safety Injection (HPSI) and Containment Spray (CS) pumps upon full opening of the sump isolation valves at the time of RAS.

(2) The impact on pump performance if any amount of air from the sump suction piping is injected into the operating pumps.

1.2 Experimental Objectives

An experimental investigation has been initiated to address this technical issue and investigate the two-phase flow patterns for the scaled horizontal and downward vertical flow segments. The objective of the Phase 1 testing was to investigate the potential for the air initially resident in the horizontal sump suction line to be forced into the vertical downward piping section.

[

]

[ ] The Phase 1 tests were configured and performed in accordance to the approved test plan (FAI, 2004).

2.0 *PHASE 1 TEST FACILITY*

2.1 Physical Arrangement

The test facility that was used for the Phase I testing was composed of two tanks with water inventories, a centrifugal pump, piping, valves, and associated instrumentation as indicated in Figure 1. 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. The horizontal segment [

]

The vertical [

]

[

]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

Figure 1 Phase 1 test configuration for post RAS air intrusion.

[ ]

2.2 Instrumentation

The test instrumentation is indicated in Figure 1 and listed in Table 1. A personal computer (PC) [ ] was used to collect data during [ ]. Each data channel was sampled at a rate of [ ] The data that was recorded for each test included:

[ ]

[ ] General observations as visible through the clear pipe sections were made and noted by the test engineers. These observations were used to characterize the air behavior and flow patterns.

Table 1

[ ]

Following the first four tests in the test matrix the test data was reduced and plotted. The results were inspected for internal consistency as well as confirmation of the proper functioning of the instrumentation. The data collected on instrument P4 appeared to be contaminated with excessive noise. [

] Thus, in addition to relocating the P4 pressure transducer it was reoriented such that instead of being at the

[

]

2.3 Scaling Considerations

[ ]

[ ]

3.0 PHASE 1 TEST MATRIX AND TESTING OBSERVATIONS

3.1 Initial Conditions and Test Matrix

The initial conditions were as follows:

[ ]

* Relative to the elevation of the center line of the horizontal segment of the pump suction line.

The test matrix as provided in the approved Test Plan was modified based on observations during the Phase 1 tests by the Westinghouse project team and the APS representatives [ ] who were observing the tests. The revised test matrix executed in the Phase 1 testing is provided in Table 2. The key observations for each test included [

]

3.2 Observations During Phase 1 Testing

During the execution of the Phase 1 test matrix several general observations were made in addition to the key object [ ]

[ ]

[ ]

[ ]

4.0 PHASE 1 TEST RESULTS

4.1 Key Observations

The key observations for the Phase 1 air intrusion test relate to the specific test objectives. The objectives are to observe the behavior of the air in the initially voided horizontal segment and the nature of the flow pattern produced in the vertical downcomer segment. The observations for the 12 tests performed in the Phase 1 testing regarding these objectives are as follows:

- the air initially resident in the voided horizontal segment is removed from the horizontal segment during the initial transient phase,
- the two-phase flow pattern produced in the vertical segment is found to be liquid continuous with the air dispersed as a bubbly flow.

4.2 Discussion of Results

The test data and movies for each of the twelve Phase 1 tests were reviewed. Table 3 summarizes the results of this review. Table 3 includes [

]

~~PROPRIETARY~~
REDACTED VERSION

Table 3
Phase 1 Test Results and Observations

[ ]

[ ]

[ ]

Figure 3A: Total flow rate (Tests 1-4).

Figure 3B: Total flow rate (Tests 5-8).

Figure 3C: Total flow rate (Tests 9-12).

[ ]

Table 4

[ ]

5.0 CONCLUSIONS

The Phase 1 tests results lead to the conclusion that the air void initially contained in the horizontal sump suction piping can be swept down and through the vertical piping in the suction line.

6.0 REFERENCES

FAI, 2004, FAI/04-61, "Test Plan for Experimental Investigation of Post RAS Air Intrusion Into ECCS Suction Piping for Palo Verde Nuclear Generating Station," September.

ATTACHMENT 2-B

FAI/04-86, Revision 0
Test Report for Phase 2 of Experimental Investigation of Post RAS Air Intrusion Into ECCS Suction Piping for Palo Verde Nuclear Generating Station
~~(Proprietary)~~
REDACTED VERSION

FAUSKE & ASSOCIATES, INC.

CALCULATION NOTE COVER SHEET

SECTION TO BE COMPLETED BY AUTHOR(S):

Calc-Note Number FAI/04-86 Revision Number 0

Title Test Report for Phase 2 of Experimental Investigation of Post-RAS Air Intrusion Into ECCS Suction Piping for Palo Verde Nuclear Generating Station

Project Arizona Public Service (APS) Project Number or Shop Order APS005

Purpose: This report documents the scaled integral experiments (Phase 2) that were conducted to investigate a past plant operability question regarding the possibility of air initially residing in the horizontal segment of the sump suction line being swept into the pump suction header and ECCS pumps. The nature of the two phase flow patterns in the ECCS suction piping was also investigated.

Results Summary:

[ ]

References of Resulting reports, Letters, or Memoranda (Optional)

Author(s): Name (Print or Type)	Signature	Completion Date
Robert J. Hammersley	Robert J. Hammersley	February 11, 2005
Robert E. Henry	Robert E. Henry	February 11, 2005

SECTION TO BE COMPLETED BY VERIFIER(S):

Verifier(s): Name (Print or Type)	Signature	Completion Date
William E. Berger	WEBerger	February 11, 2005

Method of Verification: Design Review _____, Independent Review or Alternate Calculations X, Testing _____

Other (specify) _____

SECTION TO BE COMPLETED BY MANAGER:

Responsible Manager: Name (Print or Type)	Signature	Approval Date
R. E. Henry	Robert E. Henry	February 11, 2005

CALC NOTE NUMBER FAI/04-86 **PAGE** 2

CALCULATION NOTE METHODOLOGY CHECKLIST

CHECKLIST TO BE COMPLETED BY AUTHOR(S) **(CIRCLE APPROPRIATE RESPONSE)**

1. Is the subject and/or the purpose of the design analysis clearly stated? .... YES NO
2. Are the required inputs and their sources provided? .... YES NO N/A
3. Are the assumptions clearly identified and justified? .... YES NO N/A
4. Are the methods and units clearly identified? .... YES NO N/A
5. Have the limits of applicability been identified? .... YES NO N/A
   (Is the analysis for a 3 or 4 loop plant or for a single application.)
6. Are the results of literature searches, if conducted, or other background data provided? .... YES NO N/A
7. Are all the pages sequentially numbered and identified by the calculation note number? .... YES NO
8. Is the project or shop order clearly identified? .... YES NO
9. Has the required computer calculation information been provided? .... YES NO N/A
10. Were the computer codes used under configuration control? .... YES NO N/A
11. Was the computer code(s) used applicable for modeling the physical and/or computational problems identified? .... YES NO N/A
    (i.e., Is the correct computer code being used for the intended purpose.)
12. Are the results and conclusions clearly stated? .... YES NO
13. Are Open Items properly identified .... YES NO N/A
14. Were approved Design Control practices followed without exception? .... YES NO N/A
    (Approved Design Control practices refers to guidance documents within Nuclear Services that state how the work is to be performed, such as how to perform a LOCA analysis.)
15. Have all related contract requirements been met? .... YES NO N/A

NOTE: If **NO** to any of the above, Page Number containing justification ______

FAI/04-86

Test Report for Phase 2 of Experimental Investigation of Post-RAS Air Intrusion Into ECCS Suction Piping for Palo Verde Nuclear Generating Station

Prepared For:

Arizona Public Service

Prepared By:

Fauske & Associates, LLC

16W070 West 83rd Street

Burr Ridge, Illinois 60527

TEL: (630) 323-8750

FAX: (630) 986-5481

November, 2004

ABSTRACT

This report documents the Phase 2 scaled experiments that were conducted to investigate a past operability question for the Palo Verde plants regarding the possibility of the air initially residing in the horizontal segment of the sump suction line being swept into the vertical downcomer and subsequently into the ECCS and Containment Spray (CS) pumps. The Phase 1 tests (FAI, 2004a) addressed the behavior of the vertical downcomer. The nature of the two phase flow pattern produced in the pump suction piping for the High Pressure Safety Injection (HPSI), Low Pressure Safety Injection (LPSI), and CS systems was investigated in these Phase 2 tests.

A range of containment overpressure and system flow rates were studied. [

]

Test cases were also included with the HPSI and CS pumps running at the time of RAS with the Low Pressure Safety Injection (LPSI) started later. In general these tests demonstrated that most of the air was pulled through the HPSI suction line before the LPSI pump was started. For most of these tests the HPSI pump was assumed to fail and was shutdown when the flow decreased to one-half of the initial value. Some tests were performed to address the possible operator action of keeping the CS pump on one train and shutting down the CS pump on the other train in favor of the LPSI pump if HPSI were to fail on both trains. With this event sequence, stopping the CS pump enabled the air in the lower header to rise up through the downcomer, pass backward through the check valve and be discharged into the sump thus eventually rising to the containment atmosphere. Consequently, there was no air in the header when the LPSI pump was started.

PURPOSE

This report documents the scaled integral experiments (Phase 2) that were conducted to investigate a past operability question regarding the possibility of air initially residing in the horizontal segment of the sump suction line being swept into the pump suction header and ECCS pumps. The nature of the two phase flow patterns in the ECCS suction piping was also investigated.

INPUT DATA AND ASSUMPTIONS

The Phase 2 experiments were configured and conducted per the approved test plan (FAI, 2004b). The initial conditions, major components, and key dimensions for these tests are described in the test plan.

TABLE OF CONTENTS

LIST OF FIGURES

[ ]

LIST OF TABLES

1.0 PHASE 2 TEST OBJECTIVES

1.1 Technical Issue

The Palo Verde Nuclear Generating Station (PVNGS) has identified a concern. Specifically, all three units have sump recirculation flow paths to the Emergency Core Cooling System (ECCS) pumps which contain a pocket of air trapped between the sump isolation Motor Operated Valves (MOVs) (butterfly valves) and check valve that could potentially be forced into the operating pump suction upon an initiation of a Recirculation Actuation Signal (RAS) during a design basis event. PVNGS has requested analysis of this concern to determine:

(1) If any air volume between the inboard sump isolation valve and the downstream check valve could be forced into the suction of the operating High Pressure Safety Injection (HPSI) and Containment Spray (CS) pumps upon opening of the sump isolation valves at the time of RAS.

(2) The impact on pump performance if any amount of air from the sump suction piping is injected into the operating pumps.

1.2 Experimental Objectives

Phase 1 testing (FAI, 2004a) demonstrated that the flow demand on the containment sump pump suction line following RAS was sufficient [ ] Therefore, Phase 2 experimental investigation was initiated at FAI to investigate the two-phase flow patterns [ ] The objectives of the Phase 2 testing were to investigate the extent of air transport to the HPSI and CS pumps as well as the LPSI pump for those accident sequences where this could be started. Full scaling testing of the pump performance for the resulting air intrusion will be performed in a Phase 3 test facility at Wyle Laboratories in Huntsville, Alabama. In the Phase 2 testing, the nature of the flow pattern (dispersed bubbly flow, plug flow, slug flow, etc.) at the pump suctions will be observed including the transient effects of switching the water supply from the simulated Reactor Water Tank (RWT) to the containment sump while simultaneously opening the sump suction isolation (butterfly) valves. Transparent piping was used for the horizontal and vertical segments of the simulated pump suction line to observe and record the flow pattern and the behavior of the initial air filled volume [redacted]. The Phase 2 tests were configured and performed in accordance with the approved test plan (FAI, 2004b).

2.0 PHASE 2 TEST FACILITY

2.1 Physical Arrangement

2.1.1 Configuration 2A

[

]

The use of 4 inch diameter (Schedule 40) pipe to represent the 24 inch diameter (Schedule 20 and 30) pipe in the plant defined a linear scale ratio of approximately 1/6 (FAI, 2004b). Thus, the balance of the suction line pipe lengths and valve locations also used a 1/6th scale unless there were other considerations [

]

Figure 1: Phase 2 Test Configuration 2A for Post-RAS Air Intrusion.

[

] Both the HPSI and CS pumps are single stage centrifugal pumps in the test apparatus. For the plants, the HPSI umps are eight stage centrifugal designs.

Table 1

Test Dimensions

[

]

[ ]

2.1.2 Configuration 2B

[ ]

Figure 2: [ ].

[ ]

[ ]

Figure 3: Phase 2 Test Configuration 2B for Post-RAS Air Intrusion.

[ ]

2.1.3 Configuration 2C

[ ]

Figure 4: Phase 2 Test Configuration 2C for Post-RAS Air Intrusion.

[ ]

~~PROPRIETARY~~

REDACTED VERSION

[ ]

2.2 Instrumentation

The test instrumentation is similar for all three test configurations and is indicated in Figures 1, 2 and 3 and listed in Table 2. A personal computer (PC) [ ] was used to collect data during the transient following the opening of the isolation valves as well as the subsequent steady state recirculation flow that followed. Each data channel was sampled at a rate of once per [ ] which is much faster than the hydraulic transient which takes tens of seconds.]] Each experiment had the following data recorded:

[ ]

Digital movie cameras were used to record the flow patterns in the clear piping sections. General observations in the clear pipe sections were made and noted by the test engineers. These observations were particularly important to characterize the water-air flow patterns in the various suction pipes.

2.3 Scaling Considerations

The test plan (FAI, 2004b) presented the scaling assessment for the Phase 2 tests. The scaling assessment addressed [ ] The scaling considerations are discussed below.

2.3.1 Two-Phase Flow Pattern Considerations

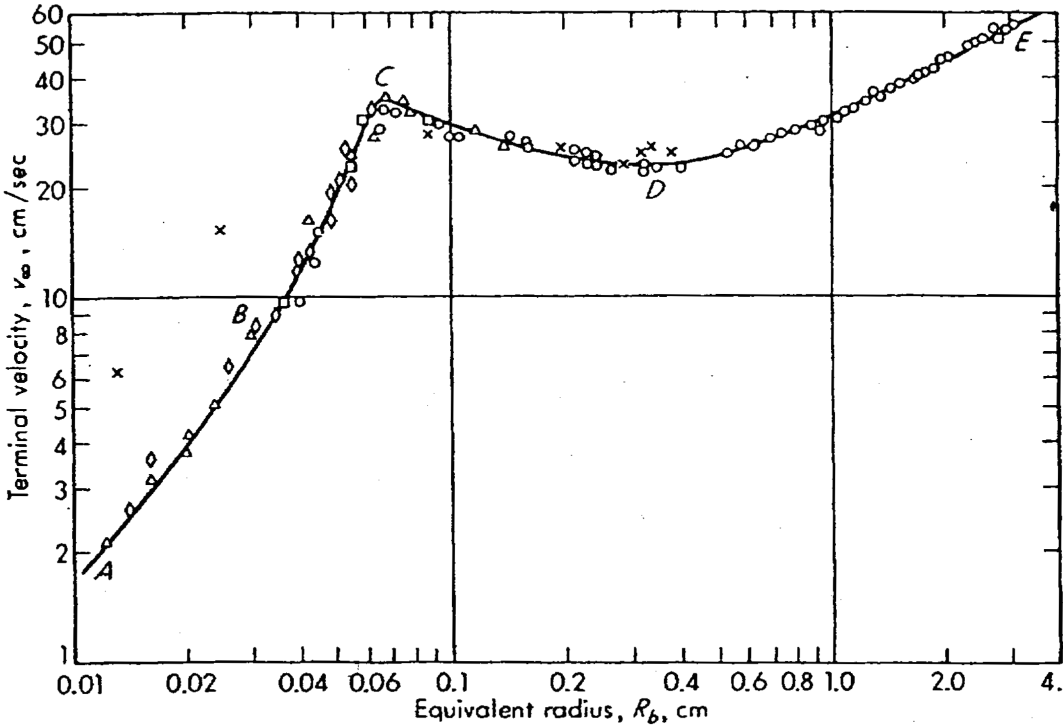
[ ]

[ ]

2.3.2 [ ]

[ ]

Figure 6: Terminal velocity of air bubbles in filtered or distilled water as function of bubble size reported by Haberman and Morton and shown in Wallis (1969).



