Arizona Public Service Company

August 23, 1984
ANPP-30304-TDS/TRB

U. S. Nuclear Regulatory Commission
Region V
Creekside Oaks Office Park
1450 Maria Lane - Suite 210
Walnut Creek, CA 94596-5368

Attention: Mr. T. W. Bishop, Director
Division of Resident
Reactor Projects and Engineering Programs

Subject: Final Report - DER 84-39
A 50.55(e) Reportable Condition Relating To LPSI And Containment Spray Pumps Have Experienced Abnormal Rumbling Noises.
File: 84-019-026; D.4.33.2

Reference: A) Telephone Conversation between J. Ball and T. Bradish on June 5, 1984
B) ANPP-29866, dated June 29, 1984 (Interim Report)

Dear Sir:

Attached is our final written report of the deficiency referenced above, which has been determined to be Not Reportable under the requirements of 10CFR50.55(e).

Very truly yours,

E E Van Brunt/ [signature]

E. E. Van Brunt, Jr.
APS Vice President
Nuclear Production
ANPP Project Director

EEVB/TRB/nj
Attachment

cc: See Page Two

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IE-27

Mr. T. W. Bishop
DER 84-39
Page Two

cc: Richard DeYoung, Director
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FINAL REPORT - DER 84-39
DEFICIENCY EVALUATION 50.55(e)
ARIZONA PUBLIC SERVICE COMPANY (APS)
PVNGS UNITS 1, 2, 3

I. Description of Deficiency

During performance verification tests on modified Low Pressure Safety Injection (LPSI) Pumps and modified Containment Spray (CS) Pumps on Unit 1 during May 1984 (reference DER 83-61 for details of modifications), an aperiodic "rumble" was evidenced in LPSI pumps 1MSIA-P01 and 1MSIB-P01 and CS pumps 1MSIA-P03 and 1MSIB-P03 and their adjacent suction piping. In the case of the LPSI pumps the "rumble" was noted in the capacity range of 2800 to 3400 gpm. In the case of the CS pumps the "rumble" was of lower magnitude and was noted in the capacity range of 1800 to 2800 gpm.

The "rumble condition" had not been reported prior to the DER 83-61 modifications as previous operation of these pumps did not include sufficient time in their respective "rumble" ranges for this phenomenon to be identified, i.e.:

> The LPSI pumps would normally be started at 100 gpm fixed (continuous) minimum flow against a closed discharge control valve, and the discharge valve then opened to permit design flow of 4300 gpm (or in the case of the 100 start test - reference DER 83-61 - maintained at a 2000 to 2100 gpm valve setting).
>
> In the case of the CS pumps, startup would normally be at 150 gpm fixed minimum flow against a closed discharge control valve which is then opened to permit the 3900 gpm design flow.

The minor modifications to the pumps (reference DER 83-61) concerned the impeller running fits and have no influence on whether or not the pumps do or do not operate with a "rumble" in the flow range (off peak efficiency) between minimum flow and design capacity.

This "rumble" phenomenon is the result of interaction between intermittent (aperiodic) inlet flow disturbances caused by the suction piping configuration and prerotation of the inlet stream caused by the pump impeller while operating off peak efficiency. The noise source is due to cavitation from collapsing of bubbles in the flow stream about one foot below the pump casing.

The root cause of the "rumble" phenomonon is explained in Reference 1 with respect to the LPSI pumps. Based on the similarity of pump designs and suction piping configurations, the same root cause is also applicable to the CS pumps.

Should prolonged operation in the "rumble" range ever become an operating requirement, this condition can be corrected by incorporating either a splitter at the pump inlet to negate the prerotation, or straightening vanes in the suction pipe below the pump to reduce the inlet flow turbulence to the pump.

The LPSI Pumps and the CS Pumps are supplied by Combustion Engineering (C-E) and are manufactured by Ingersoll-Rand (IR). They are identified by tag numbers as follows:

	Unit 1	Unit 2	Unit 3
LPSI	1MSIA-P01	2MSIA-P01	3MSIA-P01
	1MSIB-P01	2MSIB-P01	3MSIB-P01
CS	1MSIA-P03	2MSIA-P03	3SMIA-P03
	1MSIB-P03	2MSIB-P03	3SMIB-P03

II. Analysis of Safety Implications

During shutdown cooling, the LPSI pumps are used to reduce the temperature of the Reactor Coolant System (RCS) in post-shutdown periods from an RCS temperature of 350°F to the refueling temperature of 125°F. Additionally, the LPSI pumps are used to provide emergency core cooling flow following a large break Loss of Coolant Accident (LOCA) up to initiation of a Recirculation Actuation Signal (RAS).

