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FACIL:STN-50-528 Palo Verde Nuclear Station, Unit 1, Arizona Publi 05000528
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SUBJECT: LER 88-013-00:on 880325,essential motor driven auxiliary feedwater pump failed to achieve rated pressure,per Tech Specs.Caused by stress corrosion cracking/hydrogen embrittlement.Matl changes initiated.W/880325 ltr.

DISTRIBUTION CODE: IE22D COPIES RECEIVED:LTR 1 ENCL 1 SIZE: 18
TITLE: 50.73 Licensee Event Report (LER), Incident Rpt, etc.

NOTES:Standardized plant. 05000528

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	NRR/DLPQ/QAB 10	1	1	NRR/DOEA/EAB 11	1	1
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	~~NRR/DRIS~~/SIB 9A	1	1	NUDOCS-ABSTRACT	1	1
	REG FILE 02	1	1	RES TELFORD,J	1	1
	RES/DE/EIB	1	1	RES/DRPS DEPY	1	1
	RGN5 FILE 01	1	1			
EXTERNAL:	EG&G WILLIAMS,S	4	4	FORD BLDG HOY,A	1	1
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NRC Form 366 (9-83)

U.S. NUCLEAR REGULATORY COMMISSION
APPROVED OMB NO. 3150-0104
EXPIRES: 8/31/88

LICENSEE EVENT REPORT (LER)

FACILITY NAME (1)	DOCKET NUMBER (2)	PAGE (3)
Palo Verde Unit 1	0 5 0 0 0 5 2 8	1 OF 1 7

TITLE (4)
Auxiliary Feedwater Pump Degradation

EVENT DATE (5)			LER NUMBER (6)			REPORT DATE (7)			OTHER FACILITIES INVOLVED (8)	
MONTH	DAY	YEAR	YEAR	SEQUENTIAL NUMBER	REVISION NUMBER	MONTH	DAY	YEAR	FACILITY NAMES	DOCKET NUMBER(S)
0 3	2 5	8 8	8 8	— 0 1 3 —	0 0	0 6	0 3	8 8	Palo Verde Unit 2	0 5 0 0 0 5 2 9
									Palo Verde Unit 3	0 5 0 0 0 5 3 0

OPERATING MODE (9): 1
POWER LEVEL (10): 1 0 0

THIS REPORT IS SUBMITTED PURSUANT TO THE REQUIREMENTS OF 10 CFR §: (Check one or more of the following) (11)

[ ] 20.402(b)	[ ] 20.405(c)	[ ] 50.73(a)(2)(iv)	[ ] 73.71(b)
[ ] 20.405(a)(1)(i)	[ ] 50.36(c)(1)	[ ] 50.73(a)(2)(v)	[ ] 73.71(c)
[ ] 20.405(a)(1)(ii)	[ ] 50.36(c)(2)	[X] 50.73(a)(2)(vii)	[X] OTHER (Specify in Abstract below and in Text, NRC Form 366A)
[ ] 20.405(a)(1)(iii)	[ ] 50.73(a)(2)(i)	[ ] 50.73(a)(2)(viii)(A)	10CFR21
[ ] 20.405(a)(1)(iv)	[ ] 50.73(a)(2)(ii)	[ ] 50.73(a)(2)(viii)(B)	
[ ] 20.405(a)(1)(v)	[ ] 50.73(a)(2)(iii)	[ ] 50.73(a)(2)(x)	

LICENSEE CONTACT FOR THIS LER (12)

NAME	TELEPHONE NUMBER	
	AREA CODE	
Timothy D. Shriver, Compliance Manager	6 0 2	3 9 3 - 2 5 2 1

COMPLETE ONE LINE FOR EACH COMPONENT FAILURE DESCRIBED IN THIS REPORT (13)

CAUSE	SYSTEM	COMPONENT	MANUFACTURER	REPORTABLE TO NPRDS	CAUSE	SYSTEM	COMPONENT	MANUFACTURER	REPORTABLE TO NPRDS
B	B A	P	B 2 6 0	Y					

SUPPLEMENTAL REPORT EXPECTED (14)		EXPECTED SUBMISSION DATE (15)	MONTH	DAY	YEAR
[ ] YES (If yes, complete EXPECTED SUBMISSION DATE)	[X] NO				

ABSTRACT (Limit to 1400 spaces, i.e., approximately fifteen single space typewritten lines) (16)

On March 25, 1988 Palo Verde was in Mode 1 (POWER OPERATION) at approximately 100% power when the essential motor driven auxiliary feedwater pump did not achieve its rated pressure in accordance with PVNGS Technical Specifications. An engineering evaluation completed on June 1, 1988 determined the root cause to be stress corrosion cracking/hydrogen embrittlement of the shaft sleeve which permitted the sleeve to move and eventually wear the fourth stage impeller to the point that it was permitted to rotate freely about the shaft. A similar event was identified involving the Unit 1 non-essential auxiliary feedwater pump on June 1, 1987.