[ ]

[ ]

2.3.3 [ ]

[ ]

[ ]

[ ]

[ ]

2.3.4 Materials

Like the postulated accident, water and air are the fluids used in the void behavior and flow pattern observation experiments. Visual observations of the air-water two-phase flow patterns in the plastic piping provided the insights needed for the Phase 3 testing program on full scale pumps. For accident conditions, the plant sump water temperature would be elevated and the sump water could also contain chemicals such as boric acid and trisodium phosphate (TSP) due to the sources of water that accumulate in the containment and the sump pH control. Prototypic concentrations of boric acid and TSP were investigated in separate phenomenological tests and found to be [redacted].

[redacted] The approach to address sump water temperature is discussed is Section 4, **Phase 2 Test Results**.

3.0 PHASE 2 INITIAL CONDITIONS AND TEST MATRIX

The range of initial conditions were as follows:

[ ]

The test matrices for Configurations 2A, 2B and 2C as provided in the Phase 2 Test Plan (FAI, 2004b) are reproduced in Tables 3, 4 and 4 respectively. With the observations of the initial tests, the test matrix was expanded during the testing program to investigate specific phenomena as well as demonstrate reproducibility of the results. The expanded test matrix executed in the Phase 2 testing is presented in Section 4.0, **Phase 2 Tests Results**. A cross reference is provided between the expanded test matrix and the test matrix from the test plan. Key observations for each test include the two-phase flow pattern [ ] Other observations include [ ]

• Relative to elevation of center line of the lower horizontal header for the HPSI, CS and LPSI pump suction lines.

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~

REDACTED VERSION

4.0 PHASE 2 TEST RESULTS

The test data and digital movies of the Phase 2, Configurations 2A were reviewed for the tests specified for this configuration in the Phase 2 Test Plan (FAI, 2004b). After reviewing and discussing the results from the original twelve tests for Configuration 2A with APS and Westinghouse personnel, it was decided to expand the Configuration 2A test matrix to 29 tests. Table 6 summarizes the results for all 29 of the Configuration 2A tests [

]

[ ]

Upon the completion of the expanded set of Configuration 2A tests, review of the experimental data and the digital video records as well as other supporting plant analyses (Phase 4 of the overall program), it was decided to investigate two other pump combinations. The results for the Configuration 2B and 2C experiments are summarized in Tables 7 and 8. Observations and insights gained from these configurations are discussed after those resulting from Configuration 2A.

~~PROPRIETARY~~
REDACTED VERSION

[ ]

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

4.1 Configuration 2A

4.1.1 Key Observations

The key observations for the Phase 2 air intrusion tests relate to the specific test objectives, i.e. (1) to investigate the air delivery rates to the HPSI and CS pump suctions and (2) document the associated two-phase flow patterns. Observations from the 29 tests performed in Configuration 2A of the Phase 2 testing are as follows:

[ ]

4.1.2 Discussion of Results

4.1.2.1 General Comments

[ ]

[ ]

4.1.2.2 Flow Patterns

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

4.1.2.3.1 <u>Interpretation of the HPSI Air Intrusion Rate</u>

[ ]

[ ]

$$\Delta V_{air} = A_V \left(h_1 - h_2\right)$$

where:

- A_V is the cross-sectional flow area for the 8 inch pipe,
- h_1 is the initial water height, and
- h_2 is the measured water height at a later time.

Knowing the volume change means that the mass can be obtained by multiplying this with the air density which can be calculated from the perfect gas law, i.e.

$$\rho_{air} = \frac{P_{air}\, MW_{air}}{R_{gas}\, T_g}$$

where:

- P_{air} is the total pressure for the air in the gas separator,
- MW_{air} is the molecular weight of air (29.2),
- R_{gas} is the universal gas constant, and
- T_g is the absolute temperature of the gas.

(To avoid confusion in units, these parameters are evaluated in the international system of units and then converted to British units once the flow rate is determined.) Hence, the collected air mass is

$$\Delta m_{air} = \rho_{air}\, \Delta V_{air}$$

Differentiating this with respect to time produces the air mass flow rate into the separator.

Figures 25 and 26 [redacted]

[ ]

[ ]

[redacted]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

4.1.2.3.2 Interpretation of the CS Air Intrusion Rate

[ ]

4.1.2.4 [ ]

[ ]

4.1.2.5 [ ]

[ ]

[ ]

[ ]

4.2 Configuration 2B

4.2.1 Key Observations

[ ]

4.2.2 Discussion of Results

4.2.2.1 General Comments

These scoping tests included 8 experiments with the principal difference being the predetermined LPSI flow rate. Table 7 summarizes the results for all tests including the as-tested flow rates for both pumps and the corresponding Froude numbers in the different piping segments. [

]

REDACTED VERSION

4.2.2.2 Flow Patterns

[redacted]

[ ]

4.2.2.3 Interpretation of the Air Intrusion Rate

[ ]

4.3 Configuration 2C

4.3.1 Key Observations

[ ]

[ ]

[ ]

[ ]

[ ]

5.0 CONCLUSIONS

The following conclusions were derived from the three Phase 2 configurations for the integral 4 inch diameter scaled experiments representing the Palo Verde sump suction line behavior.

I. Configuration 2A

[ ]

[ ]

[ ]

II. Configuration 2B

[ ]

III. Configuration 2C

[ ]

[ ]

6.0 REFERENCES

FAI, 2004a, "FAI/04-65, "Test Report for Phase 1 of Experimental Investigation of Post RAS Air Intrusion Into ECCS Suction Piping for Palo Verde Nuclear Generating Station," September.

FAI, 2004b, FAI/04-74, "Test Plan (Phase 2) for Experimental Investigation of Post-RAS Air Intrusion Into ECCS Suction Piping for Palo Verde Nuclear Generation Station," December.

FAI, 2005, FAI/04-79, "Test Report: Phenomenological Studies for the APS Containment Suction Line," January.

NRC, 1982, "An Assessment of Residual Heat Removal and Containment Spray Pump Performance Under Air and Debris Ingesting Conditions," NUREG/CR-2792, September.

[redacted]

Ricou, F. P. and Spalding, D. B., 1961, "Measurements of Entrainment by Axisymmetrical Turbulent Jets," Jr. of Fluid Mechanics, Vol. 11, pp. 21-32.

Wallis, G. B., 1969, <u>One-Dimensional Two-Phase Flow</u>, McGraw-Hill, New York.

Wallis, G. B. et al., 1977, "Conditions for a Pipe to Run Full When Discharging Liquid Into a Space Filled With Gas," Trans. ASME, Jr. of Fluids Engineering, June 1977, pp. 405-413.

ATTACHMENT 2-C

Test Report 10530R01
Test Report for Testing of a CA Pump and WDF Pump with a Void Fraction Inlet Fluid Condition
~~(Proprietary)~~

REDACTED VERSION

~~PROPRIETARY~~
REDACTED VERSION

TEST REPORT

REPORT NO. 10530R01, Revision 0
WYLE JOB NO. 10530
CUSTOMER P.O. NO. 500281122
PAGE 1 OF 137 PAGE REPORT
DATE 01/18/05
SPECIFICATION(S) WLTP 10530TP, Revision 0

TEST REPORT FOR TESTING OF A CA PUMP AND A WDF PUMP WITH A VOID FRACTION INLET FLUID CONDITION

Arizona Public Service (APS)

STATE OF ALABAMA } SS. Alabama Professional Eng
COUNTY OF MADISON } Reg. No. 25471
Ralph D. Yeardley, being duly sworn, deposes and says: The information contained in the report is the result of complete and carefully conducted tests and is to the best of his knowledge true and correct in all respects.

SUBSCRIBED and sworn to before me this 21 day of Jan, 2005

SEAL

Notary Public in and for the State of Alabama at large

My Commission expires March 3, 2007

Wyle shall have no liability for damages of any kind to person or property, including special or consequential damages, resulting from Wyle's providing the services covered by this report.

PREPARED BY G. Smyth 1/21/05 Date
APPROVED BY 1/21/05 Date
WYLE Q. A. 2/8/05 Date

wyle laboratories

~~PROPRIETARY~~
REDACTED VERSION

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

~~PROPRIETARY~~
REDACTED VERSION

1.0 CUSTOMER Arizona Public Service Co.

ADDRESS Palo Verde Nuclear Generating Station
Tonpah, AR 85354.

2.0 TEST SPECIMEN The equipment to be tested consists of two ESF (Emergency Safety Feature) pump / motor assemblies; the CA pump and motor and the WDF pump and motor.

3.0 MANUFACTURER The pumps were manufactured by Ingersoll-Rand. The motors were manufactured by Westinghouse.

4.0 SUMMARY

This document has been prepared by Wyle Laboratories to document the results of a test program on the CA and WDF pumps and motors to determine the performance with a void fraction inlet fluid condition.

This testing was performed in accordance with Wyle Laboratories Test Procedure 10530TP, "Test Procedure for Testing of a CA pump and a WDF pump with a Void Fraction Inlet Fluid Condition". The testing meets the requirements of the APS Purchase Order 500281122.

5.0 EQUIPMENT DESCRIPTION

The equipment to be tested consists of two pump / motor assemblies; the CA pump and motor, and the WDF pump and motor.

Description: The equipment description is as follows:

CA

Motor (CA):
Westinghouse Electric Frame 5810H
Class 1E
Rated at 1000 HP, 3-Phase, 60 Hz, 4000 Volts
Speed: 3553 rpm
Weight: 4,800 lbs
Motor Identification Number: 17535LN01

Pump (CA):
4x11CA-8
Nameplate Head = 2850 ft
Horizontal shaft
Nameplate Rated flow = 900 gpm
Weight: 4,400 lbs
Suction diameter: 10" sch 40
Discharge diameter 4" sch 80

~~PROPRIETARY~~
REDACTED VERSION

RECEIVING INSPECTION DATA SHEET

PUMP DATA

TAG NO.:	087634	SERIAL NO:	087634
MANUFACTURER:	Ingersoll-Rand	RATED FLOW:	4300 gpm
NOMINAL SIZE:	8 x 20 WDF	SHUT OFF HEAD:	335 ft
END CONNECTION:	14" 300# inlet /8" outlet		

MOTOR DATA

MANUFACTURER:	Westinghouse	FRAME:	55010-P39
MODEL #: (ID)	VSWF	SERIAL #:	1S-78
INS. CLASS:	B	VOLTAGE:	4000
CURRENT @RATED VOLTAGE	62	SPEED:	1776
FREQUENCY:	60 Hz		

DESCRIBE CONDITION OF RECEIVED ITEM:

Motor received on metal pallet marked #2B. Pump casing on pallet #1B. Received box containing diffuser, pump seal piping, struts, electric box and hardware.

~~PROPRIETARY~~
REDACTED VERSION

RECEIVING INSPECTION DATA SHEET

PUMP DATA

TAG NO.:	N/A	SERIAL NO:	117814/547
MANUFACTURER:	Ingersoll-Rand	RATED FLOW:	900 gpm
NOMINAL SIZE:	4 x 11 CA x 8	SHUT OFF HEAD:	2850 ft
END CONNECTION:	10" 300# inlet /4" 1500# outlet		

MOTOR DATA

MANUFACTURER:	Westinghouse	FRAME:	5810H
MODEL #: (ID)	HSW2	SERIAL #:	17535LN01
INS. CLASS:	F	VOLTAGE:	4000
CURRENT @RATED VOLTAGE	123	SPEED:	3553
FREQUENCY:	60 Hz		

DESCRIBE CONDITION OF RECEIVED ITEM:

Pipe on bottom of pump appears to be bent. Miscellaneous parts with pump include plates and all thread. Seals, gaskets, and spare bearings included. SS shaft is s/n 557. Coupler sleeve and coupler both have tags with 62013784. Motor received on pallet.

THIS PAGE INTENTIONALLY LEFT BLANK

Attachment A1

Receiving Inspection

RESULTS

Receiving inspections were performed on November 22, 2004 for both the CA and WDF motor and pump assemblies upon receipt at Wyle Laboratories in accordance with section 3.1 of Wyle Laboratories Test Procedure No. 10530, Revision 0.

The CA pump and motor arrived as two individual pieces. The coupling and miscellaneous spare parts were supplied with the pump.

The WDF pump and motor arrived as three pieces; the inlet piping and pump casing assembly, the motor assembly and a box of miscellaneous parts including the seal piping and impeller.

The nameplate data and results of the inspection were recorded on the attached Receiving Inspection Data Sheet.

The specimen pump and motor assemblies were as described in paragraph 5.0 of this report.

REDACTED VERSION
~~PROPRIETARY~~

Attachment A2

Test Facility Description, Equipment Setup for testing and Instrumentation

RESULTS

Test Facility Description

The test facility is a two closed loop system consisting of a 30,000 gallon pressure vessel with one loop for each test specimen pump. One loop is the test loop for the CA pump motor and the piping and control valves are sized based on the supplied pump curve. The second loop is the test loop for the WDF pump / motor and the piping and control valves are sized based on the supplied pump curve.

No provision is provided for fluid cooling or heating. The pressure vessel also has the ability to be pressurized to a specified pump net positive suction head. This pressure vessel pressure can be adjusted and controlled.

The test medium is de-ionized water under ambient conditions.

The overall test facility is illustrated in Figure 1 in Attachment A6. [

]

~~PROPRIETARY~~
REDACTED VERSION

[

]

CA Pump/Motor Equipment Setup for Testing

The CA pump and motor were setup in accordance with section 3.2 of Wyle Laboratories Test Procedure No. 10530TP, Revision 0.

From December 01 to 09, the following activities were completed:

- The pump internals and visible adjacent inlet piping were inspected to ensure cleanliness and no visual damage.
- The pump and motor skid to the 10" 300# RF ANSI inlet flange and the 4" 1500# RF ANSI outlet flange was installed.
- Correct connection of seal flush piping was verified.
- The pump casing was filled and vented with water.
- Oil for the pump and motor was installed and verified by inspection of the site glass at the pump, inboard motor and outboard motor locations.
- The coupling installation was performed under the guidance of a [redacted] representative.
- The alignment and coupling of the motor to the pump was be performed under the direction of [redacted] personnel.
- The instrumentation as listed below was installed.

Instrumentation

Following the CA test specimen pump and motor installation and alignment, the instrumentation was installed.

The following table summarizes the instrumentation used for the test program and the identification numbers (TAG) used by Wyle Laboratories:

CA Pump Loop Instrumentation:

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

All Wyle Laboratories' test equipment is calibrated on a periodic basis with the calibration interval displayed on a decal. This decal is affixed to the equipment indicating the last calibration date, the next calibration due date, accuracy, and by whom calibrated. The instrumentation equipment sheet for all the instrumentation is presented in this attachment.

In addition to individual component calibration, prior to and immediately following the test series, an end-to-end system calibration was performed on the pressure transducers.

WDF Pump/Motor Equipment Setup for Testing

The WDF pump and motor were setup in accordance with section 3.3 of Wyle Laboratories Test Procedure No. 10530TP, Revision 0.

From December 09 to 13, the following activities were completed:

- The pump internals and visible adjacent inlet piping were inspected to ensure cleanliness and no visual damage.
- The pump casing was installed to the 14" 300# RF ANSI inlet flange and the 8" 300# RF ANSI outlet flange.
- The casing and casing studs and gasket surfaces were inspected for cleanliness and no visual damage.
- The motor/stuffing box/rotating element was installed into the casing under the direction of [redacted] personnel.
- The pump casing was filled and vented with water.
- Oil for the motor was installed at the proper level.
- Correct connection of seal flush piping was verified.
- The instrumentation as listed below was installed.

