UNITED STATES
NUCLEAR REGULATORY COMMISSION
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December 15, 2005

James M. Levine, Executive
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SUBJECT: PALO VERDE NUCLEAR GENERATING STATION - REVISED REDACTED VERSION OF RESPONSE TO INFORMATION REQUEST DATED FEBRUARY 10, 2005

Dear Mr. Levine:

Arizona Public Service (APS) Company's letter (102-05195-GRO/DGM/RAS) and affidavit dated February 10, 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 to the letter be withheld from public disclosure pursuant to 10 CFR 2.390. At the request of the NRC staff, APS provided Enclosure 3 to the February 10 letter, a redacted version of this submittal that was suitable for public release. The redacted version of the submittal was subsequently posted on the NRC's public website (ADAMS accession number ML05040342).

We have carefully reviewed both the original February 10, 2005, letter and the redacted enclosure. 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). Attachment 1 to this letter provides a revised redacted version of the February 10, 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 Mr. Gregg Overbeck in an NRC letter dated on May 31, 2005, (ML0515205020) 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,

Gregory [illegible] for

Troy W. Pruett, Chief
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Division of Reactor Projects

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ENCLOSURE 3

Redacted Response to Information Request in NRC Special Inspection Report 05000528/2004014; 05000529/2004014; 05000530/2004014

(Non-Proprietary Version)

Response to Information Request in NRC Special Inspection Report 05000528/2004014; 05000529/2004014; 05000530/2004014 (Non-Proprietary Version)

In NRC Special Inspection Report 05000528/2004014; 05000529/2004014; 05000530/2004014, dated January 5, 2005, the NRC requested additional information regarding the preliminary results of pump testing, associated analyses, and preliminary assessment of the safety significance of the Emergency Core Cooling System (ECCS) voided suction piping condition as submitted to the NRC in letter dated December 27, 2004. The additional information is provided below. Arizona Public Service Company (APS) will submit a comprehensive final report containing a description of the final results of the tests and analyses performed, and our final assessment of the safety significance prior to the Pre-decisional and Regulatory Enforcement Conference scheduled for February 17, 2005.

NRC Question 1

{Provide} a comprehensive account of the differences between the as-found configuration of the affected systems and the test configurations, including but not limited to the differences in components, process parameters, system operation and control, power usage, indications and environmental conditions.

APS Response

In order to determine the safety significance of this condition, the air volume fraction that could be ingested by the high pressure safety injection (HPSI) and containment spray (CS) pumps, needed to be determined. Once the air volume fraction was determined, each pump's tolerance for the projected air ingestion was assessed and ultimately the impact on the ECCS safety functions.

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 inlets. The impact on pump performance was then assessed via full-scale testing, given the projected air/fluid conditions.

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

The 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. [.][1] These results established the inlet conditions for the subsequent full-scale pump performance tests.

