B.6 LER No. 336/95-002

Event Description: Containment sump isolation valves potentially unavailable due to pressure locking

Date of Event: January 25, 1995

Plant: Millstone 2

B.6.1 Event Summary

Northeast Utilities determined that the containment sump isolation valves at Millstone 2 were subject to pressure locking, which could preclude their operating following a loss of coolant accident (LOCA). This analysis assumes the pressure-locking problem would impact plant response to a large- and medium-break LOCA, and estimates an increase in the core damage probability (CDP) over a one-year period of 3.1×10^{-5}, over a nominal value for the same period of 4.6×10^{-5}. Uncertainty in the frequency of large- and medium-break LOCAs (neither of which have been observed) and in the impact of the pressure-locking problem contribute to a substantial uncertainty in this estimate.

B.6.2 Event Description

On January 25, 1995, Northeast Utilities determined that the containment sump isolation valves (valves 2-CS-16.1A and -16.1B) at Millstone 2 were subject to pressure locking, which could preclude their operating for sump recirculation following a LOCA (see Fig. B.6.1). Pressure locking is a phenomenon where water trapped in the bonnet cavity and in the space between the two disks of a parallel-disk gate valve is pressurized above the pressure assumed when sizing the valve's motor operator. This prevents the valve operator from opening the valve when required. Water can enter a valve bonnet during normal valve cycling or when a differential pressure moves a disk away from its seat, creating a path to either increase fluid pressure or fill the bonnet with high-pressure fluid. A subsequent increase in the temperature of the fluid in the valve bonnet will cause an increase in bonnet cavity pressure due to thermal expansion of the fluid.

Valves 2-CS-16.1A and -16.1B had initially been reviewed for pressure locking and thermal binding issues in December 1989. That review, in response to an Institute of Nuclear Power Operations (INPO) Significant Operating Events Report (SOER), was conducted by Stone and Webster and concluded that these valves were not susceptible to pressure locking or thermal binding.

In 1994, following an inspection of the Millstone 1 motor-operated valve (MOV) program by the NRC and in order to address a planned NRC Generic Letter (GL) on the pressure locking/thermal binding issue (GL 95-07), Raytheon Corporation was contracted by the licensee to perform a second analysis of all safety-related "GL 89-10" MOVs. Raytheon's final report, issued in October 1994, concluded that valves 2-CS-16.1A and -16.1B were susceptible to pressure locking.

A subsequent analysis by the valve vendor, Anchor Darling, determined that the maximum pressure lock that valves 2-CS-16.1A and -16.1B could overcome and still open was approximately 1.0 MPa (150 psi). Based on information provided in NUREG-1275, Vol. 9 (Ref. 2), an increase in bonnet temperature of about 3 °C (5°F), if the bonnet were water solid, would cause this pressure.[a] Following a LOCA, water in the containment sump could reach 143 °C (289°F). During the approximately 44 min before the initiation of sump recirculation, the hot water in the containment sump would easily heat the valve bonnet by the 3 °C (5°F) required to pressure-lock the valve.

The licensee noted that the two containment sump isolation valves, as well as two downstream check valves (2-CS-15A and -15B) are subject to periodic surveillance testing. As a consequence of these tests, water tends to accumulate in the piping between the isolation valves (-16.1A/B) and the sump. This water may serve as an insulator, preventing hot sump water from reaching the isolation valves and minimizing the impact of the pressure locking condition. At the time Licensee Event Report (LER) No. 336/95-002 was written, check valve 2-CS-15A was being overhauled because the train A sump piping was found to be full of water. Evidence of water was also found in the train B piping. Further analysis by Raytheon concluded that if the sump piping was full of water, the temperature increase would only occur along the first 0.3 m (about 1 ft) of the filled pipe on the containment side.

The report of a special NRC inspection that was performed at the time of the event (Ref. 3) provides additional information concerning the testing of isolation valves 2-CS-16.1A and -16.1B and check valves 2-CS-15A and -15B, plus the arrangement and condition of the valves. Valves 2-CS-16.1A and -16.1B were cycled monthly to verify operability and measure valve opening time. When cycled, water that collected in the piping between the isolation and check valve [0.6 to 0.9 m of 61-cm pipe (2 to 3 ft of 24-in. pipe)] would flow into the longer containment piping, equalizing the water level upstream and downstream of the valves. Prior to each test, a vent valve between the isolation and associated check valve was opened to confirm that the check valve was not leaking excessively. If it was, the Refueling Water Storage Tank (RWST) was isolated from the Emergency Core Cooling System (ECCS) header during the valve test to minimize the amount of water that flowed into the containment.