Instrumentation

Following the WDF test specimen pump and motor installation, the instrumentation was installed.

[ ]

All Wyle Laboratories' test equipment is calibrated on a periodic basis with the calibration interval displayed on a decal. This decal is affixed to the equipment indicating the last calibration date, the next calibration due date, accuracy, and by whom calibrated. The instrumentation equipment sheet for all the instrumentation is presented in this attachment.

In addition to individual component calibration, prior to and immediately following the test series, an end-to-end system calibration was performed on the pressure transducers.

~~PROPRIETARY~~
REDACTED VERSION

Key of Attachments:

Instrumentation Sheet for Test Program. (3 pages)

Calibration Data for the Turbine Flow Meters. (2 pages)

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

REDACTED VERSION
~~PROPRIETARY~~

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

Attachment A3

Checkout Testing

RESULTS

Prior to the actual testing, a test facility and test specimen check out was performed to verify facility capabilities, test specimen operation and instrumentation functionality for the two test loops.

During this checkout test program, the data channels were acquired at a ~~10 samples per sec~~ sample frequency. A Test Log datasheet was used to record test run descriptions, as well as test data and time information and the ambient temperature, pressure and flow conditions. The test log datasheets obtained during the check out testing are presented in this attachment.

Note that throughout testing, two successive starts from ambient temperature are permissible provided the motor is allowed to fully coast down between starts. After two successive starts, the motor shall be idle for 30 minutes between additional starts.

Initially, the motor was bumped to check motor rotation for both pumps.

Prior to the motor/pump check out testing, a check list was used to verify that the test facility, test specimen and instrumentation were correctly configured to begin the test. A copy of the Check list for Start Up is presented in this Attachment as an illustration.

A total of five shakedown runs were performed on the pump/motor specimens as documented in the attached test log from 12/11/04 to 12/13/04. These runs were performed to verify proper facility operation, instrumentation functionality and test specimen performance. These tests were recorded as data files as follows:

~~PROPRIETARY~~
REDACTED VERSION

Run	Test Date	Data File Name	Notes
1	12/11/04	lpsicheck01	First motor/pump test on the WDF pump.
2	12/11/04	lpsicheck02	Longer duration test run on the WDF pump.
3	12/11/04	hpsicheckout01	Short Motor bump test on the CA pump.
4	12/11/04	hpsicheckout02	Long duration test to ensure the required pump curve range is achievable for the CA pump.
5	12/13/04	hpsicheckout04	Used to adjust manual valve position for pump run out protection and to check out air injection system for the CA pump.
6	12/16/04	lpsicheckout01	Checkout test prior to actual performance testing on the WDF pump.

In all cases, the data files have been supplied to APS separately.

Note that in checkout runs 1 -4 above, a 14" and 10" strainer were installed in the WDF and CA pump test loops respectively to ensure debris removal in the water inventory.

The data taken during run 4 (hpischeckout02) served to provide a CA performance pump curve prior to the air injection test program. This data is evaluated and compared to the pump performance curve after air injection in Attachment A5.

An instrumentation equipment sheet for the testing is presented in attachment A2.

REDACTED VERSION
~~PROPRIETARY~~

Key of Attachments:

Test Log Sheets for the Check Out Testing (4 pages)

Start up Check list (CA pump test) (2 pages)

~~PROPRIETARY~~
REDACTED VERSION

TEST LOG SHEET

[ ]

~~PROPRIETARY~~
REDACTED VERSION

TEST LOG SHEET

[ ]

~~PROPRIETARY~~
REDACTED VERSION

TEST LOG SHEET

[ ]

~~PROPRIETARY~~
REDACTED VERSION

TEST LOG SHEET

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

[ ]

Attachment A4

Performance Testing

RESULTS

The intent of the testing was to determine if temporary performance degradation occurs during the ingestion of a void fraction, and to identify any permanent degradation of performance after un-voided inventory returns to the pump.

A summarized test matrix for both pumps is presented in this Attachment.

During the test program, the data channels described in Attachment A3 were acquired at ten samples per second by the Wyle Laboratories data acquisition system. A Test Log datasheet was used to record test run descriptions, as well as test data and time information and the ambient temperature, pressure and flow conditions. The log is presented in Attachment A3.

Note that throughout testing, two successive starts from ambient temperature are permissible provided the motor is allowed to fully coast down between starts. After two successive starts, the motor shall be idle for 30 minutes between additional starts.

The instrumentation equipment sheet for this testing is presented in Attachment A2.

Prior to the motor/pump performance testing, a check list was used to verify that the test facility, test specimen and instrumentation were correctly configured to begin the test.

Actual Test Matrix

Throughout the test program, the required data described in Attachment A2 was recorded. This data covers the complete test program. Note that the test matrix presented here represents the target data for testing. Actual durations and peak mass flow rates were evaluated separately by APS and are not presented in this report.

The actual test data files consisting of videos of the voided fluid at the sight glass during each test, digital data for the instrumentation listing and vibration data were transmitted to APS, as documented in Wyle Transmittal No. 10530W-03 dated 1/06/05 for the complete test program.

~~PROPRIETARY~~
REDACTED VERSION

CA and WDF Pump Test Matrix

CA Pump Test Matrix

[ ]

~~PROPRIETARY~~
REDACTED VERSION

WDF Pump Test Matrix

[ ]

~~PROPRIETARY~~
REDACTED VERSION

A summary of the actual test data plots is presented here for the following test cases; 1D rerun, 2E, 3C and 4B.

~~PROPRIETARY~~
REDACTED VERSION

DataSet for Test 1D rerun

~~PROPRIETARY~~
REDACTED VERSION

~~PROPRIETARY~~

REDACTED VERSION

[ ]

[ ]

~~PROPRIETARY~~
REDACTED VERSION

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~

REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

~~PROPRIETARY~~

REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

[ ]

DataSet for Test 2E

~~PROPRIETARY~~
REDACTED VERSION

~~PROPRIETARY~~
REDACTED VERSION

~~PROPRIETARY~~

REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~

REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

~~PROPRIETARY~~

REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

~~PROPRIETARY~~
REDACTED VERSION

DataSet for Test 3C

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~

REDACTED VERSION

~~PROPRIETARY~~

REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~

REDACTED VERSION

[ ]

~~PROPRIETARY~~

REDACTED VERSION

[ ]

Dataset for Test 4B – the WDF pump

~~PROPRIETARY~~
REDACTED VERSION

~~PROPRIETARY~~
REDACTED VERSION

~~PROPRIETARY~~
REDACTED VERSION

[ ]

gpm

~~PROPRIETARY~~

REDACTED VERSION

~~PROPRIETARY~~

REDACTED VERSION

[ ]

~~PROPRIETARY~~

REDACTED VERSION

[ ]

~~PROPRIETARY~~

REDACTED VERSION

~~PROPRIETARY~~
REDACTED VERSION

~~PROPRIETARY~~

REDACTED VERSION

~~PROPRIETARY~~
REDACTED VERSION

Attachment A5

Equipment Inspection and Shipment

RESULTS

As noted in the Test Matrix in Attachment A4, a post test performance test was performed on the CA pump.

The pump head curves were developed for both the checkout02 test and the post test results were the pump was operated over the required range of flow rates.

The pump head curves are attached.

Based on the results of this performance test, not CA pump degradation was observed.

Based on the results of the air injection test on the WDF pump, no inspection was required.

Therefore no inspection of the CA or WDF pump was performed.

The motor of the CA pump was removed from the test loop and is currently in storage.

~~PROPRIETARY~~

REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

Attachment A6

Photographs

~~PROPRIETARY~~
REDACTED VERSION

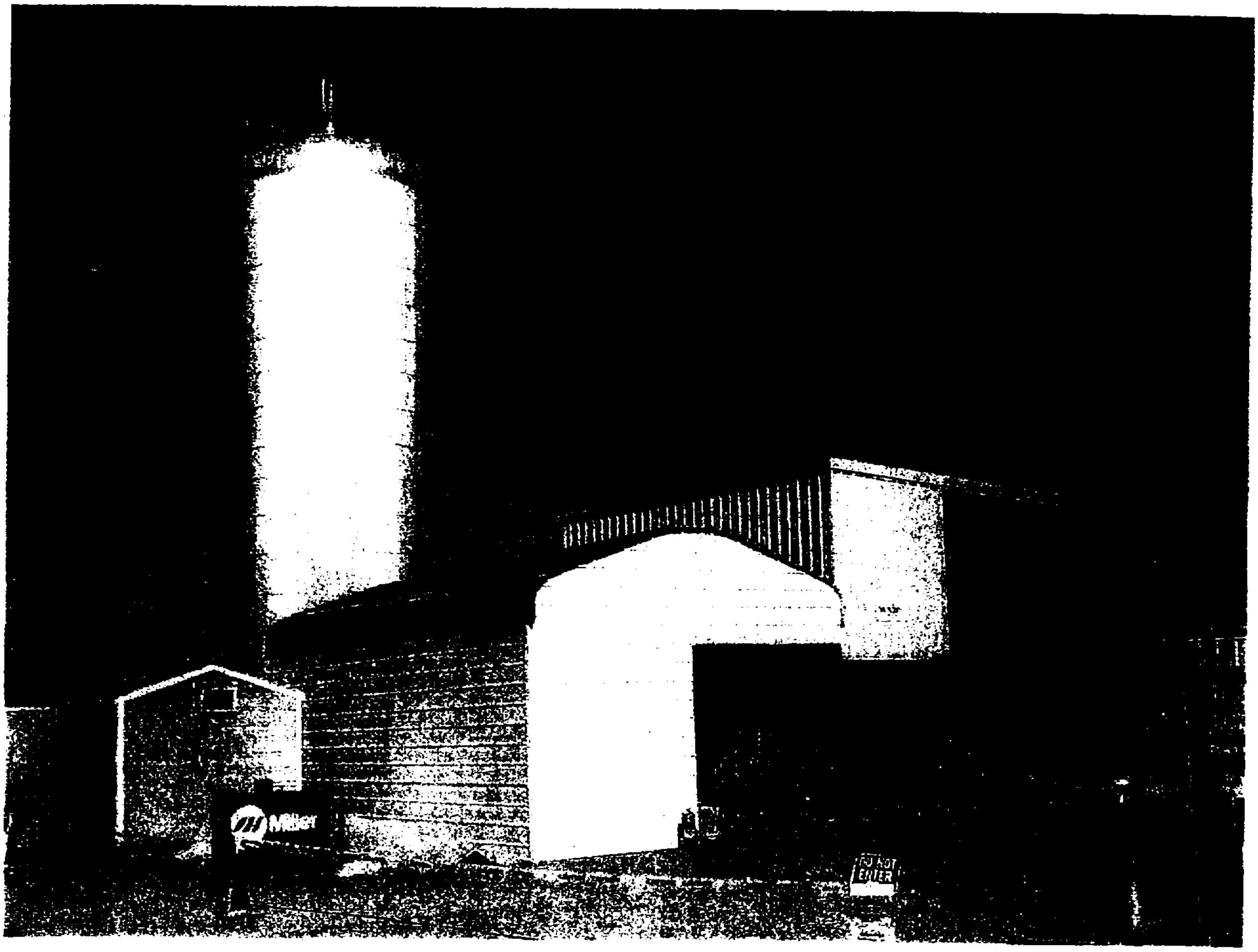


Figure 1– Overview of the Test Facility with the 30,000 gallon pressure vessel and Enclosure containing the two Test Loops and two Test Specimens.

~~PROPRIETARY~~

REDACTED VERSION

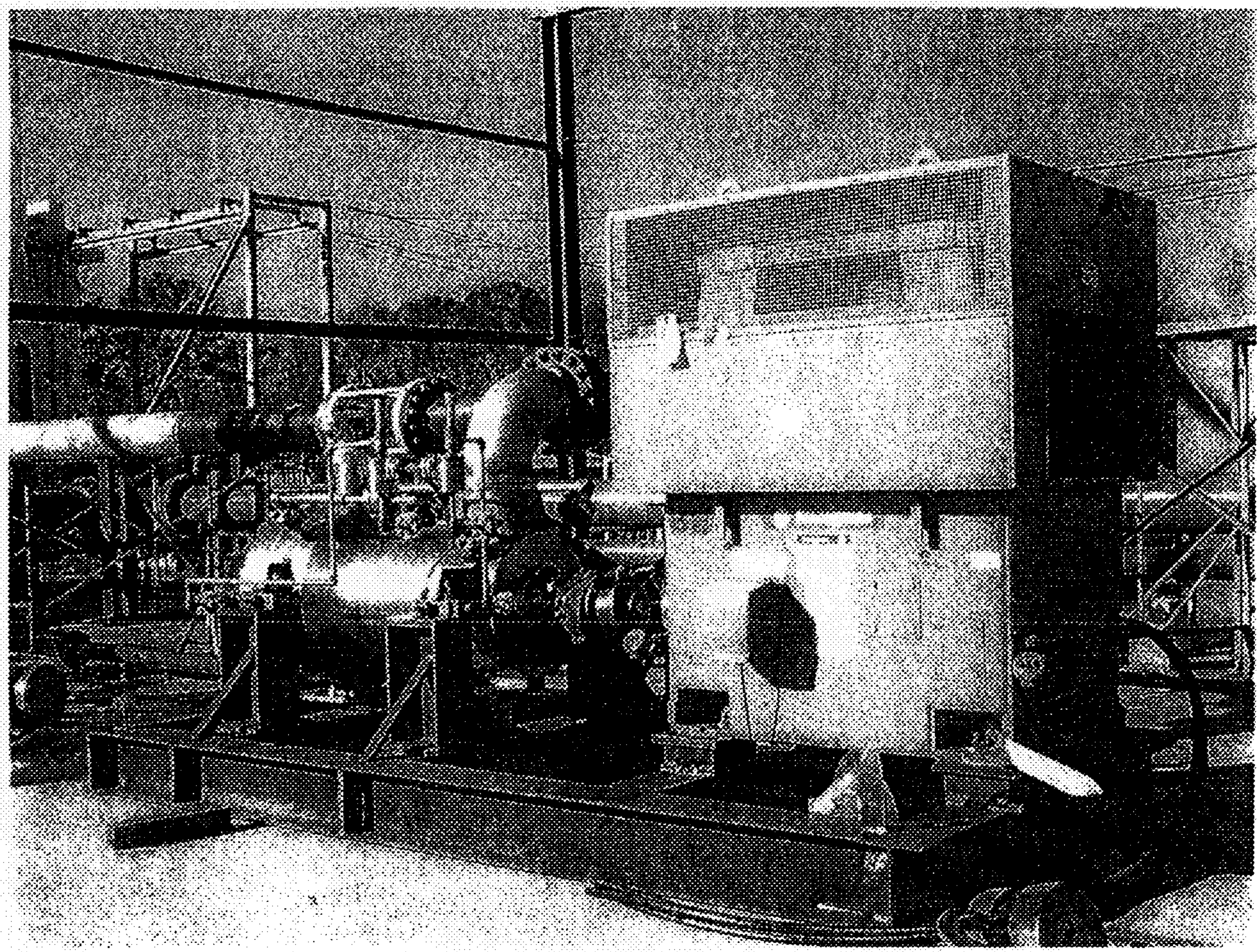


Figure 2– Photograph showing the Installation in the Test Loop for the CA Pump and Motor Test Specimen during facility construction.