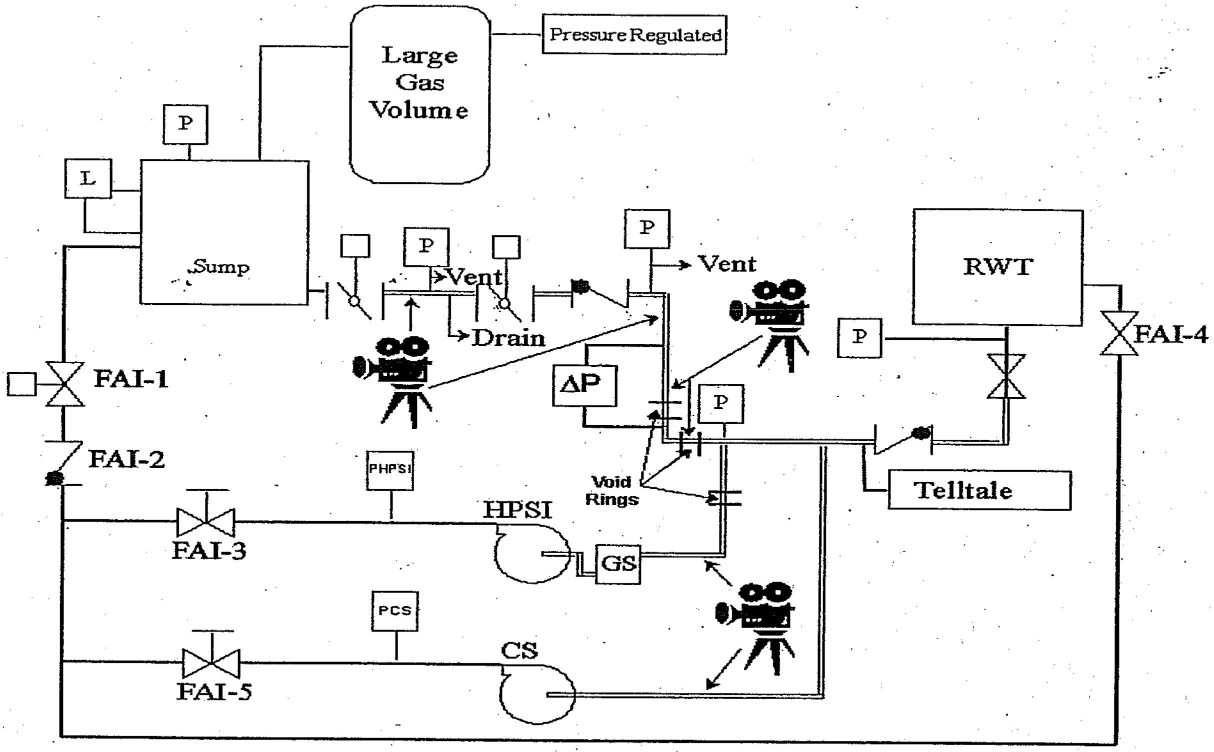
Full-scale pump tests were performed at Wyle Labs utilizing a spare Palo Verde HPSI pump and a representative CS pump to determine the impact on pump performance under the projected air ingestion conditions. [.][1]

Differences between Plant and Phase I and II Scale Model Tests

The purpose of the first phase was to demonstrate the ability to simulate the transient and measure the important parameters such as [, pressure, and flow rate][1]. For the purpose of this response to NRC Question 1, the first phase of testing need not be considered since it was a prelude to and is encompassed by the second phase of testing.

The Phase 2 test facility was composed of two tanks with water inventories (the simulated containment sump and RWT), centrifugal pumps, piping, valves, a gas separator for the HPSI suction line and associated instrumentation as indicated in the following figure:

[



][1]

The piping and valves from the upstream isolation valve, the downcomer piping as well as the pump suction header were all 4 inch in diameter and fabricated from clear plastic to facilitate observation of the initial air inventory and its behavior during the opening of the MOVs. The major differences between the plant and the Phase 2 test loop can be categorized into five areas:

1. Differences in size (geometric scaling affects)
2. Differences in geometrical scaling in different sections of the loop
3. Differences in process parameters
4. Differences in components
5. Differences in operation and control

Differences in Size (geometric scaling affects)

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. Thus, the balance of the suction line pipe lengths and valve locations also used a 1/6th scale unless there were other considerations that took precedence [

][1] (Schedule 40). As a result, linear segments in the horizontal and vertical test elements were dimensioned to be approximately 1/6th of those dimensions that apply for the plant (see Table 1). Thus, the scaled test configuration simulates the sump suction lines in all three Palo Verde units. The affect and implications of differences in geometrical difference between the plant and the test loop (i.e., scaling affects) are covered in detail in the response to NRC Question 4.

Differences in Geometrical Scaling in Different Sections of the Loop

Previous Phase 1 and Phenomenological Tests showed that it was important for the vertical downcomer to have a downward velocity like that of the plant [

] The basis and implications of these differences are also discussed in the response to NRC Question 4.