Every three months, valves 2-CS-16.1A and -16.1B, and check valves 2-CS-15A and -15B were also tested to meet the inservice testing requirements of ASME Section XI. The piping between the two valves was filled with borated water by hose-jumpering around the check valve using two vent connections. A hose and rotameter was then connected from the Primary Makeup Water (PMW) system to the vent connection between the two valves and the piping was pressurized to the normal operating pressure of the PMW system [0.86–1.0 MPa (125–150 psi)]. Flow through the rotameter indicated the partial stroking of the check valve. This test, by filling and pressurizing the fluid volume between the valves, would tend to move the downstream (pressurized) isolation valve disk away from its seat, and fill and pressurize the valve bonnet. The isolation valves were also stroked, but the testing sequence (before or after the check valve test) was not specified. If the isolation valves were stroked before the check

[a]Preliminary pressure-locking data from flexible wedge gate valve tests at the Idaho National Engineering Laboratory indicates that bonnet pressurization also occurs if small quantities of air are trapped in the bonnet, although at higher temperatures than for a water-solid condition (NRC memorandum from M.E. Mayfield to R.H. Wessman, June 25, 1996).

valves were tested, the piping between the two valves would have been left full of water following the check valve test.

A walkdown in conjunction with the inspection indicated that packing leakage had occurred on valves 2-CS-16.1A and -16.1B since the last packing change in 1992. This was indicated by boric acid crystals and rust in the packing gland areas of both valves. This leakage indicated that the valve bonnets had been filled with water at least some of the time since 1992. A closed 1984 work order for valve 2-CS-16.1B to be cleaned of boric acid crystals and for the valve packing to be tightened provides evidence of earlier water-filled valve bonnets.

In order to preclude pressure locking of valves 2-CS-16.1A and -16.1B, licensee personnel drilled a 0.3 cm (1/8 in.) diameter hole through the containment-side disk center line on these valves. These holes will prevent the volume between the two disks from pressurizing.

B.6.3 Additional Event-Related Information

Following a LOCA, the containment sump collects water from the break in the reactor coolant system, (RCS), the safety injection systems, and the containment spray system. After water in the refueling water storage tank (RWST) is depleted, the containment sump provides a source of recirculation water for continued decay heat removal and containment spray. Upon receipt of a sump recirculation actuation signal (SRAS), at 9.5% RWST level, the high-pressure and low-pressure safety injection (HPSI and LPSI) pumps and the containment spray pump suctions are automatically transferred to the containment sump by the opening of valves 2-CS-16.1A and -16.1B. The SRAS also trips the LPSI pumps to maximize the net positive suction head to the HPSI pumps and the containment spray pumps. HPSI pump flow provides decay heat removal following sump switchover.

The containment "sump" at Millstone 2 is actually the floor of the containment, and not a separate pit below the containment floor. Two 61-cm (24-in.) diameter pipes, which protrude approximately 28 cm (11 in.). above the floor, drop vertically about 1.5 m (5 ft), and then run almost horizontally, with a slight downward slope, about 6.1 m (20 ft) to valves 2-CS-16.1A and -16.1B. Check valves CS-15A and -15B are located 0.6–0.9 m (2–3 ft) downstream of the isolation valves (Fig. B.6.2).

B.6.4 Modeling Assumptions

This analysis assumes that sump isolation valves 2-CS-16.1A and -16.1B would be unavailable due to pressure locking following a large-break LOCA, and possibly following a medium-break LOCA, for those periods during which the valve bonnets were filled with water prior to drilling holes in the containment-side disks. Both of these LOCAs rapidly deplete the RWST and provide little time for thermal equilibration and valve bonnet depressurization which would permit initially pressure-locked isolation valves to operate. However, switchover to sump recirculation following a small-break LOCA occurs after about 6 h; this time is assumed to be adequate to allow the valve bonnets to depressurize to the point that the valves will operate correctly.