~~PROPRIETARY~~
REDACTED VERSION

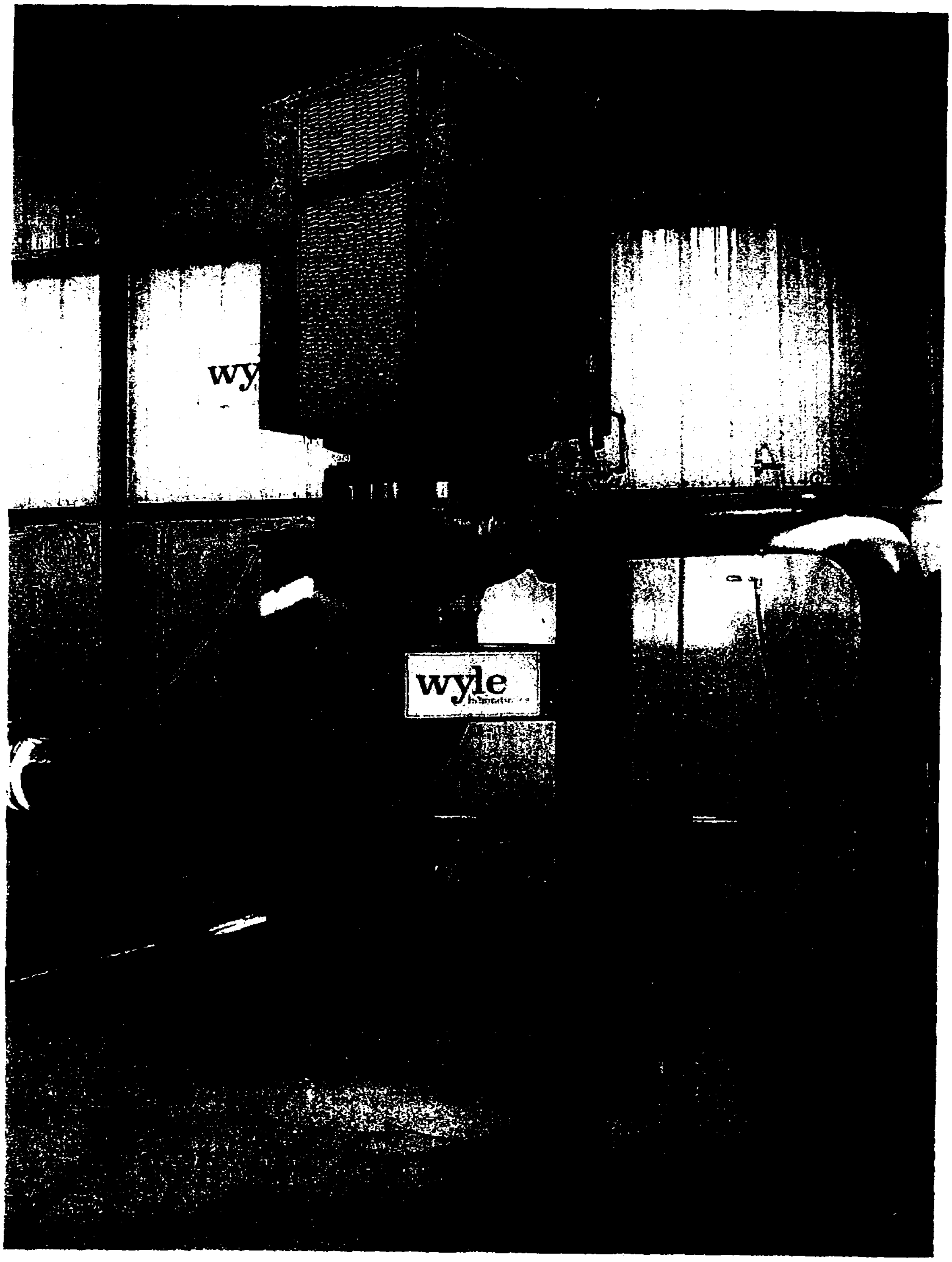


Figure 3 – Photograph showing the Installation in the Test Loop for the WDF Pump and Motor Test Specimen

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

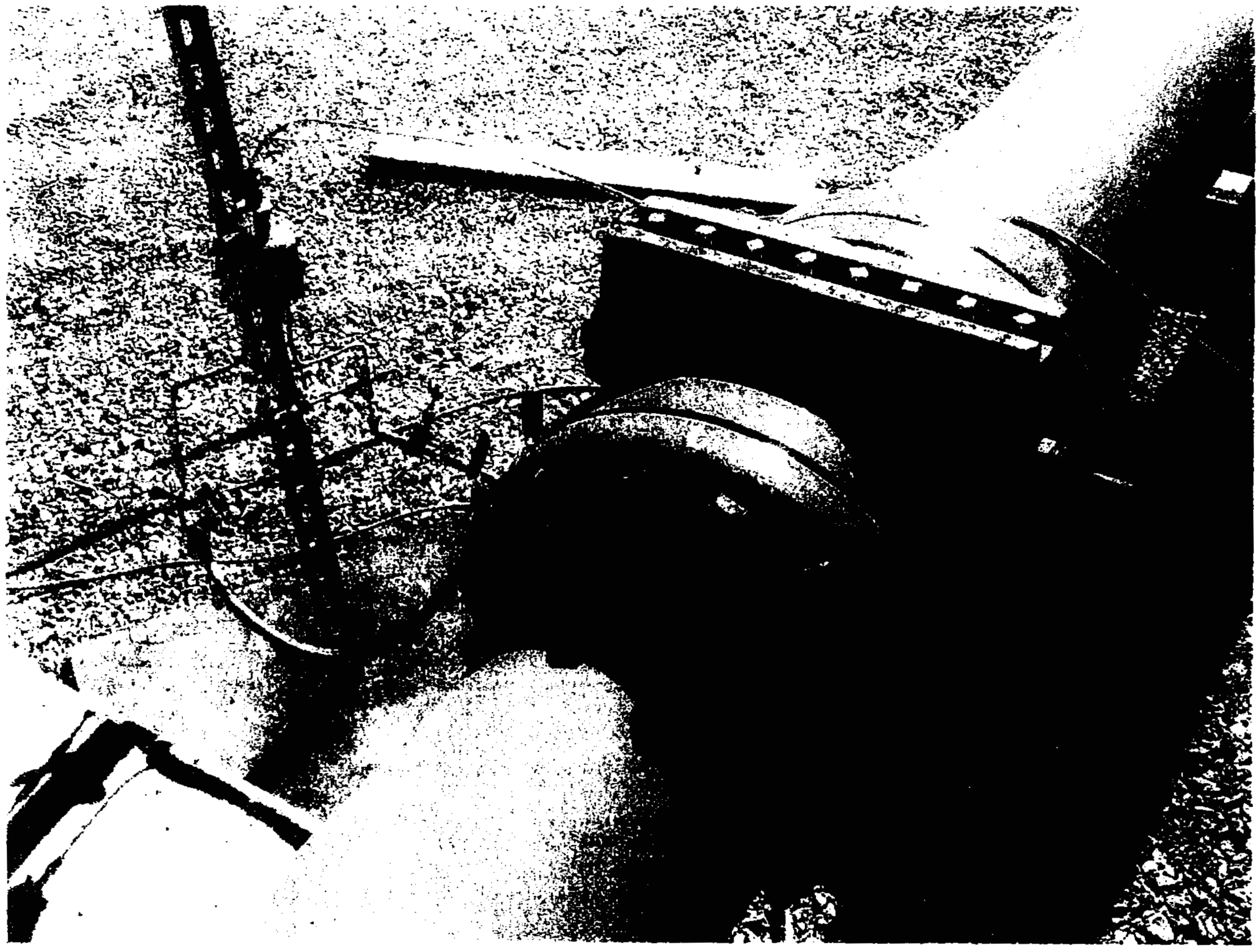


Figure 9 – Photograph showing the orifice plate assembly and differential pressure transducer for water flow rate instrumentation.

~~PROPRIETARY~~
REDACTED VERSION

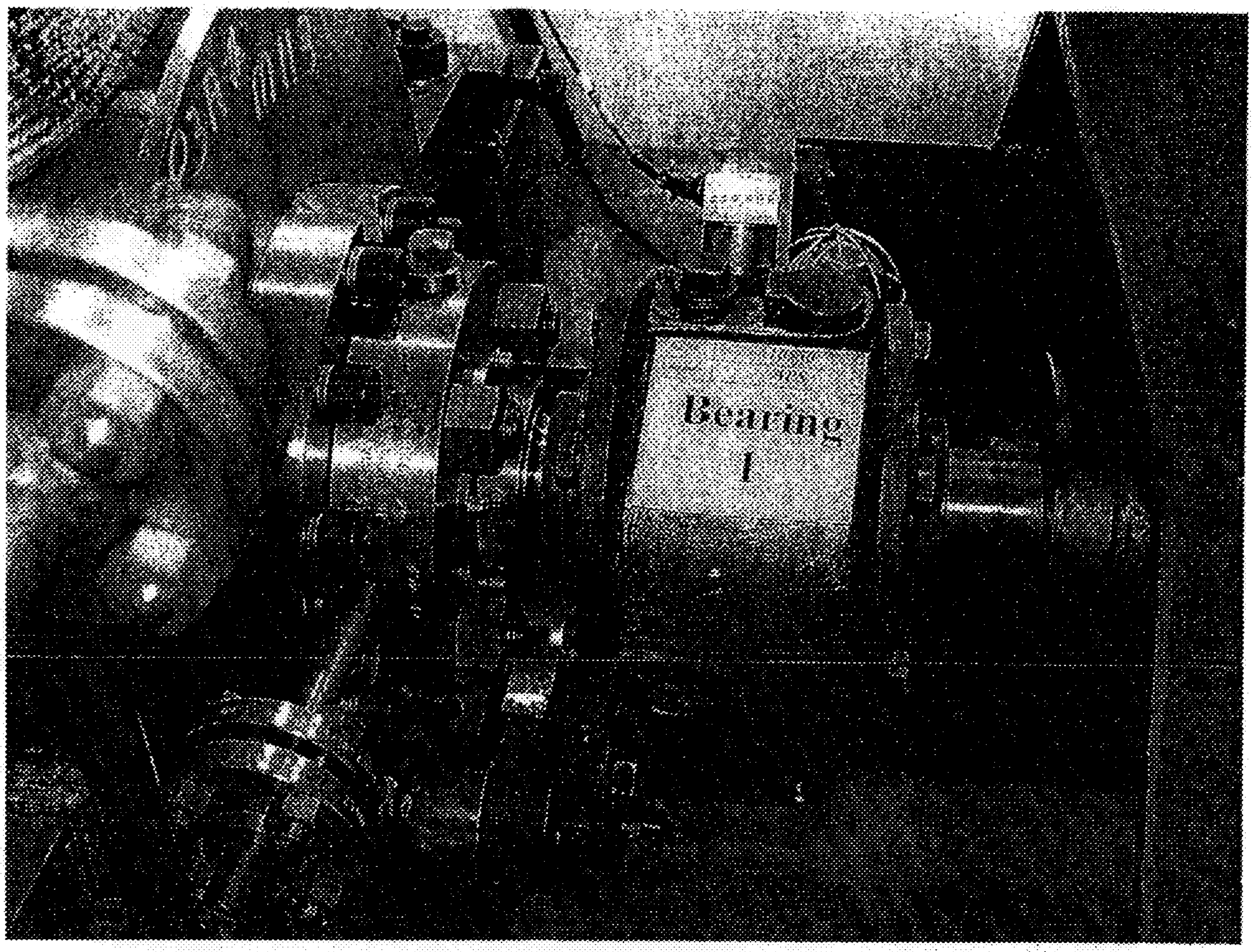


Figure 10 – Photograph showing the location of the Triaxial accelerometer for Bearing 1 on the CA pump inboard radial bearing.

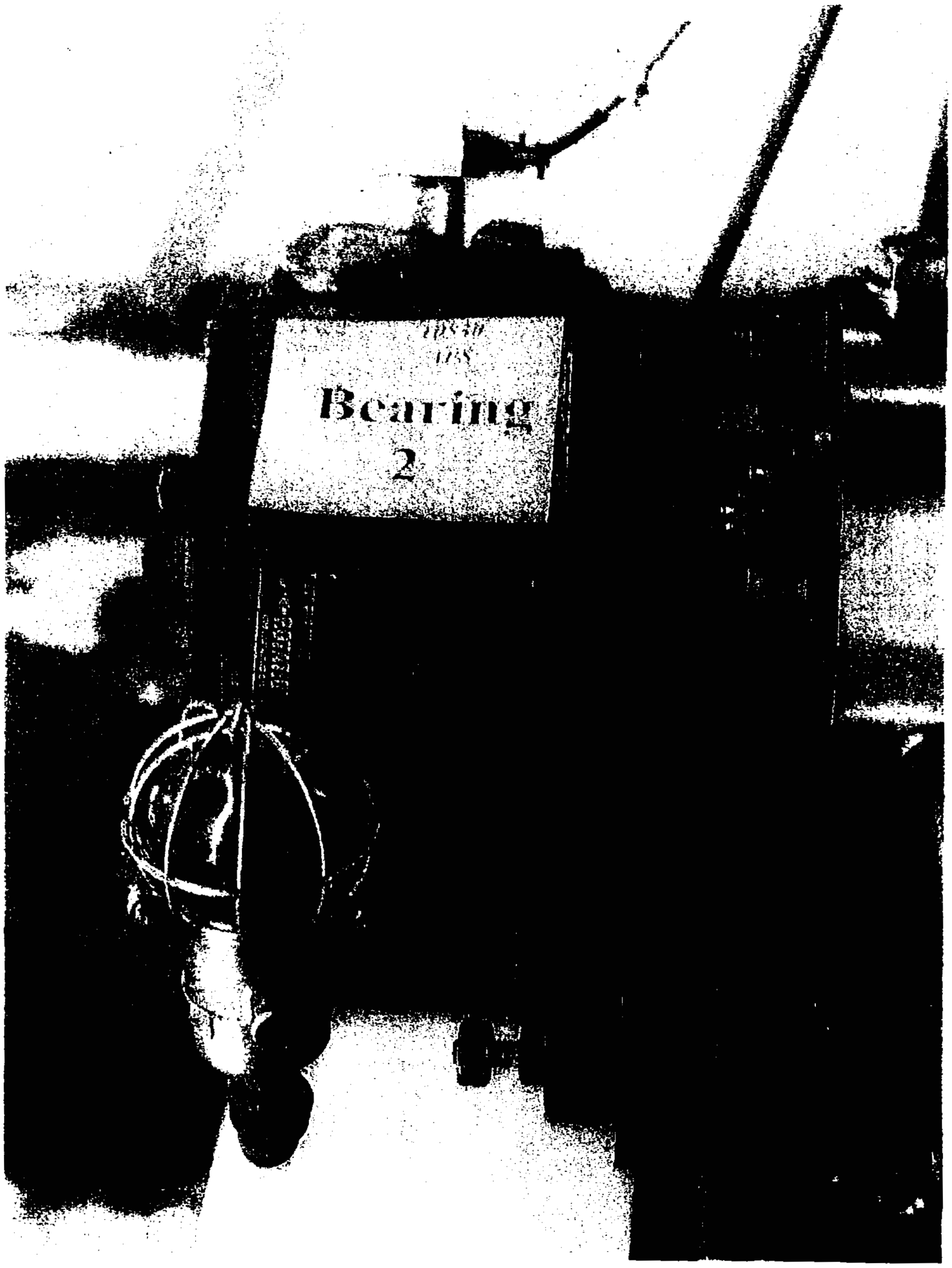


Figure 11 – Photograph showing the location of the Triaxial accelerometer for Bearing 2 on the CA pump outboard thrust bearing.