As corrective action, material changes will be incorporated into the auxiliary feedwater pumps for Units 1, 2 and 3.

This report is also being submitted pursuant to 10CFR21.

IE22
1/1

TEXT (If more space is required, use additional NRC Form 366A's) (17)

This report is also being provided pursuant to the provisions of 10CFR21. The narrative below includes the information requested by 10CFR21.21 (b)(3); however, it is being formatted to report this event in accordance with the requirements of 10CFR50.73.

I. DESCRIPTION OF WHAT OCCURRED:

A. Initial Conditions:

At the time of the first auxiliary feedwater (AFW) pump (BA)(P) degradation on June 1, 1987 at approximately 1735 MST, Palo Verde Unit 1 was in Mode 1 (POWER OPERATIONS) at approximately 40 percent power.

At the time of the second AFW pump degradation on March 25, 1988 at approximately 0324 MST, Palo Verde Unit 1 was in Mode 1 at approximately 100 percent power.

B. Reportable Event Description (Including Dates and Approximate Times of Major Occurrences):

Event Classification: Condition which caused two independent trains to become inoperable in a single system on different occasions.

Note: This section includes information requested by 10CFR21 concerning the nature of the defect and dates for which information was obtained/developed.

On June 1, 1988 an engineering evaluation was completed concerning the auxiliary feedwater pump problems described herein. Based upon this review, it was determined that the similar failure mechanism resulted in the condition being reportable pursuant to 10CFR50.73 and 10CFR21.

Palo Verde Unit 1 has experienced two similar occurrences which resulted in auxiliary feedwater (AFW) pump degradation. The most recent occurred on March 25, 1988. During the performance of a monthly surveillance test on the "B" Train essential motor-driven AFW pump, it was observed that the total delivered head was below the allowable value of 1682.2 psid. The actual total delivered head was 1538.5 psid. This value was approximately 210 psid below the value of 1748 psid which was obtained in the previous surveillance test for this pump. The pump was declared inoperable and disassembly was initiated. The following observations were made during the visual inspection of the pump's rotating assembly: First, the fourth stage impeller hub was observed to be capable of rotating freely around the stationary pump shaft. There was also evidence of grinding on the center stage piece side of the fourth stage impeller hub. Secondly, the center stage shaft sleeve was also free to rotate about the pump

shaft. By design, the center stage shaft sleeve is shrink fitted onto the shaft and also keyed to the shaft. Visual observation showed a crack on the outside surface of the center stage shaft sleeve that went axially along the entire length of the shaft sleeve at the keyway location.

The previous instance of AFW pump degradation of this type occurred on June 1, 1987. This event affected the non-seismic, non-essential, motor-driven AFW pump. The visual inspection of the rotating assembly for this pump yielded many of the same observations that were described above. Specifically, the center shaft sleeve had an axial crack, the key had been sheared, and the sleeve was free to rotate about the shaft. The key had also been sheared at the fourth stage impeller hub allowing freedom of rotation of the fourth stage impeller hub about the shaft. The rotating assembly for the pump was replaced.

C. Status of structures, or components that were inoperable at the start of the event that contributed to the event:

Other than the AFW pumps, there were no structures, systems, or components inoperable which contributed to the event.

D. Cause of each component or system failure, if known:

Note: This section includes information requested by 10CFR21 concerning the nature of the defect and dates for which information was obtained/developed.

As a result of the first failure on June 1, 1987, ANPP contacted the original equipment manufacturer (Bingham-Willamette) and the damaged rotating assembly was sent to them for their evaluation and repair. The conclusion from the vendor's initial evaluation was that the damage was due to water hammer or excessive pulsations at the discharge side of the pump. Bingham-Willamette (BW) has since revised this root cause based on the second failure.

Following the second failure, ANPP initiated an extensive investigation to determine the extent of the problems described herein. ANPP initiated a search within the industry to determine if any other plants with similar BW pumps had experienced problems of this type. The vendor was contacted and asked if they knew of any problems of this type that had been experienced by other users of their pumps. The vendor replied that they were unaware of any other failures of this type. Further investigation by ANPP revealed that South Texas Project (STP) Unit 1 had recently experienced a failure of one of their AFW pumps. Some of the damage reported by STP is similar to the damage experienced by the Palo Verde pumps. ANPP also conducted a Nuclear Plant Reliability Data System (NPRDS) search to

determine if this failure mechanism had been experienced previously at other utilities. There were no NPRDS reports of similar failures at other operating utilities.