The valve bonnets for valves 2-CS-16.1A and -16.1B were assumed to be filled with water following the quarterly tests of 2-CS-15A and -15B, during which the PMW system was used to fill and pressurize the pipe section between each isolation and check valve. Reference 3 notes that the isolation valve vendor, Anchor/Darling had concluded that a closing thrust of 12,580 N (91,000 pounds) would be required to seal the isolation valve disk against a pressure of 45 psig (a conservative estimate of the pressure the RWST head would impose on the valve disk). With a valve actuator maximum thrust of 6,220 N (45,000 pounds) [approximately one-half of the required closing thrust for 0.31 MPa (45 psig)] and an actuator torque switch trip point one-half again of the required value, it is reasonable to assume that the isolation valve disk would move away from its seat during the 0.86–1.0 MPa (125–150 psi) PMW system pressurization imposed during the tests on check valves 2-CS-15A and -15B. This disk movement would allow water to enter the space between the isolation valve disks and, with leaking packing, the isolation valve bonnet. Once a bonnet was filled with water, minor leakage past the normally-closed check valve would be sufficient to maintain the bonnet full of water.

Filled valve bonnets were assumed to remain filled until an isolation valve was cycled. When the valve was cycled, water in the bonnet and between the check valve and the isolation valve would flow into the sump piping in the containment, equalizing the water levels on both sides of the isolation valve. Evaporation[b] would gradually reduce the volume of water in the sump piping. This would explain why only evidence of water (boric acid crystals) was found in the B train piping, and not a large volume of water (the large quantity of water found in the A train piping was the result of excessive check valve leakage). Because check valves 2-CS-15A and -15B were tested quarterly and valves 2-CS-16.1A and -16.1B were cycled monthly, the valve bonnets would normally (without the excessive check valve leakage) be expected to be filled with water one-third of the time if the isolation valves were always cycled before the check valves were tested. Although no requirement was placed on the sequence of testing, the isolation valves (2-CS-16.1A and -16.1B) were typically cycled after the check valve tests (2-CS-15A and -15B) most of the time.[c] Assuming this occurred in 75% of the tests reduces the estimated fraction of time during which the sump isolation valves were subject to pressure locking to one-twelfth. (If the sump valves had always been tested after the check valves, the potential for pressure locking would be significantly reduced, or perhaps eliminated. Pressure locking of the isolation valves would only be possible under these conditions if a substantial leak path exists past both the check valve disk and the isolation valve bonnet.)

The impact of partially-filled sump piping (evidence of past water in the B train sump piping was described in the LER), caused by monthly isolation valve cycling, on reducing the potential for pressure locking was considered to be minor and was not addressed. The piping arrangement at Millstone 2 (see Additional Event-Related Information) prevents water from entering the sump piping until the containment water level reaches 28 cm (11 in.). At this point, hot water will drop into the vertical sump

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[b]Following the discovery of the potential for pressure-locking and the drilling of holes in the downstream disks, the licensee began to bypass the check valve and fill the sump piping to provide an insulating barrier against the hot sump water that would exist following a LOCA. This process is performed monthly to ensure that evaporation to the containment will not significantly reduce the volume of water in the sump piping [personal communication, D. Beaulieu (NRC) and J. Minarick (SAIC), July 26, 1996].

[c]Personal communication, M. Buckley (NRC) and J. Minarick (SAIC), February 21, 1997.

piping segment and rapidly fill the piping. The turbulence that results is expected to mix the hot containment water with the water in the partially-filled sump pipes, exposing the sump isolation valves to temperatures well above ambient.[d] However, the excessive amount of water that apparently existed in the train A sump piping due to leakage past check valve 2-CS-15A is believed to have provided an insulating barrier for MOV 2-CS-16.1A for part of the one-year period prior to discovery of the pressure locking problem (one year is the longest unavailability period used in an ASP analysis). During the time that water in the train A sump piping insulated 2-CS-16.1A, the potential impact of sump valve pressure locking was minimal (an increase in CDP less than the ASP screening value of 1×10^{-6} is calculated).