~~PROPRIETARY~~
REDACTED VERSION

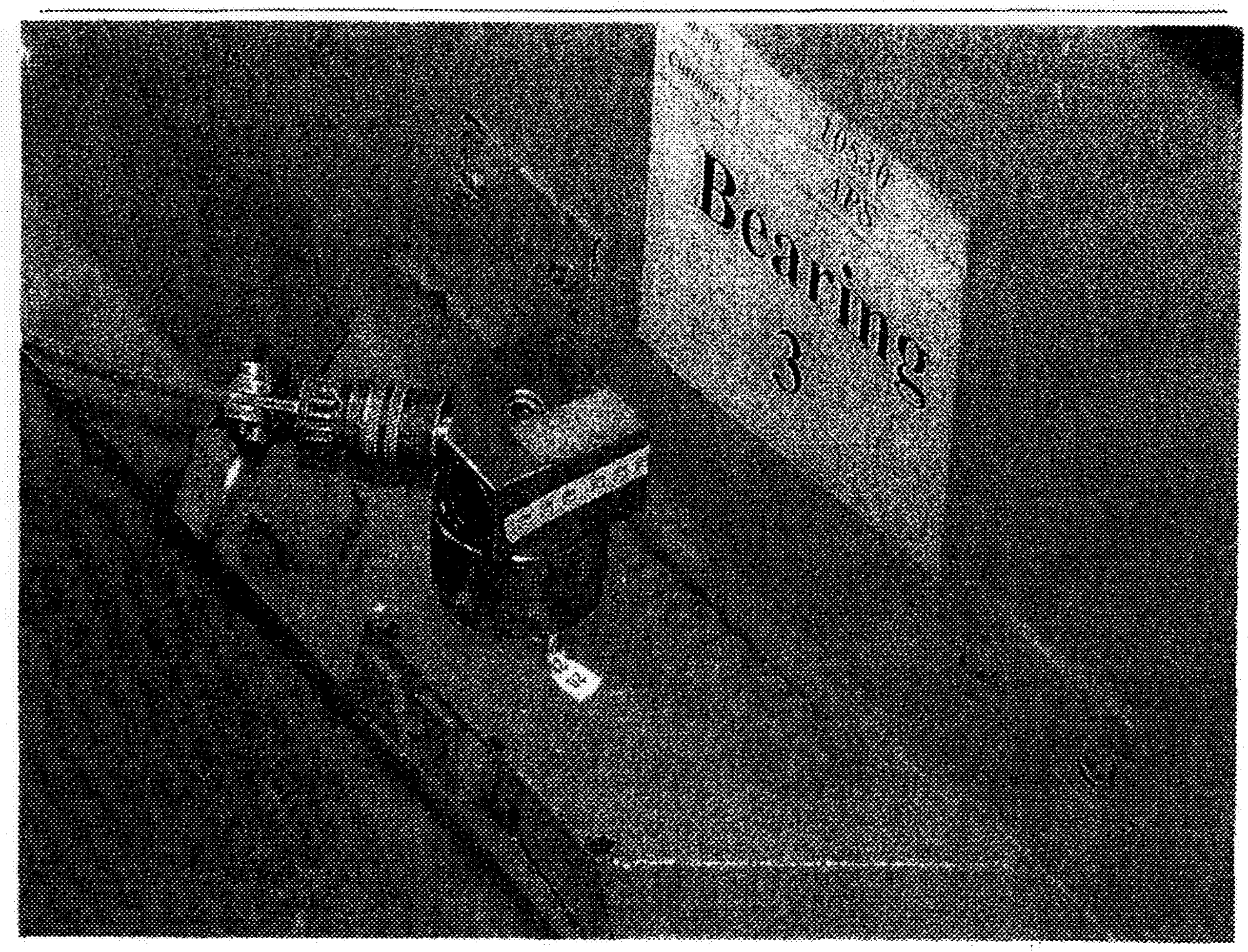


Figure 12 – Photograph showing the location of the Triaxial accelerometer for Bearing 3 on the CA pump motor inboard bearing (at coupling end).

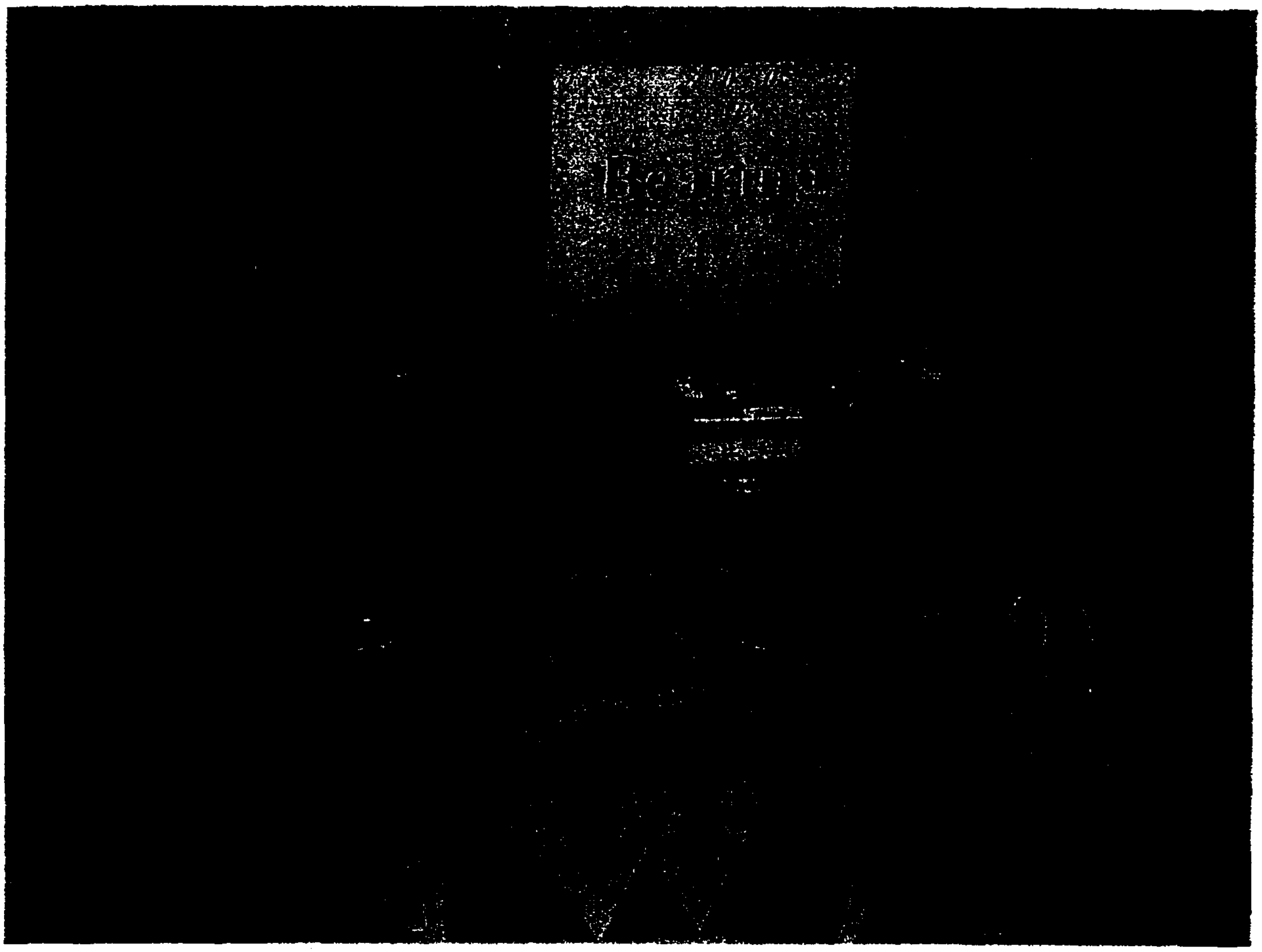


Figure 13 – Photograph showing the location of the Triaxial accelerometer for Bearing 4 on the CA pump motor outboard bearing.

~~PROPRIETARY~~
REDACTED VERSION

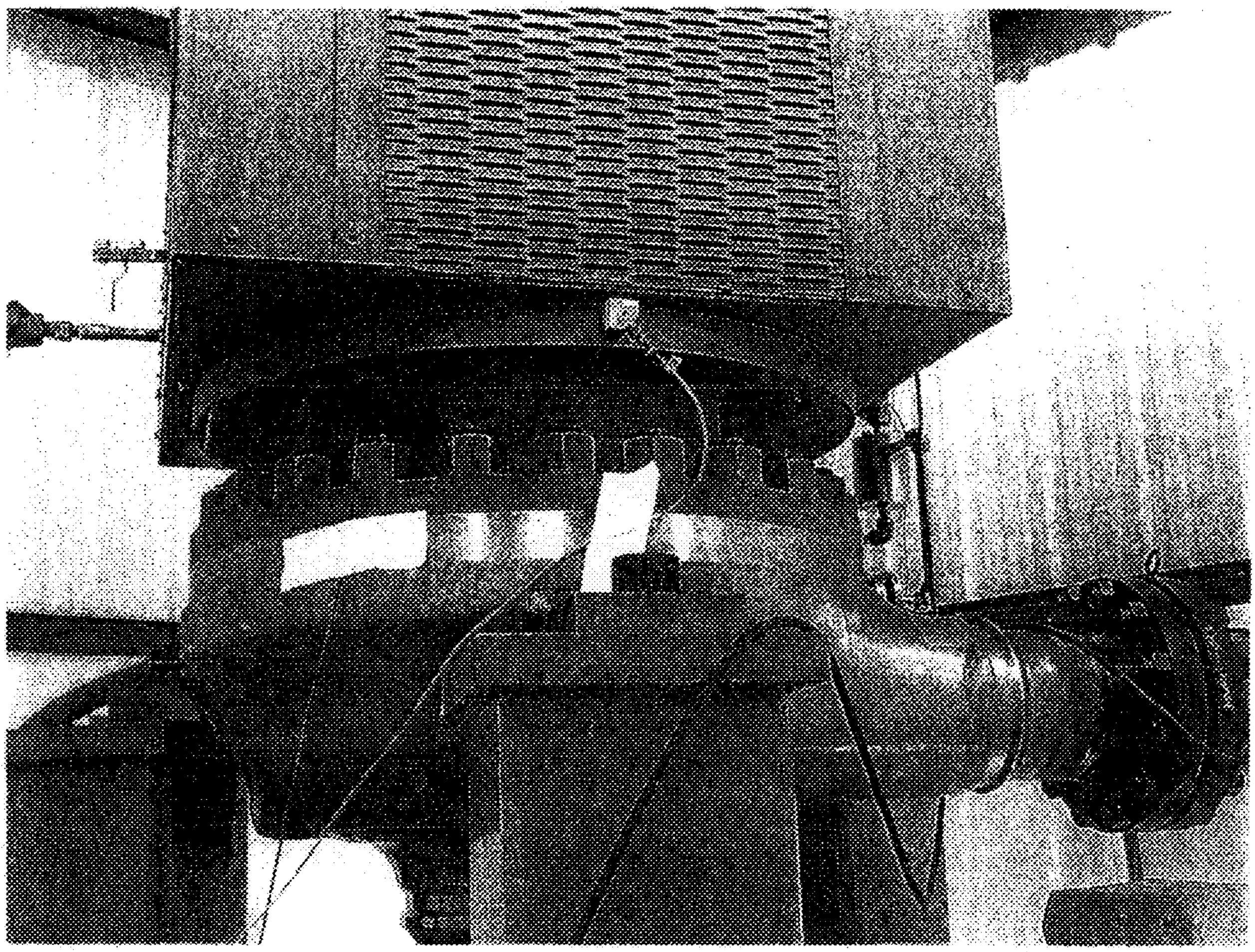


Figure 14 – Photograph showing the location of the Triaxial accelerometer for the WDF pump.

Attachment A7

[ ]

~~PROPRIETARY~~
REDACTED VERSION

DATA FILE FORMAT

The recorded data is as follows:

OVERALL g RMS DATA FOR VIBRATION DATA FILES LISTED

~~PROPRIET~~
REDACTED VERSION

~~PROPRIETARY~~

REDACTED VERSION

[ ]

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

~~PROPRIETARY~~

REDACTED VERSION

[

]

~~PROPRIETARY~~

REDACTED VERSION

[ ]

[ ]

~~PROPRIETARY~~

REDACTED VERSION

[ ]

[ ]

~~TOP~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

~~PROPRIETARY~~

REDACTED VERSION

[ ]

ATTACHMENT 2-D

FAI/05-06, Revision 0
Summary Report of MAAP4 LOCA Analysis in Support of Past Operability Assessment of Degraded HPSI Performance During Containment Recirculation at Palo Verde
~~(Proprietary)~~
REDACTED VERSION

~~PROPRIETARY~~
REDACTED VERSION

FAUSKE & ASSOCIATES, LLC
CALCULATION NOTE COVER SHEET

SECTION TO BE COMPLETED BY AUTHOR(S):

Calc-Note Number FAI/05-06 Revision Number 0

Title Summary Report of MAAP4 LOCA Analysis in Support of Past Operability Assessment of Degraded HPSI Performance During Containment Recirculation at Palo Verde

Project Arizona Public Service Project Number or Shop Order APS007

Purpose: See Section 1.0.

Results Summary: See Section 5.0.

References of Resulting reports, Letters, or Memoranda (Optional): N/A.

Author(s): Name (Print or Type)	Signature	Completion Date
Christopher E. Henry	Christopher E. Henry	February 11, 2005

SECTION TO BE COMPLETED BY VERIFIER(S):

Verifier(s): Name (Print or Type)	Signature	Completion Date
G. Thomas Elicson	G. Thomas Elicson	February 11, 2005

Method of Verification: Design Review ____, Independent Review or Alternate Calculations X , Testing ____.
Other (specify) ____________.

SECTION TO BE COMPLETED BY MANAGER:

Responsible Manager: Name (Print or Type)	Signature	Approval Date
Christopher E. Henry	Christopher E. Henry	February 11, 2005

CALC NOTE NUMBER FAI/05-06 PAGE ii

CALCULATION NOTE METHODOLOGY CHECKLIST

CHECKLIST TO BE COMPLETED BY AUTHOR(S) (CIRCLE APPROPRIATE RESPONSE)

1.	Is the subject and/or the purpose of the design analysis clearly stated?	YES	NO	
2.	Are the required inputs and their sources provided?	YES	NO	N/A
3.	Are the assumptions clearly identified and justified?	YES	NO	N/A
4.	Are the methods and units clearly identified?	YES	NO	N/A
5.	Have the limits of applicability been identified? (Is the analysis for a 3 or 4 loop plant or for a single application.)	YES	NO	N/A
6.	Are the results of literature searches, if conducted, or other background data provided?	YES	NO	N/A
7.	Are all the pages sequentially numbered and identified by the calculation note number?	YES	NO	
8.	Is the project or shop order clearly identified?	YES	NO	
9.	Has the required computer calculation information been provided?	YES	NO	N/A
10.	Were the computer codes used under configuration control?	YES	NO	N/A
11.	Was the computer code(s) used applicable for modeling the physical and/or computational problems identified? (i.e., Is the correct computer code being used for the intended purpose.)	YES	NO	N/A
12.	Are the results and conclusions clearly stated?	YES	NO	
13.	Are Open Items properly identified	YES	NO	N/A
14.	Were approved Design Control practices followed without exception? (Approved Design Control practices refers to guidance documents within Nuclear Services that state how the work is to be performed, such as how to perform a LOCA analysis.)	YES	NO	N/A
15.	Have all related contract requirements been met?	YES	NO	N/A

NOTE: If **NO** to any of the above, Page Number containing justification

~~**PROPRIETARY**~~
REDACTED VERSION

FAI/05-06

SUMMARY REPORT OF MAAP4 LOCA ANALYSIS IN SUPPORT OF PAST OPERABILITY ASSESSMENT OF DEGRADED HPSI PERFORMANCE DURING CONTAINMENT RECIRCULATION AT PALO VERDE

Submitted To:

Arizona Public Service
Phoenix, Arizona

Prepared By:

Christopher E. Henry
Fauske & Associates, LLC
16W070 West 83rd Street
Burr Ridge, Illinois 60527
TEL: (630) 323-8750
FAX: (630) 986-5481

February 2005

TABLE OF CONTENTS

TABLE OF CONTENTS

(concluded)

LIST OF FIGURES

[ ]

LIST OF FIGURES

(concluded)

LIST OF TABLES

EXECUTIVE SUMMARY

This report documents MAAP4 calculations of Palo Verde Nuclear Generating Station (PVNGS) core, reactor coolant system (RCS), and containment thermal-hydraulic response to a small-to-medium loss of coolant accident (LOCA) in which the high-pressure safety injection (HPSI) and containment spray system (CSS) become degraded. Potential failure of HPSI is also considered. Degradation and potential failure are presumed to occur when the emergency core cooling system (ECCS) and CSS transition between suction from the refueling water tank (RWT) to suction from the containment recirculation sump in response to the recirculation acquisition signal (RAS). This scenario is intended to support a justification for past operations (JPO) assessment regarding degradation and possible failure of the HPSI system due to ingestion of air that actually existed between two valves in the ECCS/CSS suction lines during past operation of the plant.