ANPP conducted a multi-disciplinary review of the AFW pump problems. The review involved different groups within ANPP as well as outside organizations. The Mechanical Group of ANPP's Engineering Evaluations Department (EED) took the lead in the investigative efforts which were aimed at determining a root cause of the AFW pump degradations. The Technical Support group of EED was involved to provide metallurgical analysis support, and they contracted with an independent laboratory, METL, to perform the actual metallurgical testing of the center stage shaft sleeve. ANPP's Engineering Department Mechanical Group and Reliability Group provided technical support and probabilistic analysis to support the effort. ANPP's Nuclear Fuel Management (NFM) Department was contacted to determine the impact of reduced AFW pump flows on the accident analyses. NFM also consulted with Combustion Engineering for their evaluation. ANPP obtained technical support from Bechtel Power Corporation (BPC) and the pump manufacturer (Bingham-Willamette) to aid in the evaluation of the AFW pump degradations. BPC then involved an independent pump consultant and BPC's Materials and Quality Services (M&QS) group. The pump manufacturer contracted with an independent laboratory, Oregon State University (OSU), to perform a metallurgical examination of the center stage shaft sleeve.

As a result of ANPP's root cause investigation, the following failure scenario was developed. The initiating event was a crack in the center stage shaft sleeve. The existence of the crack allowed the shaft sleeve to expand which eventually resulted in the shearing of the key due to the frictional forces between the sleeve and the center stage piece. The shearing of the key gave rotational freedom to the shaft sleeve. The differential pressure that is normally developed across the shaft sleeve is approximately 800 psid due to the pressure differential between eighth stage and fourth stage pressures. This pressure differential forced the center stage shaft sleeve into the fourth stage impeller hub. The shaft sleeve ground into the impeller hub removing hub and key material. Finally, the sleeve reduced the key in the impeller to such a dimension that the impeller torque sheared the remaining length of the key. The fourth stage impeller was then free from the rotation of the shaft and the developed head of the pump was reduced.

The following information is provided concerning the original equipment manufacturer's evaluation of the Palo Verde experience. On April 4, 1988, Bingham-Willamette (BW) met with ANPP personnel to discuss the problems found while disassembling the Unit 1 B-Train AFW pump. BW reviewed the video taken of the damaged rotating assembly. Discussions were also held concerning the condition of the Unit 1

non-essential AFW pump rotating assembly from the failure of June, 1987. BW stated that the damage to the two rotating assemblies is very similar. BW was given half of the center stage shaft sleeve for a failure analysis. BW then witnessed the starting of the Unit 1 essential AFW pump which had been instrumented on the suction side of the pump with pressure gauges. During the start of the B-Train AFW pump, swings from 0 to 60 psi for 3-5 seconds were observed on the suction side pressure gauge until the pump steadied out. After the run, BW performed a walkdown of the suction piping for the AFW pump. One of the BW representatives noted that there was nothing unusual about the PVNGS suction piping arrangement that would lead them to believe that this is a problem for mini-flow pump starts. They were then taken to Unit 2 to inspect the non-essential AFW pump which had been disassembled for inspection as a result of the problem discovered in Unit 1. The center stage shaft sleeve for the pump was noted to have moderate rotational marks, but no bluish tempering was found. The sleeve was in its design position, and no visual signs of any differential rotational movement between the shaft sleeve and the fourth stage impeller hub were found. The lower center stage piece revealed light to moderate signs of rubbing contact. The upper half showed very light signs of contact.

The observations made by BW during their trip to Palo Verde and the subsequent review of the essential AFW pump damage at their facility have lead them to believe that the pumps were exposed to severe operating conditions. Specifically, BW postulates that the pumps have either been subjected to dry starts (loss of suction pressure) or starts under conditions wherein the auxiliary feedwater flow is aligned for steady state flows at or near the design flow (1010 GPM) of the pump. To shear the key, a considerable torque must act on the sleeve. BW performed an analysis to estimate the maximum frictional forces which can occur during pump upsets. Particularly, the case of pumping a two phase fluid (water/vapor) was considered. A simplified model was used in which it was assumed that, in the worst case, 4 of the 8 impellers would be half filled with water and the remainder with vapor. The results are:

i) With a friction factor of 0.3 (dry steel against steel), the torque developed by this upset is only about 10% of the torque necessary to shear the key.

ii) To shear the key the sleeve must at least temporarily gall. If this happens, the necessary torque is about 4 times larger than is needed to shear the key. The fact that the center stage piece does not rotate, although held by a relatively small pin only, indicates that the shearing of the key happens rapidly with not enough time to accelerate the heavy center stage piece. This would support the argument that at least temporary sudden galling of the sleeve is necessary for shearing the key.

