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4.10.0 VOIDED PIPING CONCERNS

Learning Objectives:

1. Describe the causes of voided piping.

2. Describe the potential consequences of voided piping.

3. Describe licensee actions to minimize the consequences of voided piping.

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4.10.1 Introduction

Voided piping has been a recurring problem throughout the nuclear industry and has been the topic of several NRC and INPO publications. Voided piping can lead to the loss of function of safety-related systems, and this loss of function is often not detected by surveillance activities. Because the causes of voiding are varied and often subtle, constant vigilance is required to prevent and mitigate voided piping.

4.10.2 Causes of Voided Piping

The following is a discussion of some common causes of voided piping. This list is not comprehensive.

4.10.2.1 Leakage from Safety Injection Accumulators

Accumulator pressure is maintained by a volume of high pressure nitrogen (650 psig) in approximately the top half of an accumulator tank. Some nitrogen is absorbed by the accumulator water. Leakage of water from this source into the lower pressure components of the ECCS can release gas, as the nitrogen comes out of solution at the lower pressure.

In 2005, a leak from an accumulator at Indian Point 2 caused the inoperability of one safety injection pump due to the pump casing being filled with gas. The inspection team concluded that the other two safety injection pumps would not have functioned 75% of the time in response to certain loss-of-coolant accidents (Reference 1).

In January 1995, residual heat removal (RHR) pipe supports at Sequoyah were found to be damaged. The cause was determined to be water hammer that occurred during RHR pump testing. Large gas pockets composed of 99 percent nitrogen were later found in the RHR lines; they probably resulted from leakage of water from a cold-leg accumulator tank (Reference 2).

On three occasions in November and December of 1996, water hammer occurred in the low pressure safety injection (LPSI) system at Waterford when the LPSI pumps were started. The licensee determined that the large pressure transients were caused by the presence of a nitrogen gas volume in the pump discharge lines. The gas had come out of solution when nitrogen-saturated, 600-psig water leaked from the safety injection tanks into the lower pressure LPSI piping. When the pumps started, the compressible gas volume created a transient pressure surge in the LPSI system (Reference 3).

4.10.2.2 Check Valve Leakage from High Temperature/High Pressure Systems into Lower Pressure Systems

In 1985, San Onofre Unit 1 experienced multiple check valve failures in the feedwater lines. The feedwater lines voided with steam due to the leakage through the failed check valves. When auxiliary feedwater was subsequently introduced into the feedwater lines, the rapid condensation of the steam voids produced a severe water hammer event (Reference 4).

INPO SOER 84-3 (Reference 5) documents several examples of auxiliary feedwater (AFW) pumps disabled by steam binding after leakage of hot feedwater into AFW lines through check valves.

4.10.2.3 Evolution of Dissolved Gas Due to Pressure Changes

The following discussion is from SOER 97-1, "Potential Loss of High Pressure Injection and Charging Capability from Gas Intrusion" (Reference 6).

Units designed with centrifugal charging pumps are often equipped with minimum flow recirculation lines that are routed to the reactor coolant pump seal return line and from there back to the common charging pump suction header. During normal operation, the pressure-reducing orifices in these recirculation lines have allowed gases to be stripped from the recirculating liquid. This gas is then directed back to the charging pump suction header. Two units have reported discovering gas pockets and indications of gas binding in the charging pumps as a result of gases stripped from the fluid in the pump recirculation header.

At Beaver Valley 2, longstanding design weaknesses in the charging/high head safety injection (HHSI) system piping configuration and ineffective corrective actions caused at least two pump shaft failures and resulted in periodic pump unavailability over a 10-year period. The failures and unavailability resulted from the accumulation of gas bubbles in the suction piping and subsequent ingestion of gas into the pumps during pump starts. The station tolerated periodic venting to minimize the potential for pump damage, effectively implementing a workaround to compensate for system design inadequacies. System venting became an accepted practice over time, and was performed at a set frequency and prior to pump starts (including starts for surveillance tests), masking potentially degraded pump performance. The manual venting process was not fully effective and occasionally little or no gas was actually vented. After Unit 2 experienced an HHSI pump shaft failure on September 12, 1997, and several subsequent gas binding events occurred, station management finally assembled a team to determine the root cause for the ineffective resolution of the gas binding (Reference 7).

On January 11, 2008, Wolf Creek was shut down because voids were identified in multiple locations in ECCS piping. The shutdown was required by TS 3.0.3 because two trains of ECCS were inoperable. RHR became a source of voids when the RHR system was removed from service. Gases that had been entrained in coolant circulated by the RHR system at a higher pressure came out of solution when the system was isolated and depressurized (Reference 8).