There were also some minor differences in geometrical scaling due to the fact that it was not possible to procure the PVC pipe used in the test loop in the exact relative proportions as existed in the plant. 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. In the plants, the HPSI pump suction lines are 10 inch diameter pipes so the 1/6 scale branch line used 1.5 inch diameter (Schedule 40) pipe. Similarly, the CS pump suction branch is 18 inch diameter so the 1/6 scale branch line used 3 inch diameter (Schedule 40) pipe. Table 1 shows the actual plant pipe inside diameters, the Phase 2 test pipe inside diameters, and the ratio between the test and plant.

Table 1
Comparison of Plant and Phase 2 Pipe Diameters

	Plant	Phase 2	Ratio
Sump Common Supply Line	22.876 inch	4.026 inch	0.176
CS Pump Suction	17.376 inch	3.068 inch	0.177
HPSI Pump Suction	10.25 inch	1.61 inch	0.157

The minor difference in ratio for the HPSI pump suction relative to the Sump common supply and the CS pump supply could not be avoided and did not affect the results of the Phase 2 test. [

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Differences in Process Parameters

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In addition, there were differences in fluid temperature between the plant and Phase 2 loop. Since the Phase 2 test model was constructed primarily of clear plastic piping, the Phase 2 testing was performed under cold conditions whereas the postulated post-accident conditions include some high temperature cases. The affect of this difference in process parameter is discussed in detail in the response to NRC Question 2.

Differences in Components Comprising the System

There were some differences in the components comprising the plant system versus the Phase 2 test. The pumps used in the Phase 2 test were single stage horizontal pumps as compared with the multi-stage horizontal HPSI pump and the single stage vertical CS pump used in the plant. However, the purpose of the Phase 2 test was to maintain the properly scaled parameter [ ] in the loop. The Phase 2 testing did not investigate pump operability. Therefore, the differences in pumps between the test and plant are of no consequence.

[

]

The Phase 2 test modeled the RWT and Sump but did not model the reactor coolant system. [

]

Differences in Operation and Control

There were some minor differences in operation and control of the Phase 2 test loop resulting from the differences in components between the plant and test loop. The Phase 2 test loop did not model the reactor coolant system. When the pumps were operating with suction from the RWT their discharge was also routed to the RWT. This simplified inventory control and allowed the chosen initial conditions for each test to be maintained indefinitely. In the plant the RAS is generated by low level in the RWT. In the Phase 2 test, the initial conditions of the test included the pumps discharging back to the RWT. Therefore, RWT inventory was maintained and the RAS was manually initiated by the test operator in the Phase 2 loop.

The following test procedure was used during the Phase 2 test.

I. Pre-Conditions and Safety Checks

  A. Confirm initial conditions have been established, i.e. pressure and water levels in each tank, pump running on recirculation to RWT tank, horizontal segment voided, and vertical segment water filled.
  B. Assure data collection system is ready, instrumentation is operating, and power for three motor operated valves is available.
  C. Assure safety precautions are in place. All test personnel and observers should have proper eye protection.

II. Testing

  A. Establish applicable initial and test conditions per test matrix.
  B. Assure sump recirculation isolation valve (FAI-1) is open and the check valve (FAI-2) is closed.
  C. Start digital movie cameras.
  D. Start data collection.
  E. Start butterfly valves opening (initiate RAS).
  F. Confirm closure of check valve in pump supply line from RWT.
  G. [ ]
  H. Collect data and observe flow behavior.
  I. Stop data collection.

Step I.A of the above procedure starts the test with the pumps running on recirculation to the RWT. Step II.B of the above procedure ensures that the sump recirculation valve (FAI-1) is open and the check valve (FAI-2) is closed. Therefore, the pump discharge is aligned to both the RWT and sump. However, the initial pressure in the sump prevents the pump from discharging into the sump. The RAS is initiated in step II.E of the procedure. This causes the check valve in the pump supply from the RWT to automatically close as confirmed in step II.F. [

]

.][1]

Differences between Plant and Phase 3 Test

The Phase 2 testing identified the air volume fraction to the suction of the CS and HPSI pumps as a function of time for each case included in the test matrix. Therefore, since the purpose of the Phase 2 testing was to predict the rate of air transfer to the pump suction, it was necessary to model the physical layout of the plant, system process parameters, and system operation during the test. The Phase 2 test results were then used to define the full scale Phase 3 pump tests to determine the affect of the voided pump suction conditions on pump performance and the ability of the pump to withstand the voided conditions. As such, the Phase 3 tests were component level tests instead of system level tests. [

.][1] The Phase 3 tests were not intended to replicate the plant system operations following a RAS. The objective of the test was to determine the impact of the fluid air volume fraction on pump performance.