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BW indicated that galling marks on the center stage piece and center sleeve are strong evidence that dry starts or starts with subsequent two phase flow have occurred for the failed pumps. Each of these phenomena are discussed below:

i) Normal Starts. BW estimates that the motor-driven pump starts in less than once second. The inertia of the water in the long suction line (approximately 200 feet) prevents the water from moving into the eye of the first stage impeller at the same rate as the pump is removing water from the case. Consequently, the pressure at the suction nozzle of the pump drops below the vapor pressure of the water in the suction line. This results in two phase flow through the pump. The two phase flow can lead to one of the following two occurrences or a combination of both. First, the impeller(s) can contain a mixture of vapor and water which is not evenly distributed throughout the impeller. This imbalance condition causes the shaft to move erratically with the largest shaft deflections taking place at the center stage sleeve. The sleeve contacts/rubs the center stage piece leading to the observed galling. Secondly, two phase conditions inside the pump could exist over a large portion of the pump which reduces the hydrodynamic lift effects on the sleeve. The reduction in hydrodynamic lift leads to the sleeve contacting the center stage piece which results in the galling of both pump parts.

Compounding the above effects of two phase pump operation, the water column which separates at the pump suction nozzle will rejoin when the water in the suction line starts to move. The rejoining results in a water hammer, placing an additional load on the shaft which may be in a deflected state or moving erratically, thus causing or amplifying the radial forces which are necessary to deflect the sleeve enough to contact/rub the center stage piece.

ii) Dry Starts. BW postulates that the suction valves may have been closed when the pump was inadvertently started (Based upon ANPP's investigation into this event, it could not be established that this has occurred at Palo Verde.). This would lead to the loss of the hydrodynamic lift effect at the center sleeve. Heavy rubbing on the lower half of the center stage piece would occur with subsequent galling of the parts.

An independent pump consultant was retained by Bechtel Power Corporation (BPC) to perform an evaluation of the AFW pump degradation problems at PVNGS. This paragraph summarizes the consultant's findings. The consultant performed an inspection of the damaged rotating assembly of the essential motor-driven AFW pump before the assembly was shipped to BW. His evaluation corroborated the failure scenarios developed by ANPP. Specifically, he stated that the end to end split of the shaft sleeve initiated the failure. Once the crack was fully developed, the sleeve would expand to allow contact with the bushing. The resultant torque sheared off the key, and the sleeve, under eighth stage pressure, began drilling into the fourth stage impeller hub. After enough metal was removed from the impeller hub and shaft key, the torque sheared the shaft key which freed the impeller from positive drive. Another interesting finding from this pump consultant is that there is no reason to suspect that further mechanical problems would occur following the loss of the fourth stage impeller that would prevent continued use of the pump at a reduced flowrate. The consultant also expressed concerns regarding the shaft sleeve design. In particular, he was concerned by the thickness of the shaft sleeve, the hardness of the material, and the stress concentrations created by the 0.125 inch deep keyway in the 0.250 inch thick sleeve material. As a result of his concerns, the consultant recommended that the thickness of the center stage shaft sleeve be doubled and that the material be replaced with a material that is not as hard as that currently used. This recommendation has been evaluated and ANPP considers that this is not practical due to the increase in axial loads on the sleeve that would result from the change.

An ANPP metallurgical analysis of the cracked shaft sleeve has concluded that the cracking is due to hydrogen embrittlement cracking. This determination is based upon an investigation which includes Scanning Electron Microscopy (SEM) showing intergranular cracking, an average material hardness of Rockwell C-50, and applied radial forces on the shaft sleeve. The susceptibility of martensitic stainless steels with high hardnesses to hydrogen embrittlement is well documented and supports ANPP's conclusion. There was no evidence to suggest the ductile overload or fatigue modes of cracking. Secondary heat induced cracks were also identified on the shaft sleeve inside diameter, however, these cracks were a result of severe galling and intense localized heating. Bechtel has examined the failed shaft sleeves at a Palo Verde and STP. The examination of the Palo Verde sleeve confirms the metallurgical examination results of stress corrosion cracking/hydrogen embrittlement performed by ANPP. Additionally, Bechtel has found significant similarities between the Palo Verde and STP sleeve failures that suggest that the fracture modes are the same. These similarities are summarized below:

i) The material is Type 420 stainless steel, which was hardened to a high hardness level (50/51 HRC). Steels, including chromium stainless steels, in a high hardness condition (higher than 38 HRC) are known to be susceptible to stress corrosion cracking/hydrogen embrittlement.

ii) The fracture occurred in or around the keyway corners where the stress (residual tensile stress in the circumferential direction from heat treating and shrink fit) would be the highest.

iii) The fractures initiated at the keyway surface rather than at the outside surface of the sleeves.

iv) The sleeves show evidence of corrosion in the areas of fracture initiations.

v) The fracture faces of the splits are intergranular.