Specifically, a spectrum of break sizes and locations was evaluated to determine the case(s) that could challenge core coverage, long-term core cooling, and long-term containment heat removal. The medium break diameters in the range of roughly 3 to 6 inches were determined to be the most challenging. However, in all cases, MAAP4 predicted that the core would remain completely covered, due almost entirely to the cold leg injection of the safety injection tanks (SIT) (a.k.a., accumulators) during the post-RAS time period. Even when outright post-RAS failure of the HPSI was postulated, SIT injection maintained core coverage until post-LOCA cooldown and depressurization of the RCS below the low-pressure safety injection (LPSI) shutoff head enabled sufficient LPSI flow to provide continued core coverage and long-term core cooling.

1.0 INTRODUCTION

1.1 Background

On September 28, 2004, PVNGS staff [PVNGS, 2004a] submitted a licensee event report (LER) to the Nuclear Regulatory Commission (NRC) that reported a condition in Units 1, 2, and 3 in which air voids in the recirculation sump suction piping (serving both the ECCS and the CSS) may have prevented the fulfillment of the system safety function to removal residual heat and mitigate the consequences of a loss of coolant accident. (Reference [Westinghouse, 2004] provides some additional details that are relevant to all Westinghouse and CE designs.)

PVNGS, in conjunction with Westinghouse and its Fauske and Associates (FAI) subsidiary, investigated this condition with an approach that involved both experiment and analytical elements. Phases 1 through 3 of the investigation were predominantly experimental separate effects testing of HPSI/CSS availability and are not considered here. Phase 4 was the integral plant analysis with independent evaluations provided by the MAAP4 and CENTS codes. This report is confined to MAAP4 analysis portion of Phase 4.

Phase 4 participants from PVNGS, Westinghouse (Windsor, Connecticut office), and FAI were charged with considering the core, RCS, and containment response to post-RAS degradation and potential failure of the HPSI and CSS. Furthermore, this circumstance could result from any of the full spectrum of initiating events (LOCA, transient, station blackout, ...) that would challenge core coverage, long-term core cooling and, long-term containment heat removal (and by extension long-term containment integrity). Since the outcome of challenges could involve core overheat and damage, the MAAP4 code was selected as a contributor to the analysis in view of its ability to model degraded core progression and its influence on the RCS and containment.

1.2 Post-RAS ECCS and CSS Status

It has been established that the HPSI system within the ECCS and the CSS could become degraded or even unavailable during post-RAS operation due to ingestion of pre-existing air within the suction lines. Elaboration on some key details is instructive.

At the time of RAS, the PVNGS units are designed for automatic switchover of the HPSI and CSS systems. Specifically, these systems are stopped, realigned to the recirculation sump, and then restarted during the automatic switchover. The LPSI system is stopped as part of this process, but it is not automatically restarted. It must be manually restarted by the operator (if necessary) after completion of switchover. Furthermore, the HPSI suction line is the first system to draw from the suction header. This is followed by the CSS suction line and finally the LPSI suction line. Also, the specific configuration of the HPSI suction line makes HPSI more susceptible to air ingestion than the other systems.

Indeed, the noted Phase 1 and Phase 2 experiments, which were responsible for characterizing the two-phase flow through the suction header and individual ECCS/CSS suction lines, demonstrated that most air ingestion would occur in the HPSI system with only a relatively small ingestion by the CSS system.

Phase 3 experiments were responsible for evaluating an actual HPSI pump with air ingestion boundary conditions dictated by Phase 1 and Phase 2 experiments. These experiments demonstrated that the HPSI system would continue to operate but at a degraded flow condition, with increasing degradation (decreasing flow) at higher system pressure.

Therefore, Phase 4 analyzed both degraded and failed conditions for HPSI, a prescribed degraded condition for CSS and full availability of LPSI in the post-RAS operation. Specific details will be provided in Section 3.

1.3 Initiating Event Selection

As stated above, all initiating events were considered which would challenge core coverage, long-term core cooling, and long-term containment heat removal. Furthermore, the Level II containment event trees [PVNGS, 1992] for these initiating events were inspected to determine the most challenging set of conditions for high-pressure recirculation degradation or failure. Note, evaluation of the event trees did not entail loss of additional components concurrent with the HPSI degradation or failure. Since this was a deterministic (as opposed to probabilistic) analysis that was intended to support justification for past operation, all other systems were assumed to be available, particularly the safety injection tanks (SIT) and the operator action of post-LOCA steam generator cooldown and depressurization of the RCS via the steam generators.

1.4 Break Size and Location Selection

With these ground rules in place, it was determined that a small to medium LOCA (roughly 3 to 6 inches in diameter) initiating event is most challenging since it is responsible for significant coolant loss, but the RCS remains at elevate pressure because the break alone is not sufficient to remove decay power. [

]

2.0 MAAP CODE DESCRIPTION

2.1 What is MAAP?

MAAP is a computer code that simulates light water reactor system response to accident initiation events. The Modular Accident Analysis Program (MAAP), an integral systems analysis computer code for assessing severe accidents, was initially developed during the industry-sponsored IDCOR Program. At the completion of IDCOR, ownership of MAAP was transferred to EPRI. Subsequently, the code evolved into a major analytical tool (MAAP 3B) for supporting the plant-specific Individual Plant Examinations (IPEs) requested by NRC Generic Letter 88-20. Furthermore, MAAP 3B was used as the basis to model the Ontario Hydro CANDU designs. As the attention of plant-specific analyses was expanded to include accident management evaluations, the scope of MAAP (its design basis) was expanded to include the necessary models for accident management assessments. Through support by the U.S. Department of Energy (DOE), the MAAP4 design basis was further extended to include the Advanced Light Water Reactor (ALWR) designs currently being developed by the reactor vendors. MAAP4 has also been expanded to represent the VVER designs used in Finland and central Europe.

2.2 MAAP History

Table 2-1 summarizes the history of MAAP development in terms of the major code versions and the major advancements represented by each version. Two types of Nuclear Steam Supply Systems (NSSS) are modeled in the MAAP4 code: the Boiling Water Reactor (BWR) and the Pressurized Water Reactor (PWR). In addition, MAAP4 is the first archived code that contains a graphical representation of the reactor and containment response (MAAP4-GRAAPH). MAAP4, like MAAP 3B, is currently being maintained by Fauske & Associates, LLC (FAI) for the Electric Power Research Institute (EPRI) and the MAAP User's Group (MUG).

Table 2-1: History of MAAP Code Development.		
Year	**MAAP Code Version**	**Major Advancement**
1982	-	MAAP development initiated for BWRs and PWRs.
June, 1983	1.0	Primary system and containment thermal-hydraulic models.
June, 1984	2.0	Fission product release, transport and deposition models added; local H_2 burning (igniters).
December, 1984	2.0B	Zircaloy-tellurium binding.
January, 1986	3.0	In-vessel natural circulation, advanced models for aerosol growth and deposition, suppression pool scrubbing, gas natural circulation in steam generation, Chexal/Layman correlation for BWR core power model.
January, 1988 (MAAP Users' Group Initiated)	3.0B	Auxiliary building/reactor building model, improved suppression pool scrubbing model, increased RCS nodalization, RCS natural circulation.
1991	MAAP-CANDU	CANDU-specific models for the horizontal fuel bundle and pressure tubes, moderator tank, shield tank, multi-unit containment, and vacuum building.
September, 1993	MAAP-VVER	Fuel cans for the PWR core, horizontal steam generator, fuel movement as part of the shutdown mechanism.
May, 1994	MAAP4 MAAP4-GRAAPH MAAP4-DOSE	Accident management and ALWR models, advanced core melt progression and material creep models, in-vessel cooling, external cooling of the RPV, detailed modeling of the lower head penetrations, generalized containment, interactive graphical interface, on-site and off-site radiation dose models.

The purpose of MAAP4 is to provide an accident analysis code that can be used with confidence by the nuclear industry in all phases of severe accident studies, including accident management, for current reactor/containment designs and for ALWRs. MAAP4 includes models for the important accident phenomena that might occur within the primary system, in the containment, and/or in the auxiliary/reactor building. For a specified reactor and containment system, MAAP4 calculates the progression of the postulated accident sequence, including the disposition of the fission products, from a set of initiating events to either a safe, stable state or to an impaired containment condition (by overpressure or over-temperature) and the possible release of fission products to the environment.

Severe accident analyses can be divided into four phases: (1) prevention of core damage; (2) recovery prior to reactor pressure vessel breach; (3) recovery after vessel breach, but prior to containment failure; and (4) mitigation of releases of fission products reaching reactor/auxiliary buildings. The previous archived version, MAAP 3B, can analyze phases 1, 3, and 4 for existing reactors, which is sufficient to support the Individual Plant Examination (IPE) studies, the intended purpose of that major MAAP version. However, MAAP 3B does not have the ability to treat phase 2, recovery prior to vessel breach but after severe core damage. It has been estimated that the interval between the onset of severe core damage and the time of vessel breach could vary from 30 minutes to many hours or, as in the TMI-2 accident, vessel integrity can be maintained throughout the accident. Recovery during this interval could obviously reduce, and perhaps eliminate, the likelihood of reactor pressure vessel failure and thereby greatly limit the extent of the accident.

In evaluating the effectiveness of proposed accident management strategies, there is a need to evaluate the integral system response to the proposed actions. Because of the numerous phenomena involved the evaluation is complex, and for many severe accident phenomena, the experimental database is sparse. However, with the extensive TMI-2 data, along with the results of integral experiments such as the LOFT and CORA tests, the major characteristics of the melt progression, primary system thermal-hydraulic response, and core debris-concrete interaction have been demonstrated. Also, with EPRI-sponsored experiments, more data have become available on key phenomena, for example, the mode of vessel breach and the conditions which could prevent vessel failure. The results from these experiments have been included in the MAAP4 modeling enhancements and have resulted in major insights with respect to the effectiveness of accident management actions, particularly for maintaining the integrity of the reactor vessel.

One area where only limited experimental data are available is quenching of overheated debris prior to vessel breach. This of course, is of key interest in recovering from an accident state and was a major part of the TMI-2 accident. MAAP4 includes models for in-vessel cooling and external cooling of the RPV to evaluate whether a safe, stable state can evolve following water addition to the RCS and/or the containment if the core debris can be retained within the reactor pressure vessel.

MAAP4 also addresses the new and unique features, many of which are passive, included in ALWR designs. These are:

- passive heat removal system, such as an in-containment isolation condenser or a passive RHR system,
- gravity-fed water injection systems,
- external heat removal from the containment shell,
- a generalized nodalization scheme for the containment to accommodate the ALWR designs including an in-containment RWST, and
- the capability to analyze flow through large safety valves, such as an automatic depressurization system for PWR designs.

Since the beginning of the MAAP code development, the codes have represented all of the important safety systems such as emergency core cooling, containment sprays, residual heat removal, etc. MAAP4 allows operator interventions and incorporates these in a flexible manner, permitting the user to model the operator response and the availability of the various plant systems in a general way. The user can represent operator actions by specifying a set of values for variables used in the code and/or events, which are the operator intervention conditions. There is a large set of actions that the operator can take in response to the intervention conditions.

MAAP4 has been developed under the FAI Quality Assurance Program, in conformance with 10CFR50 Appendix B and with the International ISO 9000 Standard. Furthermore, the new software has been subjected to review by a Design Review Committee, comprised of senior members of the nuclear community, in a manner similar to that exercised for MAAP 3B.

2.3 Summary of Relevant Benchmarks

The following subsections provide a summary of relevant MAAP4 benchmarks against plant experience and large-scale integral experiments and also against one integral computer code. Plant experience and experiment benchmarks are documented in Volume 3 of the MAAP4 User's Manual [EPRI, 2003a]. (The MB-2 benchmark is awaiting incorporation into the manual in the next MAAP4 revision cycle this year.)

2.3.1 RCS Response to Small LOCA

Since RCS thermal-hydraulic performance under a small LOCA condition is essential to the analysis, some relevant benchmarks are cited here.

MAAP4 RCS thermal-hydraulics has been benchmarked against the Three Mile Island Unit 2 (TMI-2) plant experience, particularly the small LOCA phase of the accident when the pressurizer relief valve was stuck open. MAAP4 RCS thermal-hydraulics has also benchmarked against a similar stuck open pressurizer relief valve event at Crystal River Unit 3. Both benchmarks show reasonable good agreement with the plant data. While these benchmarks are for RCS hot side LOCA's in the pressurizer, they are still relevant to cold side LOCA's since the LOCA modeling in the MAAP pressurizer model is essentially the same as that used for LOCA modeling in RCS loop piping.

As part of the recent Beaver Valley atmospheric containment conversion project, MAAP4 was benchmarked against the Westinghouse small LOCA code, NOTRUMP.

2.3.2 Containment Response to LOCA

Since containment response is an important aspect of RAS timing, it is important to insure the integrity of the MAAP4 containment model. MAAP4 has been benchmarked against numerous containment experiments, both separate effects tests and large-scale integral effects tests. Herein, the containment was benchmarked as a stand-alone model with break mass and energy rates from the experiment, specified as a boundary condition to the model. This type of stand-alone benchmark can be performed within the normal MAAP4 code framework via the MAAP4 dynamic benchmarking feature, thereby exercising the exact same containment model that is used in conventional MAAP4 applications that exercise the full code.

Two benchmarks of note are the small LOCA experiment E11.2 and the medium LOCA experiment T31.5 performed at the HDR test facility in Germany, which was a reactor-scale containment that contained a decommissioned low-power reactor. MAAP4 compares well to both short-term and long-term containment pressurization in both experiments.

2.3.3 RCS Response to Steam Generator Tube Heat Transfer

Since post-LOCA cooldown and depressurization is an important operator action in this analysis, it is important to insure the integrity of the RCS response to steam generator tube heat transfer.

MAAP4 has been benchmarked the Crystal River Unit 3 plant transient, noted above. Herein, steam generators temporarily boiled dry during the transient prior to receiving auxiliary feedwater. Also, in a similar event, the Davis-Besse Unit 1 plant transient resulted in the steam generators boiling dry for a brief period until auxiliary feedwater could be provided. The MAAP4 RCS model, in particular the primary system average temperature, compares well during both the initial steam generator heat transfer and subsequent primary system heatup in the presence of dry steam generators.