The actual plant pipe diameter and layout were duplicated in the Phase 3 test from the air injection point to the suction of the HPSI and CS pumps. [

][1]

[The Phase 3 test was designed to duplicate the static pressure at the suction of the pumps. The full range of actual plant flow rates expected during post-accident operation following a RAS were bounded by the flow rates used during the Phase 3 test program.][1] Based on the results and evaluations of the Phase 2 testing, no attempt was made to perform testing with elevated water temperatures which may exist during the initiation of post-accident operation following a RAS; the Phase 3 testing utilized water at ambient temperature. Although the Phase 3 testing facility had the capability to allow testing at an elevated temperature, this would have introduced a disconnect between the Phase 2 and Phase 3 test conditions. [

.][1] These affects were all accounted for in the Phase 2 tests and therefore, it was important to maintain consistency between the two sets of tests. The implications of increased sump temperature are discussed in more detail in the response to NRC Question 2.

The Phase 3 testing used a storage tank to supply water to the pumps. In order to facilitate inventory control during the test, the pumped fluid was recirculated to the tank. [

] The purpose of the test was to quantify the pump performance under various voided conditions. The results of the Phase 3 testing were then used to analytical predict the ability of the pump to inject water into the reactor coolant system at conditions calculated to exist following post-accident operation. This is discussed further in the response to NRC Question 4.

NRC Question 2

An assessment of these differences, including the bases, relative to any final conclusions that you may reach regarding system operability and the risk significance of the voided conditions that actually existed.

APS Response

Assessment of the impact of minor differences between actual plant configuration and conditions and those utilized in the scale model and full scale pump tests are contained within the response to NRC Question 1. For these minor differences, APS has concluded that the differences have either no impact on our final conclusions, or that the differences result in conservative test results. Therefore, APS response will be provided in the context of the following aspects of the testing and analysis program:

1. The influence of sump temperature on over-all conclusions,
2. An overall assessment of conservatism within the testing and analysis program, and
3. An overall assessment of APS' conclusions regarding system operability and risk significance.

The Influence of Sump Temperature

As discussed in the response to NRC Question 1, it was not possible to perform the scale model tests at high temperatures such as could be encountered during actual accident conditions. Furthermore, it was determined that performance of the Phase 3 pump performance tests at high temperatures could not be performed in a manner that, when combined with air injection near the pump inlet (the primary purpose of the Phase 3 pump tests), would produce prototypical plant conditions. It was also judged that high temperature testing would also introduce a disconnect between the scale model tests and the full scale pump performance tests. Instead, an engineering approach was utilized to evaluate the influence of high sump temperatures.

During an actual plant accident involving a RAS, the sump water temperature entering the air volume is a function of the accident conditions. [ ]

[

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[

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Overall Assessment of Conservatism within the Testing and Analysis Program
Other conservative aspects of the scale model and full-scale pump testing program j more than compensate for any potentially non-conservative prediction of peak air volume fraction delivered to the pump inlets that may result from the inability to perform the scale model tests at high temperatures. Some of the major conservatism, and the impact on test results, are discussed below:

1. [

]

[

]

2. <u>Use of smaller [ ]:</u>
   As discussed in detail in the response to NRC Question 4, a [

   ]

3. <u>Use [ ] and air injection:</u>
   For most of the scale model tests, a [ ] was installed in the HPSI suction line upstream of the HPSI pump. It behaved as intended and [

   ] The important results from the scaled experiments are the extent of gas intrusion into the HPSI and CS pump suction lines immediately following the opening of the two butterfly valves. The results from these scaled experiments were used to develop the gas intrusion histories used in the full scale evaluations of the HPSI and CS pump performances. While this information can be characterized in a number of different ways, such as void fraction, flow regime, gas mass flow rate, etc., the most meaningful representation for full scale systems was to develop (1) a conservative characterization of [ ] and (2) the flow regime existing in the suction line as this occurs.