The shutdown cooling mode flow rate is 4500 gpm and is controlled by the operator. Operation through the 2800 to 3400 gpm "rumble" range will be of a transient nature and of short duration. No impact resulting from the "rumble" phenomenon is anticipated as a result of operating in the shutdown cooling mode.

In the emergency core cooling mode of operation, the LPSI system could operate in the "rumble" flow range. A Probabilistic Risk Assesment (PRA) was employed to evaluate the operation of LPSI pumps in the range of flow where the "rumble" occurs. The probability of operating in this flow range is very low, calculated to be a mean occurrence of 4.65 x 10-4 per operating year. Operation in the rumble range will depend on the combination of pumps running, LOCA break size and configuration, decay heat rate, andd operation of the steam generators as an alternate energy removal path, (reference 2).

The upper limit of time for which the rumble could occur, assuming no corrective operator action, would be four hours. This is based on a maximum Refueling Water Tank (RWT) volume of approximately 700,000 gallons with only one LPSI pump operating until automatic shut-off by the RAS.

The RWT is the safety injection system suction reservoir prior to RAS. C-E has stated (reference 3) that if a LPSI pump operates for at least one minute, there are no break sizes where an LPSI failure would result in significant core damage. Also, IR has confirmed (reference 3, enclosure 2, item 4) that operation in the rumble range for up to four hours would not cause pump damage.

The pumps were field tested with the same system conditions as would be encountered during a LOCA. LPSI pump 1B was run in its "rumble" range during tests for a duration of about two hours. Post-test inspection revealed no pump degradation.

The CS pumps are designed to remove heat from the containment atmosphere in the event of a LOCA while pumping at a rate of 3750 gpm. They are also used (below 200°F) to circulate reactor coolant, at a rate of 4500 gpm, to remove decay heat during the latter stages of shutdown cooling.

The CS pumps will not have occasion to operate in the range where rumbles occur.

Based upon the above, the "rumble" condition for both the LPSI and CS pump systems are evaluated as not reportable under the requirements of 10 CFR part 50.55(e) since, if left uncorrected, it would not represent a significant safety condition.

Also, this condition is evaluated as not reportable under the requirements of 10 CFR Part 21 since it does not constitute a substantial safety hazard and, if left uncorrected, would not adversely affect the capability to safely shut down the reactor.

III. Corrective Action

NCRs SM-4201 and SM-4229 have been dispositioned to use the pumps as is. No corrective action is required as a result of this condition, (reference 3). The LPSI pump operating procedures are being revised to incorporate a warning not to operate in the 2500 to 3500 flow range during the shut-down cooling mode of operation.

IV. References

(1) Root Causes of "Rumble" in LPSI Pumps, Palo Verde Project.

(2) Probability Calculations.

(3) V-CE-30530 dated July 10, 1984 with two enclosures.

Root Causes of "Rumble" in LPSI Pumps
Palo Verde Project

The LPSI pumps develop noise and vibration when operating in a flow range of 2800 to 3400 gpm. Based on aural observations and on accelerometer and pressure data obtained by the startup personnel, the cause of this "rumble" (noise and associated vibration) has been determined to be as follows:

The fact that the problem only occurs in the 2800 to 3400 gpm range which is at approximately 75% of rated flow, strongly suggests that prerotation induced by back flow from the impeller is part of the cause.

The intermittency of the events suggests that some other source of flow disturbance is combining with the prerotation to produce the noise and vibration. The aural observation indicated that the noise was due to cavitation which occurs in the intake pipe about 1 foot below the pump casing. The cavities collapse within the water column. In such cases, the cavitation produces vibration and sound but no metal damage.

Aural observation of the intake piping at several locations disclosed that strong turbulence develops in the flow aperiodically. The bends, tees and reducers in the system are sufficient to generate random, large scale turbulence.

It is concluded, therefore, that cavitation conditions develop intermittently when the swirl, associated with a burst of turbulence, interacts with the prerotation induced in the intake pipe by operation of the pump at partial discharge. Justification for this conclusion is as follows:

- Tests conducted at the California Institute of Technology, for pumps of about the same specific speed as those at Palo Verde, demonstrated that backflow from the impeller induced prerotation in certain partial flow ranges depending on the impeller design.