ANPP conducted a review of the operating history of the AFW pumps in each unit. One of the factors that was investigated was how many full flow pump starts the essential AFW pump had experienced in each unit. The results of the review indicate that the Unit 1 pump had experienced an estimated 27 full flow pump starts, the Unit 2 pump had 3, and the Unit 3 pump only had 2 full flow starts. The reason the Unit 1 essential AFW pump has experienced more full flow starts is attributed to additional preoperational testing that was conducted only in the lead unit. Based upon a BW hypothesis concerning galling during full flow pump starts and the operating history data, ANPP expects that more galling would have occurred in Unit 1 than Units 2 and 3. This has been partially confirmed by the inspections conducted on the essential AFW pumps in Units 1 and 2. The cracked shaft sleeve for the Unit 1 pump had indications of severe galling while no signs of galling were present on the Unit 2 pump's shaft sleeve. As an additional note, full flow starts of the steam turbine driven and non-essential AFW pumps are not a concern for this investigation due to design and procedural considerations which preclude full flow starts of these pumps. Additional operating information has been gathered to aid in the reliability analyses that ANPP has performed. The demand and run times associated with the Units 1, 2, and 3 AFW pumps are summarized in the following table.

AFW PUMP RUN TIME/STARTS

		Steam Turbine Driven Essential Pump	Motor Driven Essential Before Failure	Non-Essential Pump	Non-Essential Pump After Failure (1)
Unit 1	D^t	200	249(2)	147	63
	H^t	331	606(2)	3643	959
Unit 2	D^t(3)	123	109	143	-
	H^t(3)	200	330	1960	-
Unit 3	D^t(3)	31	124	27	-
	H^t(3)	80	390	560	-
TOTAL	D^t(3)	354	482	317	63
	H^t(3)	611	1326	6163	959

D^t = Start/Stop Cycles
H^t = Run Time (Hours)

Notes: (1) Includes starts and run hours that this pump experienced in Unit 3 prior to being moved to Unit 1 in June, 1987 .

(2) Unit 1 essential, motor-driven AFW pump failed on 3/25/88.

(3) Estimated values in Units 2 and 3 during operational phase.

E. Failure mode, mechanism, and effect of each failed component, if known:

See Section D above.

F. For failures of components with multiple functions, list of systems or secondary functions that were also affected:

Not applicable - Other than feedwater flow during different operational conditions, the AFW pumps do not have multiple functions.

G. For failure that rendered a train of a safety system inoperable, estimated elapsed time from the discovery of the failure until the train was returned to service:

The non-essential AFW pump was discovered to be inoperable at approximately 1735 MST on June 1, 1987. The pump was repaired and returned to service at approximately 1627 MST on June 4, 1987. The pump was inoperable approximately 70 hours and 52 minutes.

The essential AFW pump was discovered to be inoperable at approximately 0324 MST on March 25, 1988. The pump was repaired and returned to service at approximately 0917 MST on March 27, 1988. The pump was inoperable for approximately 53 hours and 53 minutes.

H. Method of discovery of each component or system failure or procedural error:

The problems with the AFW pumps not producing the required head were discovered during the performance of routine surveillance testing. The failed shaft sleeves were discovered as a result of maintenance and engineering investigation into the reason for the AFW pump not meeting the appropriate surveillance acceptance criteria requirements.

I. Cause of Event:

This section includes information requested by 10CFR21 concerning the nature of the defect.

Two separate root causes have been identified for the failure scenarios discussed previously. Before these root causes are discussed, it should be noted that all parties involved in the investigation are in agreement on the end portion of the failure scenario. Specifically, the different groups looking into this event agree that galling between the center stage shaft sleeve and the center stage piece must exist in order to generate high enough forces to shear the shaft key. After the shaft key shears, the shaft sleeve is free to rotate which leads to machining of the fourth stage impeller hub. The fourth stage impeller hub eventually breaks free from the shaft. Two failure mechanisms have been developed to explain how and why the galling of the shaft sleeve occurs. These two failure mechanisms are presented below.

i) <u>Suction Transients</u>

The galling of the center stage shaft sleeve to the center stage piece could occur as a result of suction transients on the AFW pumps. Suction transients can be caused by either plant operation or plant design. Normal starting of the motor-driven AFW pumps can lead to a condition where the pressure at the suction nozzle of the pump drops below the vapor pressure of the water in the suction line. This is due to the inertia of the water in the suction line which prevents the water from moving into the eye of the first stage impeller at the same rate that

the pump is removing water from the case. This condition can result in galling of the center stage sleeve by either causing an imbalance of the pump shaft or by reducing the hydrodynamic lift effect at the sleeve location. Another plant operating problem that can lead to galling occurs if the non-essential AFW pump is started with at least one of its two motor operated suction isolation valves closed (It could not be established that this situation has occurred at Palo Verde). Again, this leads to an inadequate suction water supply for the pump which could lead to galling of the shaft sleeve due to loss of the hydrodynamic lift effect at the center stage shaft sleeve. One possible plant design problem that could lead to galling is long horizontal runs of suction piping impacting pump startup. If the piping is not adequately vented following system maintenance, then air could be ingested at the pump suction again leading to galling of the center stage shaft sleeve.