[

]

[ ] For the plant system under accident conditions, air transported through the HPSI line could degrade the pump performance and cause a decrease in the flow rate being pumped, which decreases the HPSI suction flow rate thereby reducing the rate of air intrusion. With these considerations, it is clear that the air mass flow rate deduced from these scaled experiments with [ ] provides a conservative representation of the plant response for an accident condition.

[

]

4. <u>Prolonged exposure to peak [ ]:</u>
In the Phase 2 scale model tests, the [

], as illustrated in the following figures (figures are for a series of tests for a 1310 gpm equivalent HPSI flowrate. All tests results are similar in this regard).

[

]

[

]. Again, the resulting test of the pump's tolerance for air ingestion is judged to be much more severe than would have been experienced in the actual plant.

Overall Assessment on APS Conclusions Regarding System Operability and Risk Significance

As described in the preliminary report dated December 27, 2004, it is concluded that for all reactor coolant system (RCS) break sizes equivalent to [2" in diameter or greater], the HPSI pump would have experienced a temporary reduction in developed head and flow but would have continued to operate without failure or air binding. At some break size [

.][1]

From the discussion in the preceding sections of the response to NRC Question 2, Palo Verde's assessment is that the sum total of the differences between the test conditions and configurations and the corresponding plant conditions and configurations results in an overall conservative prediction of the conditions that would have been experienced at the plant, specifically with respect to the air ingestion rates that would have been experienced by the ECCS pumps. Accordingly, the conclusion that the HPSI pumps would have continued to function throughout the course of the accident following receipt of the RAS, for break sizes corresponding to [2 inches in diameter and larger][1], is a conservative conclusion.

In the Palo Verde Probabilistic Risk Assessment (PRA) model changes made to incorporate this conclusion and determine the corresponding increase in total risk, it was assumed that the HPSI pump would remain functional for [all medium and large][1] break Loss of Coolant Accidents (LOCAs). Since the break size that represents the boundary between [ ][1] in diameter [( )][1], additional conservatism is introduced. With this assumption, the risk significance is considered to be very conservative.

NRC Question 3

{Address} any differences between the predicted test results and the actual tests results.

APS Response

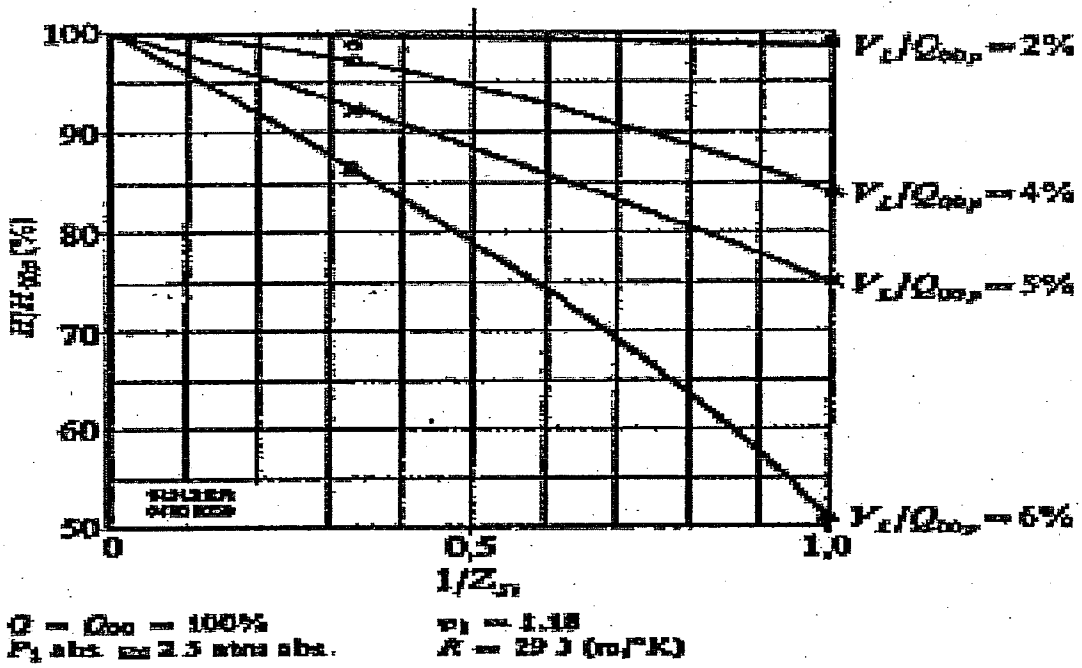
APS did not attempt to predict the results of any of the scale model or full scale tests. It was well understood that the phenomenology involved was complex. In general, APS had only three expectations that the tests would demonstrate:

1. The air in the originally voided sections of piping would be swept out of this horizontally oriented piping and would not self-vent back into containment. This expectation was based on the initial evaluation of the voided condition performed upon its discovery by the Palo Verde engineering staff. This evaluation concluded that the flow velocity in this section of piping would be sufficient for the pipe to run full and was based on correlations presented in the industry literature in Reference 1. [As described in the December 27, 2004 preliminary report, results of the scale model tests were consistent with this expectation.][1]

2.

3. [The 8-stage HPSI pump would be more tolerant of air ingestion, from a hydraulic standpoint, than single stage pumps for which most of the data available in the literature are based on. This expectation was developed based on review of Reference 2, which is the only recorded report of tests or information for multi-stage pumps under air ingestion identified during an extensive literature search. This report is also cited as Reference 32 in NUREG/CR-2792 (Reference 3). The following figure is a reproduction of Figure 4-8 from NUREG/CR-2792. As reported in this NUREG, performance degradation for a multi-stage pump is much less pronounced than for single-stage pumps. The author of the test report attributes this to the fact that air is raised to a higher pressure (i.e., compressed) at each stage and has progressively less effect on the performance of the next stage.][1]

[



8 Influence of number of stages Z_{st}.

The above figure provides reported performance degradation, in terms of developed head, for a single stage pump (1/Z=1/1=1) and for a 3-stage pump (1/Z=.33). As illustrated, pump degradation is much less for the 3-stage pump. The 8-stage HPSI pump (1/Z=.125) would be expected to experience even less degradation.

][1]

It is noted that this expectation was based on hydraulic performance only. Neither APS nor the pump vendor had data or information regarding the pump's tolerance from a mechanical standpoint. [

][1]

References for Response to NRC Question 3:

1. 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.

2. [

][1]

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

NRC Question 4

{Provide} a more comprehensive discussion on the scaling factors used to establish the test conditions for the full scale pump tests (e.g., system resistance).

APS Response

The following response is provided in three parts:
1. Fluid dynamic scaling,
2. Geometrical, volumetric, mass and time scaling, and
3. System resistance.

Horizontal Sump Exit Piping
In this horizontal orientation, the principal scaling parameter has been well established previously (e.g., references 1 & 4) to be the Froude number which is a ratio of the inertial and buoyancy forces:

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

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][1]