4.10.2.4 Failure to Properly Vent When Filling System

Reference 8 also identifies that at Wolf Creek the section of piping between the RHR pump discharge and the SI and charging pump suctions (called the piggyback line) contained excess air and some hydrogen partly because the pipe sloped the wrong way and could not be properly vented.

On July 28, 2004, the Palo Verde licensee identified that ECCS suction piping voids in all three Palo Verde units could have resulted in a loss of the ECCS during transfer to the recirculation mode for some loss-of-coolant accident (LOCA) conditions. The condition had existed since plant startups in 1986, was contrary to the Palo Verde final safety analysis reports (FSARs), and would not have been identified during testing because water is not drawn from the containment emergency sumps during tests (Reference 9).

4.10.2.5 Failure of Level Instruments to Indicate Correct Level

In May 1997 at Oconee Nuclear Station Unit 3, hydrogen ingestion during a plant cooldown damaged and rendered nonfunctional two high-pressure injection (HPI) pumps. The level instrumentation on the B&W equivalent of the volume control tank had a common reference leg which developed a leak. The resulting false high level indication led to depletion of tank inventory and subsequent hydrogen binding of the HPI pumps. If the operators had started the remaining HPI pump, it too would have been damaged. The NRC responded with an augmented inspection team (Reference 10). The NRC team reported that there had been a total lack of HPI capability during power operation, a failure to meet technical specification (TS) HPI operability requirements, design deficiencies, inadequate maintenance practices, operators who were less than attentive to plant parameters, a failure to adequately assess operating experience, and a violation of Criterion III of Appendix B to 10 CFR Part 50.

4.10.2.6 Column Separation

Column separation refers to the breaking of liquid columns in fully filled pipelines. When the pressure in a pipeline drops to the vapor pressure at specific locations, liquid columns are separated by a vapor cavity or cavities. This may result in water hammer, in which the collision of two liquid columns, or of one liquid column with a closed end, may cause a large and nearly instantaneous rise in pressure. This pressure rise travels through the entire pipeline and forms a severe load for hydraulic machinery, individual pipes and supporting structures.

On November 9, 1999, the vacuum break check valve for the "C" SW pump at Beaver Valley Unit 2 failed to open, causing a water hammer event (Reference 11). The service water pumps draw from a water source that is ~ 30 feet below the pump location. If the vacuum breaker fails to open when the pump is stopped, the static column of water draws a vacuum in the suction pipe, causing the formation of low temperature steam. This steam provides virtually no flow resistance when the pump is started, leading to a severe water hammer event. The water hammer caused deformation of an expansion joint downstream of the "C" SW pump which rendered the pump inoperable.

4.10.2.7 Vortexing in Suction Sources

There are many instances of RHR suction vortexing with the RCS in reduced inventory operation. This phenomenon can lead to gas binding of an RHR pump leading to the loss of RHR cooling. Chapter 4.9 of this manual has more information on this topic.

4.10.3 Safety Consequences of Voided Piping

The following are six examples of how voiding can have safety implications. This information is from Generic Letter 2008-1 (Reference 12).

4.10.3.1 Air Binding of Pumps

Gas binding of a centrifugal pump is a condition in which the pump casing is filled with gases or vapors to the point that the impeller is no longer able to contact enough fluid to function correctly. The impeller spins in the gas bubble, but it is unable to force liquid through the pump. This can lead to cooling problems for the pump's packing and bearings.

Air binding can render more than one pump inoperable when pumps share common discharge or suction headers, or when gas accumulation affects more than one train, greatly increasing the risk significance. Such a common-mode failure would result in the inability of the ECCS or the decay heat removal (DHR) system to provide adequate core cooling and in the inability of the containment spray system to maintain the containment pressure and temperature below design limits. An air-bound pump can become damaged quickly, eliminating the possibility of recovering the pump during an event by subsequently venting the pump and suction piping.

The amount of gas that can be ingested without a significant impact on pump operability and reliability is not well established.

A single-stage pump with significant clearances between moving parts, can often withstand a large slug of gas that completely stops flow, and the pump may be restored to operation when the gas is removed. However, in some cases, physical pump failure has occurred after gas ingestion. A similar no-flow or reduced-flow condition in a multistage pump that has close tolerances between moving parts, such as the multi-stage pumps used in the ECCS, will likely cause permanent damage.

At reduced flow rates even small gas ingestion rates can be a problem, as gas can accumulate with time and the pump can eventually become gas bound. Gas binding because of this effect is a potential concern since ECCS pumps are often initially operated at low flow rates when the gas volume passing through the pump may be at a maximum.

4.10.3.2 Reduced Pump Capacity

All pumps exhibit a loss of developed head when exposed to gas at the pump impeller.