The MAAP4 steam generator model has been compared against an integral steam generator experiment known as the Westinghouse Model Boiler 2 (MB-2). Herein, the steam generator is treated as a stand-alone model with primary system boundary conditions from the experiment provided via user input. Again, like the stand-alone containment benchmark, a stand-alone steam generator benchmark can be performed within the normal MAAP4 code framework via the MAAP4 dynamic benchmarking feature, thereby exercising the exact same steam generator model that is used in conventional MAAP4 applications that exercise the full code. Revision MAAP 4.0.5, which is the code revision used for this analysis, was successfully benchmarked against loss of feedwater tests (both simulated full power and decay power transients) performed at MB-2.

2.4 Regulatory Understanding of MAAP

The U.S. Nuclear Regulatory Commission (NRC) reviewed and approved MAAP 3.0B for support of probabilistic risk assessment (PRA) activities at licensed power reactors in the U.S., particularly the individual plant examinations (IPE's) that occurred in the late 1980's and early 1990's.

While MAAP4 has not undergone a formal review process by the NRC, the code owner, the Electric Power Research Institute (EPRI), Fauske and Associates (FAI), and the MAAP User's Group (MUG) previously engaged in MAAP4 familiarization activities with the NRC when MAAP4 was first released. Recently, a MAAP4 Information Exchange between these parties has been undertaken in view of the expanding scope of MAAP4 application and MAAP4-supported submittals to the NRC.

MAAP4 has been used previously for safety analyses outside of the risk arena with NRC approval. For example, an NRC Safety Evaluation Report (SER) was written for the D.C. Cook plant in its assessment of minimum safe sump level in the containment recirculation sump during a small LOCA event. This assessment involved small LOCA scenarios that are similar to those in the present analysis for PVNGS.

2.5 MAAP4 Limitations

2.5.1 MAAP4 RCS Model

The MAAP4 RCS model uses momentum equation selectively for sub-models that demand a momentum equation for model adequacy. One of the aspects for which a full-fledged momentum equation is not implemented is water flow. Consequently, MAAP4 cannot void the core by reversing flow from the core to the downcomer and loop piping during a large LOCA event. However, small breaks of the size being analyzed for this analysis do not engage in such significant flow reversal, so this limitation is not relevant to this analysis.

2.5.2 MAAP4 Containment Model

The MAAP4 containment model can accommodate most physical phenomena that would occur. However, since it does not entrain pre-existing liquid and condensate from heat sink surfaces, it does not mechanistically bring suspended water droplets into the containment atmosphere (although the model could accommodate droplets if such liquid entrainment was added). Consequently, it is conservatively predicts excess gas-phase superheat and pressurization during the blowdown stage of a large LOCA event.

Again, small breaks of the size being analyzed for this analysis do not promote significant gas superheat, so this limitation is not relevant to this analysis. Furthermore, superheat and excess pressurization are conservative for this analysis since they would lead to earlier RAS timing. As noted previously, the HDR T31.5 and E11.2 containment benchmarks are testament to the adequacy of the containment model for predicting short-term and long-term containment pressurization under small and medium LOCA conditions, which is necessary for an accurate depiction of containment spray actuation signal (CSAS) timing in this analysis.

2.6 Refinements to the MAAP4 Code Revision

The latest MAAP4 archived revision, MAAP 4.0.5 [EPRI, 2003b], was used with the latest PVNGS-specific plant model (a.k.a., parameter file). [

]

[ ]

~~PROPRIETARY~~
REDACTED VERSION

3.0 DESIGN INPUT AND ASSUMPTIONS

3.1 Design Input

3.1.1 Base Code Revision and Plant Model

The base code revision is the latest MAAP4 archived revision, MAAP 4.0.5 [EPRI, 2003b]. In addition, a revision to the archived subroutine WFLOW was included in this analysis to address a finding made during the analysis, as discussed in detail in Section 2.

The base plant model is the latest PVNGS-specific plant model, or parameter file, [PVNGS, 2001] for MAAP4.

3.1.2 Analysis-Specific Plant Model Parametric Input Data

Table 3-1 summarizes the analysis-specific plant model parametric input data that is most influential to the analysis. Some values are taken directly from the PVNGS base plant model. Others are analysis-specific changes. (Parameter input of secondary importance is not discussed here, and their values are taken from the base plant model without alternation.) [

]

[

]

[ ]

[ ]

[ ]

3.1.3 Analysis-Specific Assumptions of Plant and Operator Response

In addition to plant model parametric input data, there are analysis-specific modeling assumptions of plant and operator response, which area summarized in Table 3-2. As with the parametric input data, assumptions are primarily best-estimate, but some key assumptions, which have a large bearing on RCS and containment response, are biased in a conservative manner. These are discussed here.

[ ]

3.1.3.1 RCS Void Fraction for Phase Disengagement

The MAAP RCS model tracks a global primary system average void fraction. When the void fraction exceeds the value of a user input model parameter VFSEP, the gas- and liquid-phases will disengage (or separate). The phases can re-engage if the void fraction is reduced below user input model parameter VFCIRC. Phase disengagement is an important consideration because it has a substantial influence on the rate at which the RCS can depressurize.

Specifically, while the phases are engaged and under natural circulation through the coolant loops, gas and liquid are essentially in thermodynamic equilibrium. The net effect of this condition is that the break discharges at a higher mass and energy rate, which leads to a larger depressurization rate. While the phases are disengaged, gas and liquid are in thermodynamic non-equilibrium. If the phases are disengaged (but all other conditions remain the same), the break discharges at a lower mass and energy rate, which leads to a smaller depressurization rate.

The FLECHT-SEASET was a scaled integral experiment, which studied two-phase natural circulation through the RCS, including phase disengagement. For RCS configurations with inverted U-tube steam generators, phase disengagement occurred at a best-estimate void value of roughly 50%. However, there is significant uncertainty in this quantity. Sensitivity studies of MAAP with the PVNGS plant model showed that a value of VFSEP = 0.10 would disengage the phase early relative to the noted best-estimate value, leading to the noted slower depressurization rate, which is conservative for this analysis. This is demonstrated for the 3-inch LOCA in Figure 3-1. (Values below 0.10 did not result in significantly early disengagement.) Therefore, this value is used as a conservative bound, and it is paired with a corresponding value of VFCIRC = 0.05 for possible re-engagement, although re-engagement does not occur during this analysis.

[ ]

3.1.3.2 Post-LOCA Cooldown Methodology

The post-LOCA cooldown delay time and rate are roughly based upon a representative PVNGS simulator run [PVNGS, 2004b]. Herein, the delay time between LOCA initiation and cooldown initiation was roughly 720 seconds (12 minutes). A conservative value of 1500 seconds (25 minutes) was used in the analysis to maintain the RCS at an elevated pressure for a longer period. The cooldown rate in the simulator exercise was roughly 90 F/hr. However, there is not explicit guidance in the EOP's for a nominal cooldown rate, aside from the caveat to not exceed 100 F/hr. For standard industry practice encompassing both normal and emergency operations, a typical range is 30-100 F/hr. Given the 90 F/hr used during emergency operation on the simulator, a conservative value of 75 F/hr is appropriate for this analysis.

Another significant assumption within the cooldown methodology is the entry condition for the cooldown since this can influence the overall timing of the cooldown progression. The typical operator practice in post-LOCA cooldown is that, if any excess overpressure exists within the steam generators, the operator opens the turbine bypass (SDBCS) system to rapidly diminish the generators to a saturation pressure corresponding to the current core exit temperature. This removes excess energy from the steam generators, which may have been acting as a heat source to the primary system (depending upon the size of the break), and it readies the generators to act as a heat sink. At this point, the operator controls the SDBCS system to provide the core exit temperature with the desired cooldown rate noted above. The operator monitors and updates (if necessary) the SDBCS roughly every 10 minutes. (In the current MAAP analysis, this update is presumed to occur in a stepwise manner. If indeed the cooldown is determined to be more of a linear profile rather than a stepwise profile, then this can be easily changed, but ultimately this is a cosmetic consideration that has no bearing on the integral result.)

If during the update of the cooldown, the operator finds that the cooldown is occurring at a rate that is faster than the target rate due to the primary system fluid acting as a heat sink on the steam generator rather than a heat source (which can occur in some of the larger medium LOCA's), then it is assumed that the operator will not "chase" the primary system cooldown with the steam generator cooldown. Instead, it is assumed that the operator will scale back the

SDBCS in an attempt to slow the steam generator cooldown rate and attain the target rate. This assumption is consistent with operator training to maintain a rate of less than 100 F/hr to protect the primary system structure components (particularly the vessel) from rapid overcooling even if the primary fluid is cooling itself at a higher rate due to a medium-to-large break size. This methodology is also conservative for this analysis since it slows the primary system depressurization.

3.1.3.3 Post-RAS HPSI Status

[ ]

3.1.3.4 Post-RAS CSS Status

[ ]

[ ]

3.1.3.5 Post-RAS LPSI Status

As discussed in the background in Section 1, it is virtually impossible for LPSI to experience post-RAS degradation since post-RAS restart of LPSI is not automatic and must be done by remote operator action, which carries a substantial delay relative to the automatic switchover performed by HPSI and CSS.

Therefore, it is assumed that LPSI is available in post-RAS for RCS injection and, if necessary, containment spray and long-term containment heat removal through the containment spray heat exchangers. Even though both LPSI trains are available during post-RAS operation, it is conservatively assumed for this analysis that only 1 train is aligned for post-RAS injection, and no LPSI trains are used to assist contain spray and heat removal.

4.0 MAAP CASES

This section of the MAAP analysis report (and the corresponding section of the CENTS analysis report) is organized in terms of several case series, with each series devoted to a particular combination of major boundary conditions (break location, ECCS trains, HPSI availability, etc.). (The full scope of boundary conditions is provided in Section 3.) Specific results associated with a series are discussed as part of its presentation below.

An overall summation of the analysis highlights will be conducted in Section 5.

4.1 Series 1

This series is defined by the following boundary conditions:

- Break location: Cold leg discharge
- Break size: Break diameters of ½, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 inches
- At SIAS: 2 HPSI; 2 CSS; and 2 LPSI trains available
- At RAS: No HPSI; 2 CSS trains degraded to 25% of non-degraded flow; 1 LPSI to RCS; and 1 LPSI in reserve.

[ ]

~~PROPRIETARY~~
REDACTED VERSION

[ ]

[ ]

[ ]

4.1.1 Detailed Profile of the 3-Inch Case

A detailed profile is being provided for the 3-inch case in Series 2 since its break location is lower and therefore potentially more challenging than Series 1. A dedicated profile for the 3-inch case in Series 1 is not necessary since the same generic insights can be obtained from the profile in Series 2.

4.2 Series 2

[ ]

[ ]

4.2.1 Detailed Profile of the 3-Inch Case

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[

]

4.3 Series 3

This series is defined by the following boundary conditions:

[ ]

Core coverage and long-term core cooling are never vulnerable, which is expected since the corresponding HPSI failure cases showed no core uncovery.

4.4 Series 4

This series is defined by the following boundary conditions:

[ ]

[ ]

[ ]

[ ]

Core coverage and long-term core cooling are never vulnerable, which is expected since the corresponding HPSI failure cases showed no core uncovery.

4.5 Series 5

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

[ ]

5.0 MAAP ANALYSIS SUMMARY AND CONCLUSIONS

5.1 RCS Thermal-Hydraulic Performance

Key figures-of-merit are summarized for Series 1 cases in Table 5-1 and Series 2 cases in Table 5-2. The fundamental conclusion illustrated in these tables and discussed in detail in Section 4 is that core coverage is maintained without the use of HPSI for an extensive period between the time of RAS and the time of significant post-RAS LPSI flow, which provides long-term cooling. This is true for even the most challenging break sizes and conservative assumptions for key boundary conditions, particularly early RCS steam-water phase disengagement and a post-LOCA cooldown rate that is substantially less than the maximum allowable by emergency operating procedures.

[ ]

[ ]

[ ]

5.2 Containment Thermal-Hydraulic Performance

The MAAP containment analysis in Section 4 demonstrated that the 3-inch case is generally the most challenging break size since [ ]

[ ]

[ ]

As shown in Section 4, this results in a post-RAS pressure peak in containment that is largest for the 3-inch case. However, this peak is well within the containment design basis strength.

Thus, it can be concluded that, even for the overly conservative assumption of substantial CSS degradation, post-RAS long-term containment heat removal can be achieved.

6.0 NOMENCLATURE

ADV	Atmospheric Dump Valves
BAF	Bottom of Active Fuel
CENTS	Combustion Engineering Nuclear Transient Simulation Code
CSAS	Containment Spray Actuation Signal
CSS (or CS)	Containment Spray System
ECCS	Emergency Core Cooling System
EOP	Emergency Operating Procedures
EPRI	Electric Power Research Institute
FAI	Fauske & Associates, LLC
HLI	Hot Leg Injection
HPSI	High-Pressure Safety Injection
JPO	Justification for Past Operations
LOCA	Loss of Coolant Accident
LPSI	Low-Pressure Safety Injection
MAAP	Modular Accident Analysis Program
MUG	MAAP User's Group
PVNGS	Palo Verde Nuclear Generating Station
RAS	Recirculation Actuation Signal
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RWT	Refueling Water Tank
SDBCS	Steam Dump and Bypass Control System
SIAS	Safety Injection Actuation Signal

SIT	Safety Injection Tank
TAF	Top of Active Fuel
TMI-2	Three Mile Island Unit 2

7.0 REFERENCES

EPRI, 2003a, "MAAP4: Module Accident Analysis Program for LWR Power Plants," Computer Code User's Manual, May 1994 – January 2003 (Updated to MAAP 4.0.5 specification in January 2003).

EPRI, 2003b, "MAAP4: Module Accident Analysis Program for LWR Power Plants – Transmittal Document for MAAP 4.0.5," FAI/03-13, January.

Ferraraccio, F., 2005, "PVNGS MAAP and CENTS Evaluation Data," Westinghouse Letter LTR-PS-05-13 to Mark Radspinner (APS), dated February 10.

"Westinghouse
Letter LTR-PS-05-13.

Janke, M., 2004, e-mail from Westinghouse, "Boundary Conditions for Palo Verde Units 1 and 3 LOCA Analysis," to Christopher Henry (FAI), dated November 5.

"Boundary
Conditions for Palo V

PVNGS, 1992, "Palo Verde Probabilistic Risk Assessment, Section 11 Containment Analysis," Revision 0, dated April 7.

PVNGS, 2001, "Palo Verde MAAP 4.0.4 Parameter File," PVNGS Document No. 13-NS-C36, Revision 1, dated March 29.

PVNGS, 2004a, "Palo Verde Nuclear Generating Station (PVNGS) Units 1, 2, and 3 Licensee Event Report 2004-009-00 (Docket No. STN 50-528, 50-529, 50-530) (License No. NPF 41, NPF 51, NPF 74)," Letter 192-01154-DMS/RAS to the U.S. Nuclear Regulatory Commission, dated September 28.

"PVNGS Licensee
Event Report 2004-0

PVNGS, 2004b, "Simulator Scenario for 2.0" LOCA Cold Leg Break with Failed HPSI Pumps," November 9.

"Simulator
scenario.doc"

Thompson, D. P., 2005, Letter from Westinghouse to F. Ferraraccio (Westinghouse), dated February 8, 2005.

"Weir height hi res.pdf"

Westinghouse, 2004, "Containment Sump Line Fluid Inventory," Nuclear Safety Advisory Letter NSAL-04-7, dated November 15.

"FW NSAL Distribution Request

ATTACHMENT 2-E

DAR-OA-05-3, Revision 0
Report of SBLOCA Analyses with Degraded ECCS Flow After RAS Performed for Arizona Public Service in Support of Palo Verde Nuclear Generating Station Units 1, 2, and 3
~~(Proprietary)~~
REDACTED VERSION

WESTINGHOUSE ELECTRIC COMPANY LLC

DAR-OA-05-3
Revision 0

REPORT OF SBLOCA ANALYSES WITH DEGRADED ECCS FLOW AFTER RAS PERFORMED FOR ARIZONA PUBLIC SERVICE IN SUPPORT OF PALO VERDE NUCLEAR GENERATING STATIONS UNITS 1, 2, & 3

February 2005

Originator: see bottom of page Date: __________
Mark C. Janke,
Westinghouse Electric Company LLC

Technical Reviewer: see bottom of page Date: __________
Tyler Upton,
Westinghouse Electric Company LLC

Management Approval: see bottom of page Date: __________
Stephen P. Rigby, Manager Operations Analysis,
Westinghouse Electric Company LLC

Official record electronically approved in EDMS 2000.