ii) <u>Environmental Cracking</u>

The galling of the center stage shaft sleeve could have been initiated by the observed axial crack in the shaft sleeve. Specifically, the crack in the shaft sleeve was initiated by intergranular attack. When the crack had fully propagated, it reduced the diametral clearance between the center stage piece and the shaft sleeve. This led to inadequate cooling flow to the shaft sleeve which resulted in galling.

ANPP analysis indicates that the root cause of failure is due to environmental cracking or a combination of environmental cracking and suction transients. From the evidence cited below, ANPP concludes that the dominant failure mechanism is environmental cracking and that sleeve cracking is a prerequisite condition for suction transients to contribute to pump failures.

i) Primary Root Cause (environmental cracking).

- Metallurgical analysis has indicated that the chief mode of cracking on the Palo Verde center stage shaft sleeves is intergranular cracking due to hydrogen embrittlement. The above conclusion is supported by fractographic examination along the fractured face of the failed sleeve. The micro hardness measurements indicate that, during the early sequence of the event, the sleeve had rubbed or galled against the center stage piece. Therefore, it can be concluded that the sleeve had expanded sufficiently to reduce and/or possibly eliminate cooling/lube water, which would result in an upset condition causing the key to shear.

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- During the April, 1988 inspection of the Unit 2 non-essential motor-driven pump, BW indicated that the lower half of the center stage piece showed signs of heavy rubbing. BW believes that this is an indication that dry starts have occurred (ANPP could not establish that this has occurred at Palo Verde.). Further investigation by Nondestructive Examination (NDE) revealed that both the center stage and throttle sleeves did not have any ID or OD cracks.

- Sleeve cracking existed for the two observed Palo Verde pump failures.

ii) Secondary Root Cause (environmental cracking/suction transients).

- Sleeve cracking and suction transients do not exist simultaneously for the Palo Verde Unit 2 pumps that have been inspected.

- During the BW trip to Palo Verde in April of 1988, a normal start (estimated to be one second or less) of the essential AFW pump was performed. The suction line was fitted with a compound (vacuum/pressure) gauge and the pump was aligned for mini-flow operation. In this configuration, the pressure at the pump suction pegged the pressure gauge to less than zero. Based on BW's observations and subsequent analysis of the pump start during minimum flow operation, BW indicated that starts with the pump aligned for flows at or near the design flow would degrade suction pressure to the extent that the pump would operate under two phase conditions.

- Interviews with ANPP personnel have indicated that the essential motor-driven AFW pump in Unit 1 had lost suction flow at least once over the operating history of the pump. During the performance of a startup procedure on July 15, 1984, the pump's suction was transferred from the Condensate Storage Tank (CST)(KA) to the Reactor Makeup Water Tank (RMWT)(CB). During the transfer sequence, the pump discharge pressure dropped and the test was discontinued. A subsequent investigation revealed that the suction line from the RMWT was not vented and the pump had become air/vapor locked with the resulting loss of discharge pressure. To complete the test, the suction line from the RMWT was vented, the pump was restarted and proper discharge pressure established when testing continued. The pump was not inspected prior to the continuation of testing.

- Sleeve cracking and suction transients existed for one of the observed PVNGS pump failures.

- BW's experience has shown that a shaft sleeve crack by itself is not always a sufficient condition for pump failures.

In summary, ANPP has determined that the root cause is material selection for the center stage shaft sleeve. The sleeve cracking alone can result in galling of the center stage shaft sleeve. It has been determined that suction transients can contribute to the galling; however, sleeve cracking is required as a precursor event.

J. Safety System Response:

There were no safety system responses and none were necessary.

K. Failed Component Information:

Note: This section includes information reqeusted by 10CFR21 concering the identification of the firm supplying the basic component and the number and location of the AFW pumps at Palo Verde. Additional information concerning the number and location of similar AFW pumps supplied to other facilities should be obtained from the manufacturer.

There are three Auxiliary Feedwater (AFW) pumps for each Palo Verde unit. The AFW system for each PVNGS unit consists of one Seismic Category I motor-driven pump, one Seismic Category I steam turbine-driven pump, and one non-seismic motor-driven pump.