- The source of the noise was determined from aural observations and was corroborated by the vibration data. The accelerometer data showed a definite time lag between the beginning of an event for an accelerometer mounted on the intake pipe and units mounted upstream. Calculation of the apparent acoustic wave speed gave values of approximately 3750 feet per second, a value to be expected. It is apparent, therefore, that the noise and vibration starts in the intake pipe.

- During early startup a strainer was installed in the spoolpiece upstream from the intake. This strainer was concentric but was placed in an eccentric reducer. It, therefore, presented an eccentric configuration to the flow. While it was in place the "rumbles" occurred at from 2800 to 3200 gpm. After removal of the strainer, the "rumbles" moved to the 3200 - 3400 gpm range. This substantiates the conclusion that the piping configuration is contributing to the event and that minor changes can cause appreciable changes in results.

PROBABILITY CALCULATIONS

The probability of a LPSI pump running at 2500 to 3500 gpm during safety injection is determined by the probability that a leak would occur which would require the LPSI pump to deliver 2500-3500 gpm, and the probability that the number and configuration of running pumps requires the LPSI pump(s) to deliver 2500-3500 gpm. The "rumble" was determined by tests to occur in the 2800 to 3400 gpm flowrange. For conservatism, this range was expanded to 2500 to 3500 gpm for these calculations.

P Rumble = P Leak X P Matching Configuration

	Number Running		Gallons/Minute		
Case	LPSI	HPSI	LPSI	HPSI	Total
1	2	2	5000	2400	7400
			7000	2400	9400
2	2	1	5000	1200	6200
			7000	1200	8200
3	2	0	5000	0	5000
			7000	0	7000
4	1	1	2500	1200	3700
			3500	1200	4700
5	1	0	2500	0	2500
			3500	0	3500

A range of leaks between 2500 gpm and 9400 gpm could thus cause the rumble.

The LPSI pumps shutoff at 475 feet of head (204 psi) and run out at 5100 gpm at 285' (124 psi). They will run at 2500-3500 gpm in the SI mode at about 145-165 psi.

Flows of 2500-9400 gpm at 145-165 psi would come from reactor coolant system leaks with equivalent hole diameters of 2-1/2" to 5". Such leaks are classed as medium LOCA's. The mean probability of a medium LOCA is 4.65 X 10^{-4} per year, Reference A. The sum of the probabilities of a leak giving the required flow for each specific case is equal to this number. We are conservative if we use the medium LOCA frequency for all cases.

The LPSI pumps run for about 40 minutes in the injection mode before the recirculation actuation signal (RAS), triggered by low RWT level, will shut them off. This shortest run time applies when both HPSI pumps, both LPSI pumps, and both CS pumps are running. If only one LPSI pump were running at 2,500 gpm, it would take 3.2 hours to reach RAS cutoff. The probability of only one LPSI pump running is 3.32 X 10^{-8} lower than having all pumps running.

PROBABILITY CALCULATIONS (continued)

The probability of having a given combination of pumps running is determined as follows:

P Running + P Failure = 1 or P Running = 1- P Failure

Case	Comb.	Probability
1	2L 2H	$(1-PL)^2 \times (1-PH)^2 \cong 1$
2	2L 1H	$PH\ (1-PH) \times (1-PL)^2 \cong PH$
3	2L OH	$(PH)^2 \times (1-PL)^2 \cong (PH)^2$
4	1L 1H	$(PH) \times (PL) \times (1-PH) \times (1-PL) \cong PHPL$
5	1L OH	$(PH)^2 (PL) \times (1-PL) \cong PH^2 PL$

Where PH = Probability of failure to start or run (HPSI)
PL = Probability of failure to start or run (LPSI)

	HPSI	LPSI	
Failure to start	3.29×10^{-3}	3.29×10^{-3}	Reference A
Failure to run for one hour	$.03 \times 10^{-3}$	$.03 \times 10^{-3}$	Reference A
PH	3.32×10^{-3}		
PL		3.32×10^{-3}	

Evaluating the cases:

$P1 = (1-3.32 \times 10^{-3})^2 \times (1-3.32 \times 10^{-3})^2 \cong 1.0$

$P2 = PH = 3.32 \times 10^{-3}$

$P3 = (PH)^2 = 1 \times 10^{-5}$

$P4 = PH \times PL = 1 \times 10^{-5}$

$P5 = (PH)^2 (PL) = 3.32 \times 10^{-8}$

As Case 1 dominates the configurations with probability of 1, and the probability of leak is conservatively equal to the probability of a medium LOCA, the mean probability of LPSI pumps operating in the SI mode in the flow range where rumbles will occur is 4.65×10^{-4}/yr or less than once in 2150 years of plant operation.