Gas introduced into a pump can render the pump inoperable, even if the gas does not air bind the pump, because the gas can reduce the pump discharge pressure and flow capacity to the point that the pump cannot perform its design function. For example, an HPI pump that is pumping air-entrained water may not develop sufficient discharge pressure to inject under certain small-break LOCA scenarios.

4.10.3.3 Water Hammer

Gas accumulation can result in water hammer or a system pressure transient, particularly in pump discharge piping following a pump start, which can cause piping and component damage or failure. Gas accumulation in the DHR system has resulted in pressure transients that have caused DHR system relief valves to open. In some plants, the relief valve reseating pressure is less than the existing RCS pressure, a condition that complicates recovery. This was encountered, for example, during an event at Sequoyah in which a pressure pulse resulting from gas in RHR discharge piping caused a relief valve to open and rendered both RHR trains inoperable for 6 hours because the relief valve failed to reseat.

4.10.3.4 Premature Failure of Pumps

(1) Unbalanced loads caused by entrained gas and or (2) the reduction in inlet pressure at a pump because of gas in a vertical suction line that causes pump cavitation can result in additional stresses that lead to premature failure of pump components.

4.10.3.5 Interruption of Natural Circulation Flow in the Reactor Coolant System

Gas accumulation can result in pumping noncondensible gas into the reactor vessel or coolant loops that may affect core cooling flow.

4.10.3.6 Delay in Flow Delivery

The time needed to fill voided discharge piping can delay the delivery of water beyond the time frame assumed in the accident analysis.

4.10.4 Control of Voiding

In the Westinghouse improved standard Technical Specifications, surveillance requirement 3.5.2.3 requires the licensee to “Verify ECCS piping is full of water” with a 31-day frequency. This verification usually involves a combination of ultrasonic testing and venting.

Venting of affected systems has often been difficult, mostly where the vent valves are not located at system high points. These locations can sometimes be cleared of voids with a high flow rate of circulating fluid to sweep the gas from the high points. Some licensees have installed additional vent valves to enable proper venting. Generic Letter 2008-1 says “No specific NRC requirement mandates the installation of vent valves on the subject systems. However, failure to translate the design basis of assuring the system is maintained sufficiently full of water to maintain operability into drawings, specifications, procedures, and instructions is a violation of Criterion III in Appendix B to 10 CFR Part 50."

Steam generator water hammer is the specific type of water hammer experienced by San Onofre and others (Reference 4) caused by the introduction of cold feedwater to a feedwater line voided by steam. This was a significant problem in the mid-1970s, but has been well controlled by a combination of design and procedure changes.

The steam voiding of auxiliary feedwater (AFW) has been controlled through check valve improvements and monitoring of AFW piping temperatures.

4.10.5 Summary

Voided piping is a longstanding NRC concern. Voiding can lead to damaged safety-related equipment and loss of safety function. Licensee diligence is required to control voiding in safety-related piping systems.

4.10.6 References

1. Indian Point 2 – NRC Inspection Report 05000247/2005006 Preliminary White Finding, Accession No. ML051680119

2. NRC IR 50-327, Accession No. 9503080217

3. LER 1997-002-00 Potential Common Mode Failure ff Shutdown Cooling, Waterford

4. NUREG-1190, Loss of Power and Water Hammer Event at San Onofre, Unit 1, on November 21, 1985, Accession No. ML063560431

5. SOER 84-3, Auxiliary Feedwater Pumps Disabled by Backleakage

6. INPO SOER 97-1, Potential Loss of High Pressure Injection and Charging Capability from Gas Intrusion, Accession No. ML081980741

7. INPO Significant Event Notification 179, Long-Standing Design Weaknesses and Ineffective Corrective Actions Cause Gas Binding Failures of High Head Safety Injection Pumps

8. Wolf Creek Generating Station – NRC Special Inspection Report 5000482/2008007, Accession No. ML081160060

9. Palo Verde Nuclear Generating Station, NRC Special Inspection Report 05000528/2004014, 05000529/2004014, AND 05000530/2004014; Preliminary Greater Than Green Finding, Accession No. ML050050287

10. IN 97-38, Level-Sensing System Initiates Common-Mode Failure of High-Pressure-Injection Pumps, June 24, 1997, Accession No. ML031050514

11. LER 99-011-01, 10 CFR 50.73(a)(2)(i)(B) and 10 CFR 50.73(a)(2)(ii)(B), Inoperability of Service Water System Train B Due to Deformed Discharge Expansion Joint on In-Service Pump 2SWS*P21C, Accession No. ML003700492

12. NRC Generic Letter 2008-01: Managing Gas Accumulation in Emergency Core Cooling, Decay Heat Removal, and Containment Spray Systems, Accession No. ML072910759

13. NRC Information Notice 97-40 Potential Nitrogen Accumulation Resulting from Backleakage from safety Injection tanks, Accession No. ML031050497