[

- ρ_w is the water density

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

$$N_{Fr} = \frac{U}{\sqrt{gD}}$$

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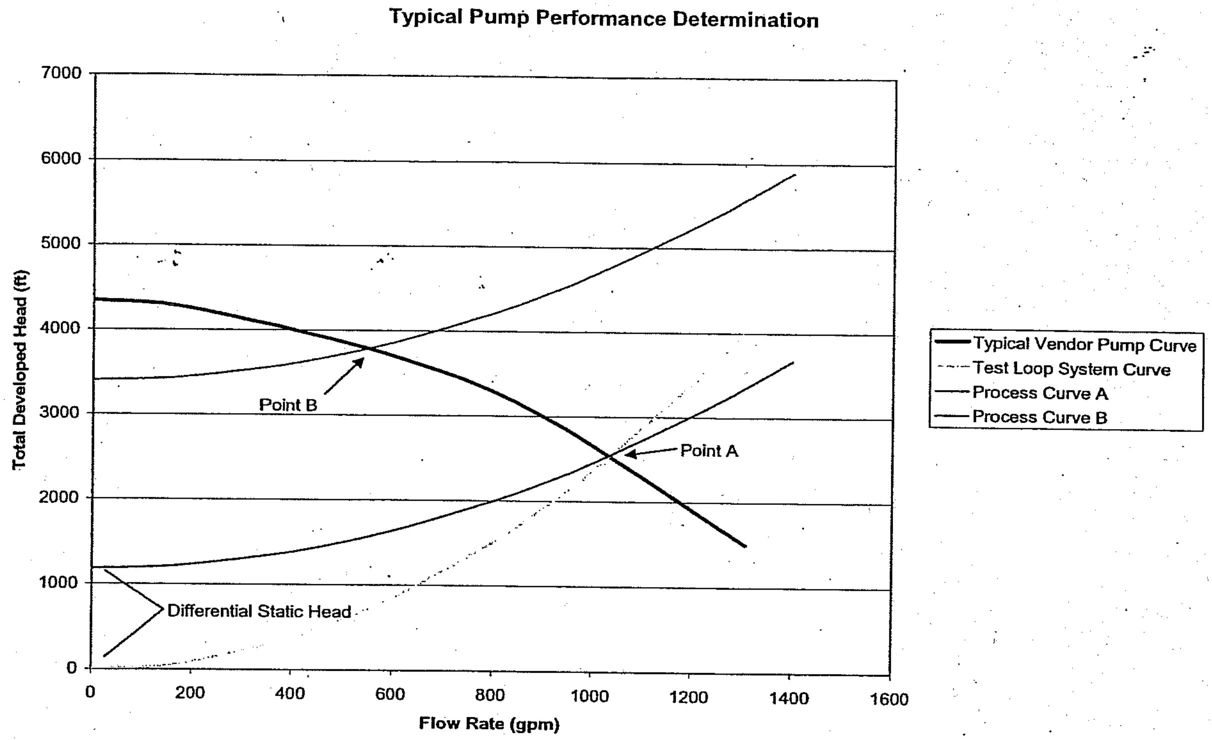

As illustrated in the above figure, the pump's performance (developed discharge head and flowrate) is determined by varying the system resistance, usually by setting the position of a throttle valve on the discharge of the pump. The result is a test loop system curve like the yellow line in the above figure. For any centrifugal pump, its performance at a particular system resistance will be set at the intersection of the system curve and the pump curve. For this example, point A represents the pump's performance in a test loop at a representative point corresponding to a certain position of the discharge control valve. Varying of the position of the throttle valve by opening or closing the valve will decrease or increase the concavity of the parabolic shape of the example test loop curve, maintaining the same zero intercept. There is little or no static head component to the system curve since in most test loops the suction and discharge sources are the same. When placed in a process system, however, the pump's performance will be determined by the intersection of the process system curve and the pump curve. The process system curve may involve other elements in addition to system resistance. Two examples are illustrated in the above figure. The blue line (Process Curve A) would occur by a case in which a combination of differential static head and system resistance combine to produce an intersection with the pump curve at the same point as in the test loop. The system curve can be analytically developed using Bernoulli's extended energy equation. For the example illustrated by the blue system curve, the pump will produce the same developed head and flow rate as it did in the test loop, even though the system resistance in the process system is different than in the test loop.][1]

[The green line (Process Curve B) illustrates what happens when the same pump operates within a system with greater static head (e.g. due to increased system back pressure). Again, the intersection of the system curve with the pump curve (Point B) determines the pump performance. In this example, the pump would develop greater discharge head but less flow rate. The example illustrates how a pump's performance can be determined for process systems that have no relationship in terms of system resistance to that with which the pump was originally tested under. For the system being considered, the required variation in pump performance is the sole result of variations in static head with a fixed system resistance.

Degraded Pump Performance

The process for determining how a degraded pump would perform, in a process system in which the system resistance is different than that in which the pump performance tests were conducted, is essentially the same as discussed above for a typical centrifugal pump. A degraded pump curve was developed by measuring the developed head and flowrate of the pump at several different test loop system resistance conditions, as illustrated in the following figure.