Reference 3 notes that 2-CS-15A leaked excessively during a test on December 8, 1993, when water completely filled the train A sump piping, as evidenced by an increase in containment sump level. No further incidents of gross check valve leakage were identified. In early 1995, when the sump valves and piping were inspected, the water level in the train A pipe was found to be at the top of the 2-CS-16.1A disk (because of the slight upward slope of the sump lines towards containment, the water only partially filled the horizontal pipe). The reduction in water level since December 8, 1993, is assumed to have been caused by evaporation. This reduction is reasonably consistent with a licensee estimate of the evaporation rate in the sump piping, performed to support a strategy of maintaining the sump lines full of water to prevent pressure locking (described in footnote b), and submitted as a part of Reference 4 (calculation GL89-10-1243 M2, Rev. 1).

Following the December 8, 1993, check valve leakage, when the sump piping was completely filled, MOV 2-CS-16.1A would be protected from heatup during a LOCA. At some time thereafter, as water in the sump piping evaporated, the MOV would become susceptible to pressure locking. Licensee memorandum NE-95-SAB-297, dated July 26, 1995, and also included in Reference 4, concluded that the water level in the sump piping should be maintained above –7.3 m (–24 ft) [0.6 m (2 ft) below the top of the vertical sump piping shown in Figure B.6.2] to eliminate the potential formation of thermal diffusive currents, which could cause sump valve heatup and pressure locking following a LOCA. The licensee estimated that water in a completely full sump pipe would evaporate to –7.3 m (–24 ft) in about 106 d. Applying this estimate in this analysis, 2-CS-16.1A, and, therefore, both 2-CS-16.1A and -16.1B, were assumed to be potentially vulnerable to pressure locking for [1 – (106/365)], or 0.71 of the one-year period prior to discovery. Combining this value with the fraction of time the valves were considered subject to pressure locking based on the testing regimen at Millstone 2, 0.083, results in an overall estimate of 0.059.

The Accident Sequence Precursor (ASP) Program typically considers the potential for core damage following four postulated initiating events in pressurized water reactors: transient, loss of offsite power (LOOP), small-break LOCA, and steam generator tube rupture (SGTR). Supercomponent-based linked fault tree models are available for each of these postulated initiating events. The two initiating events that are of concern in this analysis (i.e., large- and medium-break LOCAs) are not currently modeled. However, for both of these initiating events, unavailability of sump recirculation is assumed to result in core damage in all probabilistic risk assessments.

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[d] A simple mixing calculation, without consideration of the sump piping as a heat sink, supports an assumption that the sump piping would have to be initially almost full to preclude a substantial temperature increase.

The significance of this event was estimated by first considering the increase in CDP over the unavailability period. Since a nonrecoverable failure of valves 2-CS-16.1A and -16.2B will fail both high- and low-pressure recirculation, and recirculation is required following a medium- or large-break LOCA, the significance of the event can be estimated directly from the change in the probability of recirculation failure and the probability of a medium- and large-break LOCA in the unavailability period.

During the time period that valves 2-CS-16.1A and -16.1B were assumed to be subject to pressure locking, this pressure-locking condition was assumed to prevent the valves from opening for sump recirculation following a large-break LOCA (LBLOCA). Sump recirculation would be initiated by an SRAS signal about 44 min after the break, allowing little time for bonnet depressurization. The RWST would be empty about 4 min later, allowing little time for corrective action.

Following a medium-break LOCA (MBLOCA), the condition of the valves is considered indeterminate. Additional time (well over 1 h) exists before the RWST is depleted, and this time may allow for depressurization of at least one of the valve bonnets to the point that the valve will operate. For a medium-break LOCA, a sump isolation valve failure probability of 0.5 was assumed, given the pressure-locking condition existed.

The frequency of a large-break LOCAs is estimated to be 2.7×10^{-4}/yr, while that of a medium-break LOCA is estimated to be 5.0×10^{-4}/yr. These values are based on a survey of large- and medium-break LOCA frequencies performed in support of the analysis of Turkey Point LER 250/94-005 in the 1994 precursor report (see Appendix H to Ref. 5 for additional information).