The nine AFW pumps at PVNGS were manufactured by Bingham Willamette (BW) of Portland, Oregon. The pumps are BW Model 4x6x10-1/2 B MST eight stage units. Each essential AFW pump has a rated capacity of 1010 gpm at 3280 feet Total Dynamic Head (TDH). The non-essential AFW pump has a rated capacity of 1010 gpm at 2960 feet TDH. The pumps are eight stage, single suction, double volute with a horizontal split casing. The rotating element is supported with sleeve journal bearings at both ends outboard of the stuffing box and the pump has an oil-lubricated ball thrust bearing assembly located opposite of the driver end. The configuration of the impellers on the pump shaft is commonly called the opposed impeller arrangement. The purpose of this arrangement is to reduce axial thrust loading. In this arrangement, the first four impellers are arranged on the pump shaft facing in one direction with the remaining four impellers facing in the opposite direction. This design requires an interstage bushing assembly to separate the opposed impellers at the pump center between impellers four and eight.

The interstage bushing (center stage shaft sleeve) is approximately 3 inches long and 0.25 inches thick. It is manufactured from AISI 420 material, hardened to Rockwell C-50.5 hardness. The sleeve is shrunk-fit to the shaft to form a small interference fit of 2 mils or less. The sleeve is also keyed to the shaft by a key that is common with fourth stage impeller. The sleeve is surrounded by a stage piece forming a hydrodynamic bearing. There is a groove within the center stage piece that spirals around the center stage sleeve for pumped fluid flow. While the pump is at rest, the center shaft sleeve is resting on the center stage piece. Upon startup, the rotating shaft is then supported by a film of pumped fluid that is forced through the annulus region between the center stage piece and the sleeve by the pressure differential between the eighth and fourth stages. Thus, upon startup, there is usually contact between the center stage shaft sleeve and the center stage piece.

II. ASSESSMENT OF THE SAFETY CONSEQUENCES AND IMPLICATIONS OF THIS EVENT:

Note: This section contains the information requested by 10CFR21 concerning the nature of the safety hazard which is created or could be created.

ANPP performed an evaluation of the affect of the degraded AFW pump performance on the relevant accident analyses. ANPP first determined the impact of a loss of the pump's fourth stage on the amount of flow delivered to the steam generators. Information was also obtained from BW as to the impact on the pump's flowrate for the loss of the fourth stage impeller. The ANPP analysis indicates that one AFW pump will deliver 559 gpm to the steam generators following the loss of the fourth stage impeller. This is compared to the 750 gpm which is assumed in the current accident analyses. It should be noted that the degraded AFW pump will still be capable of delivering this reduced flow to the steam generators under all conceivable operating pressures (i.e., up to the lift setting of the main steam safety valves). Once an estimate of the degraded pump flowrate was obtained, Combustion Engineering (CE) was asked to evaluate the impact of this reduced flowrate on the PVNGS accident analyses. CE responded that they had previously performed some calculations for a similar 3800 MWt plant. The calculations concluded that an AFW flow of 440 gpm would be sufficient to maintain adequate heat removal for the limiting Loss of Coolant Accident (LOCA) event and the limiting non-LOCA event. CE also reviewed the long term cooling function of the AFW pump for the natural circulation cooldown event. CE determined that a flowrate of not more than 450 gpm would be required after the first hour of the event. For the first hour of the event, the existing inventory of the steam generators along with the reduced AFW pump flow is sufficient for decay heat removal. In conclusion, ANPP's evaluation has provided confidence that the plant will respond adequately to the postulated accidents assuming the degraded AFW pump performance associated with the loss of the fourth stage impeller. Additionally,

ANPP and the independent pump consultant believe that the degraded pump will be capable of continuing to deliver the degraded flow for an extended period of time following the loss of the fourth stage impeller. This is supported by the fact that the essential AFW pump was started twice for troubleshooting immediately following the fourth stage impeller failure. The pump was operated for a total of 30 minutes and an engineer (utility, non-licensed) was present for both runs. The engineer did not observe any abnormalities, unusual noises, or increased vibrations from the pump.

ANPP also evaluated the safety consequences and implications resulting from a total loss of AFW pump function. As a result of the failure mode described above (i.e. environmental cracking), ANPP determined that the pump's throttle bushing sleeve is susceptible to the same failure scenario in developing a crack. As evidenced by the failure which occurred at South Texas Project, it is evident that a throttle bushing failure could result in pump seizure; however, the completed complete failure of an AFW pump has not been observed. Therefore, ANPP performed a reliability analysis which was based upon the operating history experienced at Palo Verde and at the same time considered the effects of a complete AFW pump failure.

The AFW pumps have experienced two failures (i.e., degraded flow events) in approximately 1216 demands, with both failures having occurred in Unit 1. A statistical analysis of this data was performed assuming that hydrogen embrittlement cracking occurs randomly in time. This reliability analysis conservatively assumed the total loss of flow from and AFW pump. The essential, motor-driven AFW pump was selected for the purpose of determining the largest allowable incremental risk. The results of the analysis indicate that the incremental risk incurred from operating with this deficiency for a period of 18 months (i.e., a full cycle of operation) is less than that which results from the removal of the essential motor-driven AFW pump from service for 72 hours. Technical Specification 3.7.1.2 allows one AFW pump to be removed from service for 72 hours without requiring a plant shutdown.