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[

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[

3. Wallis, G. B., 1969, One-Dimensional Two-Phase Flow, McGraw-Hill Book Company, New York.

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]1

Additional NRC Question 5

Address any potential negative impacts stemming from water hammers.

APS Response

The ECCS voided piping condition did not present any negative impacts stemming from waterhammer. Numerous analyses and experiments have been performed to evaluate the influence of air in a system during a strong hydraulic transient such as a pump start (Chaiko and Brinckman, 2002 (reference 1), Lee and Martin, 1999 (reference 2), and Martin, 1976 (reference 3)). As stated by Martin:

> *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 run out 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.

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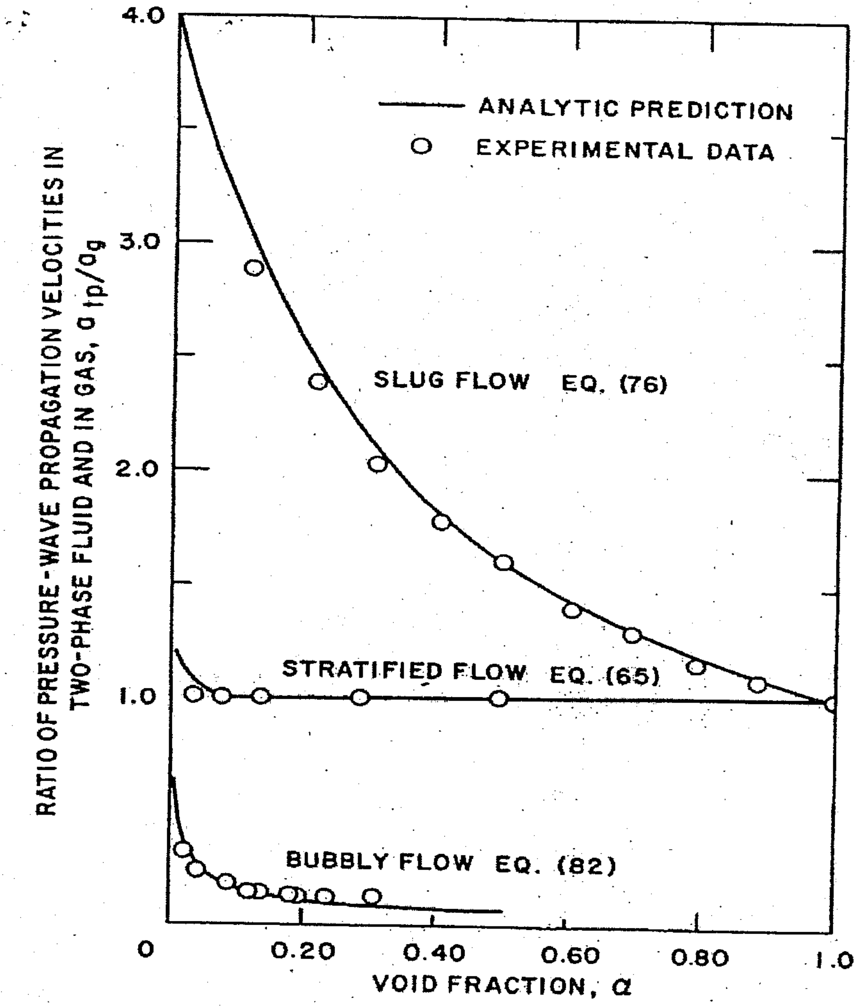
[Comparison of the ratio of the two-phase propagation velocities to the water sonic velocity for selected flow patterns (Reference 4)



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 (1976) – Reference 3.][1]

..][1] Thus, it is concluded there are no negative impacts due to water hammer stemming from the presence of air in this section of the ECCS piping.

References for Response to Question 5:

1. 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.
2. [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.][1]
3. [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.][1]
4. [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.][1]

'[ ][1]" indicates that this bracketed information is considered PROPRIETARY to APS