The increase in core damage probability due to LBLOCAs and MBLOCAs based on these initiating event frequencies and the assumed probability of pressure locking are given below. The probability of core damage due to a LBLOCA is

$$2.7 \times 10^{-4} \begin{Bmatrix}\text{prob of a LBLOCA} \\ \text{over a 1-yr period}\end{Bmatrix} \times 0.059 \begin{Bmatrix}\text{prob that pressure-} \\ \text{lock condition exists}\end{Bmatrix} \times$$

$$\left[1.0 \begin{Bmatrix}\text{prob of sump recirc failure} \\ \text{due to press-locked valves}\end{Bmatrix} - 2.6 \times 10^{-4} \begin{Bmatrix}\text{nominal failure prob} \\ \text{for two sump valves}\end{Bmatrix} \right]$$

$$= 1.6 \times 10^{-5} \begin{Bmatrix}\text{increase in core damage} \\ \text{prob due to a LBLOCA}\end{Bmatrix}.$$

The probability of core damage due to a MBLOCA is

$$5.0 \times 10^{-4} \begin{Bmatrix}\text{prob of a MBLOCA} \\ \text{over a 1-yr period}\end{Bmatrix} \times 0.059 \begin{Bmatrix}\text{prob that pressure-} \\ \text{lock condition exists}\end{Bmatrix} \times$$

$$\left[0.5 \begin{Bmatrix}\text{prob of sump recirc failure} \\ \text{due to press-locked valves}\end{Bmatrix} - 2.6 \times 10^{-4} \begin{Bmatrix}\text{nominal failure prob} \\ \text{for two sump valves}\end{Bmatrix} \right]$$

$$= 1.5 \times 10^{-5} \begin{Bmatrix}\text{increase in core damage} \\ \text{prob due to a MBLOCA}\end{Bmatrix}.$$

B.6.5 Analysis Results

Combining the estimates for large- and medium-break LOCAs results in an estimated increase in the CDP because of the sump isolation valve pressure locking over a 1-year period of 3.1×10^{-5}. The dominant core damage sequences for these events involve

- a postulated large-break or medium-break LOCA and
- the failure of high-pressure recirculation.

The dominant sequence for a large-break LOCA is highlighted on the event tree in Figure B.6.3. A similar sequence exists for the medium-break LOCA.

A greater than usual uncertainty is associated with this estimate. This uncertainty is dominated by the uncertainties in the frequencies of large- and medium-break LOCAs (neither of which have occurred) and by uncertainties in the assumptions regarding the inoperability of the sump isolation valves because of the pressure-locking problem.

The nominal CDP over a one-year period estimated using the ASP Integrated Reliability and Risk Analysis System (IRRAS) models for Millstone 2 is 4.6×10^{-5}. The increase in the CDP because of the unavailable sump isolation valves (3.1×10^{-5}) was added to the nominal CDP for a one-year period (4.6×10^{-5}) to estimate a CCDP of 7.7×10^{-5} for the one-year period prior to discovery of the pressure locking problem. For earlier one-year periods, when 2-CS-15A was not leaking excessively, the CCDP for the event would not be affected by the flooded train A sump piping. For such periods, a CCDP of 8.9×10^{-5} would be estimated.

Section 6.3.3.1 of the Millstone 2 FSAR states that during normal operation the containment sump recirculation lines between the sump isolation valves and the HPSI pumps will be filled with stagnant water, while portions between the sump inlets and the sump valves will not be filled with water. As described in the Event Description, piping downstream of the isolation valves was not maintained full of water following valve testing, and water was allowed to accumulate in the sump piping upstream of the isolation valves. If the licensee had taken measures to adhere to the FSAR statement, the isolation valves would most likely have been subject to pressure locking at all times. This would have increased the CCDP associated with the event to 5.7×10^{-4}.

B.6.6 References

1. LER 336/95-002, Rev. 1, "Containment Sump Isolation Valves—Potentially Subject to Pressure Locking," July 7, 1995.

2. *Operating Experience Feedback Report—Pressure Locking and Thermal Binding of Gate Valves*, NUREG-1275, Vol. 9, March 1993.

3. "Millstone 2 Motor-Operated Valve Inspection," NRC Special Inspection Report 50-336/95-08, U.S. Nuclear Regulatory Commission, March 22, 1995.

4. "Generic Letter 95-07, Pressure Locking and Thermal Binding of Safety-Related Power-Operated Gate Valves," Response to Request for Additional Information," letter from T. C. Feigenbaum, Northeast Utility Services Company, to U. S. Nuclear Regulatory Commission, August 7, 1996.