Reference A - Pickard, Lowe and Garrick, Inc., Generic Database for PWR's.

REFERENCE (3)

C-E Power Systems
Combustion Engineering, Inc.
1000 Prospect Hill Road
Post Office Box 500
Windsor, Connecticut 06095-0500

Tel. 203/688-1911
Telex: 99297

227523

N.9.02

JUL 16 '84

POWER SYSTEMS

July 10, 1984
V-CE-30530

Mr. W. G. Bingham
Bechtel Power Corporation
12400 East Imperial Highway
Norwalk, CA 90650

Subject: Low Pressure Safety Injection (LPSI) System Disturbance

Reference: (A) B/CE-E-48279 dated May 30, 1984
(B) B/CE-E-48429 dated June 20, 1984

Enclosure: (1) LPSI Pump Probability Risk Assessment (PRA)
(2) LPSI System Noise Anomaly

Dear Mr. Bingham:

This letter addresses the LSPI system disturbance/noise/rumble found to occur when a LPSI pump is operated in the 2800 to 3400 gpm range. An evaluation has been made to determine if the safety functions of the system would be impacted by this rumble phenomenon. The LPSI pump/system is used to provide safe cooldown to cold shutdown in a shutdown cooling mode of operation and also may provide emergency core cooling flow in the short term (up to RAS actuation) if there is a LOCA.

The shutdown cooling flow rate is 4500 gpm and is controlled by the operator. Operation through the 2500 - 3500 gpm will be of a transient nature and of very short duration. No impact resulting from the rumble phenomenon is anticipated as a result of operating in the shutdown cooling mode.

In emergency core cooling mode of operation, one can expect the system to operate at the "rumble" flow rates. It is felt that the upper bound of the time period for which rumble could occur assuming no corrective action would be four hours. This is based on a maximum RWT volume of approximately 700,000 gallons with one LPSI pump operating. Enclosure (1) provides a more detailed analysis of required run times for various break sizes.

Operation in the rumble mode will depend on the combination of pumps running, break size and configuration, decay heat rate, and operation of the steam generators as an alternate energy removal path. The approximate break size range where one would anticipate flows in the rumble region for different pump combinations would be breaks of 3 to 8 inch diameters (0.05 ft^2 to 0.35 ft^2).

The pumps have been field tested in the same configuration and the same system conditions as would be encountered during a LOCA. One pump was run during testing in the rumble mode for a duration of about 2 hours. No pump degradation was observed as a result.

Further, IR has advised that operation in this mode for 4 hours was not expected to be detrimental to pump performance or its expected life.

An analysis was also performed from a survey of LOCA analyses. Specifics of the survey are shown in Enclosure (1). The reference to "significant fuel damage" pertains to fuel clad temperatures in excess of 2200°F.

The results of the survey show that if the LPSI pump operates for at least one minute or more, there are no break sizes where a LSPI failure would result in significant core damage, consequently, from a PRA standpoint, no increase in risk would be predicted.

Of the two assessments, the latter is considered the more realistic situation; one LPSI pump operating requirement between 1 minute and 1 hour.

Reference (B) asked for Ingersoll Rand input to three questions. Their replies plus their reply to a fourth C-E question are included in Enclosure (2).

Reference (A) requested that C-E have Ingersoll Rand (IR) design and fabricate a flow straightening device for the LPSI pump suction. C-E understands that this effort has been put on hold. Please be advised that IR has completed the design portion of this effort.

If you should have any questions, please contact me.

Very truly yours,

C. Ferguson

C. Ferguson
Project Manager

CF/JDI/CDB:slc
F73181
cc: Messrs:
E. E. Van Brunt, Jr. w/e
J. Vorees w/e
W. H. Wilson
R. H. Holm
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S. N. Mager
D. B. Amerine w/e
W. L. MacDonald
J. R. Bynum

ANPP/PALO VERDE
LPSI SYSTEM NOISE ANOMALY
PROBABILITY RISK ASSESSMENT (PRA)

DISCUSSION

A noise, in itself, of course will not contribute to risk. The extent to which the "rumble" is indicative of over-stressing of pump or piping components is currently unknown. The discussion below is based on consideration of two alternative cases:

Case 1: A rumble that persists for more than one minute is assumed to lead to a complete loss of pump flow.