Continued operation of the Palo Verde units with the existing AFW pumps does not pose a risk to plant safety. The evaluation of the Palo Verde accident analyses provides confidence that any conceivable accident can be mitigated in the unlikely event that one AFW pump loses its fourth stage impeller. The reliability analysis has shown that continued operation for up to a complete refueling cycle does not result in a significant risk to public health and safety. In fact, it results in less risk than would be incurred if the essential, motor-driven AFW pump were removed from service for 72 hours. Due to the low risk involved in future pump failures of this type, ANPP does not believe that it is necessary to shutdown the Palo Verde units solely for the implementation of AFW pump material changes.

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TEXT (If more space is required, use additional NRC Form 366A's) (17)

III. CORRECTIVE ACTIONS:

This section contains the information requested by 10CFR21 concerning the corrective action which has been, is being, and will be taken; the organizations responsible for the corrective action; and the length of time for accomplishing the corrective action. It should be noted that the schedule for completing the corrective action discussed below does not include an "Estimated Completion Date." This information is not available since the length of time for accomplishing the corrective action is dependent upon the manufacturer's capabilities for provding the necessary replacement parts and materials. ANPP does however anticipate that the corrective action discussed below will be completed by December, 31, 1988.

A. Immediate:

As described above, the AFW pumps were repaired and returned to service.

B. Action to Prevent Recurrence:

BW and ANPP have conducted a comprehensive review of the pump design. The objective of this effort was to incorporate design changes which will eliminate the possibility of a failure due to the two root causes identified. ANPP has initiated changes to address material modifications of the stationary and rotating pump parts. The material modifications are being selected to maximize the material's resistance to the hydrogen embrittlement phenomena and lower its susceptability to galling to produce a more forgiving design. In addition to the material changes, the keyway design for the throttle and center sleeves will be optimized to reduce the operating stresses inherent to the keyway. The modifications to be implemented include:

i) Stationary parts to be changed to Ni-Resist #2.

ii) Rotating parts to be changed to 410 stainless steel with a hardness in the range of 250 to 300 BHN.

iii) Keyway design for the throttle and center sleeves is to be optimized. It is noted that "optimized" is intended to mean that the fillet radii of the keyways are to be as large as possible without causing excessive bearing stresses due to the reduced contact area between the key and its mating parts.

iv) Change the key material from 416 to 410 stainless steel. This modification is being considered as a design enhancement.

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TEXT (If more space is required, use additional NRC Form 366A's) (17)

These modifications will be implemented in the nine AFW pumps as soon as the new rotating elements and necessary supporting parts are available from the manufacturer.

One of the identified possible contributing causes of the AFW pump degradation is full-flow starts of the AFW pumps. Presently, full-flow starts of the essential AFW pump occur only during performance of Integrated Safeguards (ISG) testing. To eliminate this potential cause of degradation to the pump, the ISG test procedure will be revised to eliminate the full-flow pump start. The essential AFW pump will now be started on minimum flow recirculation. The minimum flow start is also closer to the conditions that the pump will see post-accident due to the fact that the AFW pump discharge valves open slowly in relation to the acceleration of the pump.

IV. PREVIOUS SIMILAR EVENTS:

There have been no previous similar events reported in accordance with the requirements of 10CFR50.73.

Arizona Nuclear Power Project
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192-00379-JGH/TDS/DAJ
June 3, 1988

U. S. Nuclear Regulatory Commission
NRC Document Control Desk
Washington, D.C. 20555

Dear Sirs:

Subject: Palo Verde Nuclear Generating Station (PVNGS)
Unit 1
Docket No. STN 50-528 (License No. NPF-41)
Licensee Event Report 88-013-00
File: 88-020-404

Attached please find Licensee Event Report (LER) No. 88-013-00 prepared and submitted pursuant to 10CFR 50.73. In accordance with 10CFR 50.73(d), we are herewith forwarding a copy of the LER to the Regional Administrator of the Region V office.

This report is also being submitted pursuant to 10CFR21 and includes the information requested in 10CFR21.21(b)(3). In accordance with 10CFR21.21(b)(2), three copies of this report are being provided to the Director, Office of Nuclear Reactor Regulation.

If you have any questions, please contact T. D. Shriver, Compliance Manager at (602) 393-2521.

Very truly yours,

JG Haynes

J. G. Haynes
Vice President
Nuclear Production

JGH/TDS/DAJ/kj

Attachment

cc: O. M. DeMichele (all w/a)
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