Table of Contents

1.0 Background / Purpose

This report was prepared by Westinghouse Electric Co. for Arizona Public Service (APS) in support of Palo Verde Nuclear Generating Station (PVNGS) Units 1, 2 & 3 . This analysis is part of a project to determine the past operability of the PVNGS units with air in the Emergency Core Cooling System (ECCS) suction lines to the containment sump.

If a Loss of Coolant Accident (LOCA) were to occur with air in the ECCS pump suction line to the sump, it is postulated that the High Pressure Safety Injection (HPSI) pump operability could be compromised due to air binding in the pump volute. This is postulated to occur at the time of the Recirculation Actuation Signal (RAS), when the HPSI and containment spray pump(s) suction shifts from the Refueling Water Tank (RWT) to the containment sump.

Two different scenarios of HPSI pump degradation have been analyzed. In the first scenario, LOCA's of various break sizes are analyzed with complete failure of the HPSI pumps after RAS initiation. Since the Low Pressure Safety Injection (LPSI) pumps de-energize at RAS, the plant operator is assumed to restart one LPSI pump to maintain Reactor Coolant System (RCS) makeup flow, in accordance with plant emergency operating procedures. In the second scenario, the same LOCA transients are analyzed with degraded HPSI pump flow, for a duration of four minutes, after which the air in the pumps has been discharged into the system and pump performance is considered to return to normal. For this second scenario, there is no operator action to restart a LPSI pump. The degraded HPSI flow condition is based upon pump performance tests performed for this project at Wylie Corporation which is documented in an APS letter to the NRC, # 102-05195-GRO/DGM/RAS, dated 12/27/2004.

Since this analysis is intended to look at past operation, best estimate conditions are assumed. This analysis is in no way considered to be part of the PVNGS licensing basis nor has it been performed to satisfy any requirements of 10CFR50.46.

The purpose of this report is to describe any detrimental effects (core uncovery) that occur or are exacerbated by the HPSI pump degradation (total loss of operability and / or degraded operation) during various small and medium break size LOCA events.

Break sizes of 1 to 10 inches in diameter are analyzed in both the cold discharge leg (CDL) and the Reactor Coolant Pump (RCP) Suction Leg (SL). Breaks smaller than one inch are not analyzed because they do not cause a Containment Spray Actuation Signal. Thus, sprays pumps are not needed and the time to RAS is sufficiently long to allow a plant cooldown and shift to shutdown cooling. For these small breaks, pressurizer level is regained without RCS water levels dropping below the level of the hot legs. Breaks greater than 10 inches in diameter are not analyzed because RCS pressure is well below the LPSI pump shutoff head at the time of RAS. Therefore, flow from the LPSI pump, restarted by the operator after RAS, is greater than normal HPSI pump flow from two pumps. Thus, break sizes greater than 10 inches in diameter are not considered limiting. Only the two cold leg break locations are analyzed because any breaks in the hot leg would allow venting of steam produced in the reactor core directly to the containment, without need for loop seal clearing or draining. RCS depressurization occurs without depressing water level below the top of the core. Thus, cold side breaks are limiting regarding core uncovery. A sensitivity case with a break in the pressurizer was performed to verify the limiting nature of cold leg breaks.

This report was prepared according to Westinghouse Procedure WP 4.25, Rev. 2, 11/30/04, and is supported by Westinghouse Calculation Note CN-OA-05-1, Rev. 0, dated 02/11/05.

2.0 Code Description

The Westinghouse CENTS computer code has been utilized for this analysis. CENTS is an interactive, best-estimate simulation computer code that calculates the transient behavior of a PWR for plant maneuvers, accidents and operator actions, in a wide range of variations in plant state, from steady state to severe upsets, as well as lower mode operation at mid-loop.

A modular node-flowpath network models the primary system thermal-hydraulics. Within each node, the model supports full thermal non-equilibrium, local pressures and thermodynamic properties, phase separation, bubble generation, flow regime dependent steam condensation, and transport dynamics of non-condensable gases, boron and radio-nuclides. A point kinetics model receives reactivity feedbacks from moderator, fuel, boron and rods, and an input axial shape. The core heat transfer model employs boiling curves over the full range of conditions, and calculates axial/radial temperature distributions in the fuel rod.

The primary sides of the steam generators (SGs) have detailed representation of the thermal profiles, accounting for forward and reverse heat transfer from relevant correlations. The coolant levels and their effect on the fluid state, heat transfer area and heat flux are modeled on both the primary and secondary sides. The secondary system representation provides sufficient detail for accurate modeling of the recirculation phenomena and the downcomer and evaporator water levels.

A modular control system provides for generic definition of control logic for scram channels, rod control, emergency safety signals, primary and secondary system relief and makeup, and ancillary systems. Detailed control systems are designed via input from modules that perform standard arithmetic, integral-differential and logical transforms.

The origin of CENTS is the SBLOCA code, CEFLASH-4AS. CENTS is the RCS model set for several full scope simulators, including the NRC simulator for the CE 2700 Mwt design plant. It has since been licensed by the USNRC for Chapter 15 (non-LOCA) safety analyses of PWRs designed by CE and Westinghouse. There is an SER limitation placed on the code when used for referencing in licensing actions with respect to the calculation of transient behavior. It states that due to a lack of benchmarking provided in the topical report, that CENTS should not be used for LOCA licensing analysis for demonstrating compliance to 10CFR50.46 criteria. Nor shall it be used for severe accident analysis. However, it is acceptable for use in modeling small breaks for non-regulatory acceptance criteria. (Note that small breaks are usually defined to be approximately 1.0 ft^2 or less)

The analysis performed with CENTS in this report meets the above limitation, in that this is considered a best estimate analysis that is not used to assure compliance with 10 CFR 50.46 criteria. Nor is the code being used to define core temperature conditions to ascertain if severe accident conditions exist.

A modification was made to the CENTS code to provide a loop seal model for the RCP suction lines. This was considered appropriate for this analysis because timing of the loop seal clearing for the cold discharge leg breaks is important in determining RCS pressure response and core two-phase level at the time that loop seal clearing occurs. In support of the loop seal model added to the code, the PVNGS base deck configuration was re-nodalized in the suction leg regions to employ two nodes for each suction leg from the steam generator to the RCP.

As a check on the CENTS loop seal model design, benchmark cases were run against an analysis performed with the CEFLASH-4AS REM code, a Westinghouse best estimate SBLOCA code. These benchmark cases were performed for the Waterford -3 plant, which is a CE design PWR of similar size, power level and loop seal design to that of the PVNGS Units. Three inch CDL and SL breaks were analyzed for this benchmark. The transient attributes of interest in the benchmark were the behavior of the loop seal (i.e. the timing of the loop seal clearing and its affect on break flow and enthalpy) and the overall RCS pressure and core level during the transient. The benchmark showed that the behavior of the loop seal model was in good agreement between the two codes. This supports the acceptability of the loop seal modeling modifications made to the CENTS code.

3.0 Case Descriptions & Input Parameters

3.1 COMMON INITIAL CONDITIONS AND PLANT PARAMETERS

3.1.1 Initial Plant Conditions

The initial plant conditions are identical for all cases and represent nominal full power parameters.

- Core Power Level: 100% (3876 Mwt)
- Core Inlet Temperature: 553°F
- Pressurizer Pressure: 2250 psia
- Core Flow: 45500 lbm/sec
- Pressurizer Level: 21.2 ft
- Steam Generator Level: 37.3 ft
- Feedwater Enthalpy: 408.4 BTU/lbm

3.1.2 ECCS Parameters

The initial ECCS conditions and assumptions are the same for all cases except the sensitivity cases. These parameters are as follows.

[ ]

[ ]

3.2 BREAK PARAMETERS

[ ]

3.3 CORE DECAY HEAT

[ ]

3.4 CONTAINMENT SPRAY PUMPS

[ ]

3.5 OPERATOR ACTIONS

Operator actions are in accordance with the APS emergency operating procedures. In particular, the Loss of Coolant Accident Procedure [ ], was used to determine the simulated operator responses to the transient. The actions taken are similar for all the cases analyzed, though the timing of some actions is different for each case. The actions are summarized as follows:

- **Secure two RCPs 5 minutes after reactor trip.** The "Trip 2 - Leave 2" strategy is based upon step 7 of the procedure.

- **Secure all RCPs if subcooling is <24°F.** This action is also based upon step 7 of the procedure. The initial waiting period of 5 minutes for securing RCPs is based upon the time for operator diagnosis of the situation.

- **Cooldown the plant to Shutdown Cooling Entry conditions.** This is assumed to start at 1500 seconds, based upon a reasonable delay for the plant operator to assess the situation and take immediate post trip actions, etc. This is based upon step 22 of the procedure. An aggressive cooldown rate of 90°F/hr is assumed. It is assumed that the operator uses the core exit temperature at 1500 seconds as the starting point. Thereafter, the operator will not perform any action to exceed the 90°F/hr rate. Note that for many of the cases analyzed, particularly the larger breaks, the cooldown rate may greatly exceed the procedural limit of 100°F/hr due to energy loss out the break and not due to operator action. In this case the operator is only cooling the steam generator secondary by relieving steam through the automatic dump valves, but this does not affect the RCS cooldown, as long as steam generator secondary temperature is greater than RCS temperature. [Note that the actual cooldown rate setpoint used in the CENTS code controllers was set at 85°F/hr since the controllers simulate action by the operator every 300 seconds. Since there is this set frequency of action, 85°F/hr is conservatively used to help assure that 90°F/hr is not exceeded for certain time intervals.]

- **Secure 1 of 3 Charging Pumps when RWT level approaches 50%, secure a second Charging Pump at 40% RWT level and secure the third pump at 30% RWT level.** This is based upon step 48 of the procedure.

- **When RAS occurs, if both HPSI pumps completely fail, it is assumed that the operator will re-start a LPSI Pump.** This is based upon functional recovery guidelines to maintain a source of reactor makeup water. In the cases of this analysis, re-starting a LPSI pump is assumed to occur as soon as the HPSI pumps are lost. For those cases where the RCS pressure is below the LPSI shutoff head, this means flow is never lost. If RCS pressure is above the LPSI shutoff head as it is for the smaller break sizes, then ECCS pump flow ceases till pressure drops.

3.6 SENSITIVITY CASES

Seven sensitivity cases have been analyzed to support this analysis. The sensitivity cases are intended to show the effects on overall case acceptability for those parameters which play an important role in the transient and could vary in some significant way from the values chosen for the various series of cases. Details are discussed below.

[ ]

4.0

[ ]

5.0 Case Results

[ ]

[ ]

[ ]

[ ]

5.2 DISCUSSION OF INDIVIDUAL CASE RESULTS

In the discussion below, the failed HPSI and degraded HPSI cases are discussed together. Prior to RAS these cases are identical. After RAS, it is useful to compare how the relative ECCS flows affect the remainder of the events.

A review of the figures showing ECCS flow provides some perspective on the overall effect of degraded HPSI flow for four minutes, after RAS. As an example, for the [ ] CDL break with degraded HPSI, Figure 7.2.3.3 shows the ECCS flow. RAS occurs shortly after [ ] seconds. A visual review of the degraded HPSI flow indicates that the depleted flow is a very small portion of the integrated flow over the course of the event. It would be expected to have very little effect on event results. This fact is supported by the Sensitivity case [ ] which show that nominal vs. degraded HPSI flow does not significantly change case results.

[ ]

5.2.1 Series 1 & 2 Cases: Cold Discharge Leg (CDL) Breaks

CDL -1

[ ]

[ ]

5.2.2 Series 3 & 4 Cases: Suction Leg (SL) Breaks

[ ]

[ ]

5.2.3 Series 5 Cases: Sensitivity Cases

[ ]

[

]

5.3 CASE SUMMARY

[ ]

6.0 Conclusions

The series of cases described above show that degraded HPSI flow caused by the air in the ECCS sump suction line will not lead to situations where core uncovery would occur. Two cases with total HPSI pump failure at RAS led to some partial core uncovery for an extended period of time, due to a depletion of RCS inventory. Those were the 3" and 4" CDL breaks. **There were no cases with degraded HPSI pump flow which had any partial core uncovery associated with the degraded ECCS flow.**

There were some additional cases, both failed and degraded HPSI flow cases, that showed short periods of partial uncovery due to loop seals filling and clearing; however, this phenomenon is expected for both CDL and SL breaks and is not due to the degraded flow in the ECCS system. This was verified by Sensitivity Case 7.

7.0 Figures

7.1 SERIES 1: CDL BREAKS, FAILED HPSI AFTER RAS

7.1.1 CDL-1

[ ]

[ ]

7.1.2 CDL-2

[ ]

[ ]

[ ]

7.1.3 CDL-3

[ ]

[ ]

[ ]

7.1.4 CDL-4

[ ]

[ ]

7.1.5 CDL-5

[ ]

[ ]

7.1.6 CDL-6

[ ]

7.1.7 CDL-7

[ ]

7.1.8 CDL-8

[redacted]

7.1.9 CDL-9

7.1.10 CDL-10

7.2 SERIES 2: CDL BREAKS, DEGRADED HPSI AFTER RAS

7.2.1 CDL-1 DH (Case not Required)

7.2.2 CDL-2 DH (Case not Required)

7.2.3 CDL-3 DH

[ ]

[ ]

7.2.4 CDL-4 DH

[ ]

[ ]

7.2.5 CDL-5 DH

[ ]

[ ]

7.2.6 CDL-6 DH

[ ]

7.2.7 CDL-7 DH

[ ]

7.2.8 CDL-8 DH

[ ]

[ ]

7.2.9 CDL-9 DH

[ ]

7.2.10 CDL-10 DH

[ ]

7.3 SERIES 3: SL BREAKS FAILED HPSI AFTER RAS

7.3.1 SL-1

[ ]

[ ]

[ ]

7.3.2 SL-2

[ ]

[ ]

7.3.3 SL-3

[

]

[ ]

[ ]

[ ]

7.3.4 SL-4

[ ]

[ ]

[ ]

7.3.5 SL-5

7.3.6 SL-6

[ ]

[ ]

7.3.7 SL-7

[ ]

7.3.8 SL-8

[ ]

[ ]

7.3.9 SL-9

7.3.10 SL-10

7.4 SERIES 4: SL BREAKS, DEGRADED HPSI AFTER RAS

7.4.1 SL-1 DH (Case not Required)

7.4.2 SL-2 DH (Case not Required)

7.4.3 SL-3 DH

[ ]

7.4.4 SL-4 DH

[ ]

7.4.5 SL-5 DH

[ ]

[ ]

7.4.6 SL-6 DH

[ ]

7.4.7 SL-7 DH

[ ]

7.4.8 SL-8 DH

[ ]

7.4.9 SL-9 DH

[ ]

7.4.10 SL-10 DH

[ ]

[ ]

7.5 SERIES 5: SENSITIVITY CASES, FAILED HPSI AFTER RAS, 2" SL BREAK

7.5.1 SL-2 75F CD

[ ]

[ ]

7.5.2 SL-2 1 HPSI

[ ]

[ ]

7.5.3 SL-2 SIT Gamma = 1

[ ]

7.5.4

[ ]

[ ]

7.5.5

[ ]

[ ]

7.5.6 CDL-6

[ ]

7.5.7 CDL-8

[ ]