Case 2: A rumble that persists for more than one hour is assumed to lead to complete loss of pump flow.

C-E performed a survey of LOCA analyses in order to determine which approximate break sizes could lead to LPSI pump flow in the range of 3000 $\pm$ 500 gpm for sufficient time to cause pump damage (See Cases 1 & 2 above). The results of the survey indicate that:

For Case 1 (i.e., one minute rumble tolerance) LPSI pump failure would not be predicted for break sizes greater than about 0.2 ft^2. For breaks in the range of 0.005 to 0.2 ft^2, LPSI pump failure could occur but the LPSI pumps would not be needed for either injection or post-LOCA shutdown cooling. For breaks smaller than about .005 ft^2, the LPSI pump would not produce flows in the 3000 gpm range prior to post-LOCA shutdown cooling. In post-LOCA shutdown cooling the LPSI pump flow can be controlled to avoid the 3000 gpm range.

For Case 2 (i.e., one hour rumble tolerance) no break sizes would be expected to lead to LPSI pump failure. Operation in the injection mode is not required for longer than one hour. In post-LOCA shutdown cooling the LPSI pump flow can be controlled to avoid the 3000 gpm range.

RISK IMPACT

The recent Calvert Cliffs IREP assumed LOCA frequencies of approximately:

Small, Small LOCA,	S_2 (<.02ft^2)	3×10^{-2} per year
Small LOCA,	S_1 (.02 - 0.1)	3×10^{-4} per year
Large LOCA,	A (>0.1)	1×10^{-4} per year

Using these frequencies as a basis, we can draw the following preliminary conclusions:

CASE 1 & 2

Given a one minute, or one hour rumble tolerance, there are no break sizes that would result in LPSI failure leading to significant core damage. Therefore, based on traditional PRA consideration, no increase in risk would be predicted. However, there must be assurance that the pumps can really tolerate the rumble at the time that they are demanded. To be sure of this would require making sure that the rumble is not a symptom of continual cumulative degradation of the pump or piping such that flow delivery reliability is decreasing with age. The tests conducted at PVNGS and the subsequent inspection provide this assurance.

Enclosure (2) to
V-CE-30530

ANPP/PALO VERDE
LPSI SYSTEM NOISE (RUMBLING) ANOMALY

1. In IR's opinion, what is causing the disturbance (noise) in the subject system?

IR: It was the conclusion of hydraulic experts at site, including IR, that noise was emanating from the piping upstream of the pump. There probably is some interaction of pump with the system in that changes to the pump alone or system above could affect the rumbling. This is not known for certain. It is known that identical pumps with different piping do not exhibit the rumbling.

2. What would be IR's recommendation to alleviate the problem? (As you are aware, a crosspiece type straightener in the suction spool piece did not reduce the rumble.)

IR: Since individual elements such as elbows, reducers, and tees interact, it is difficult to recommend piping changes without a flow visualization model test. There are various combinations of flow straighteners or baffles that might work. Several have been examined. The two under consideration (are at the strainer and the other just upstream of impeller) were recommended due to ease of installation and expected hydraulic benefit.

3. Does IR recommend the installation of straightener vanes in the pump case suction? Why? Will the vanes solve the problem?

IR: IR has previously advised that straightening vanes upstream of the impeller may sufficiently correct non-uniform flow to the pump to reduce or eliminate the rumbling. While these vanes are expected to help. IR cannot say for sure that rumbling will decrease.

4. Is the problem detrimental to the pump performance or its expected life?

IR: The rumbling does not appear to be related to a loss in pump performance. It has been noted that when the rumbling occurs there is a minor fluctuation of the discharge gage. Normally pump head-capacity is affected by pre-whirl (rotating flow) into the impeller but in this case the disturbance is cyclical and apparently the full head-capacity is still being produced. The life of the pump may be affected by continuous operation in the rumbling mode. IR has previously advised in response to C-E questions that operation in this mode for a few hours was not expected to harm the pumps. (Per Telecon, C-E/IR this includes 4 hours).