5. *Precursors to Potential Severe Core Damage Accident Sequences: 1994, A Status Report*, NUREG/CR-4674, Vol. 21, December 1995.

Figure removed during SUNSI review.

Fig. B.6.1. Containment Sump/RWST Configuration for Millstone 2 (Source: *Millstone 2 Individual Plant Examination*).

Figure removed during SUNSI review.

Fig. B.6.2. Millstone Unit 2 Containment Sump Piping (Source: "Millstone 2 Motor-Operated Valve Inspection," NRC Special Inspection Report 50-336/95-08, March 22, 1995).

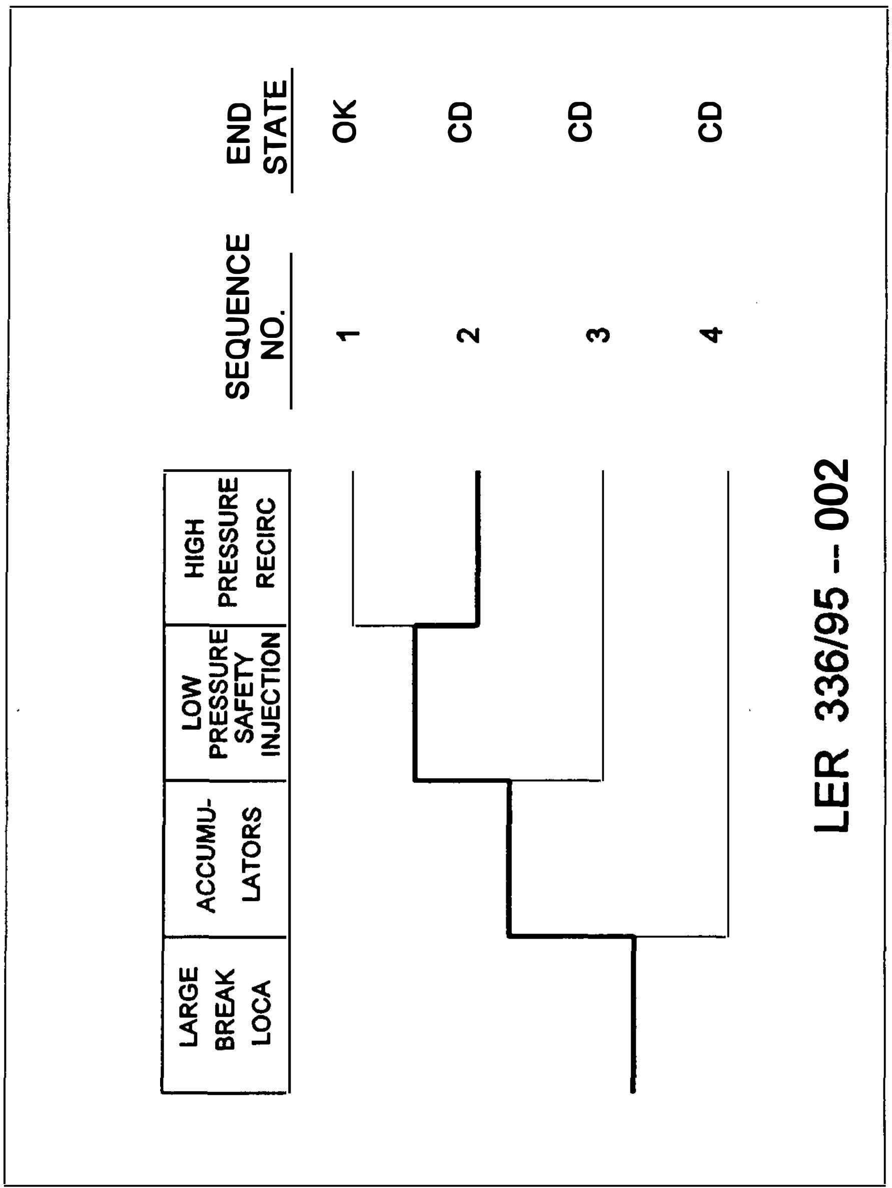

Fig. B.6.3. Dominant core damage sequence for LER No. 336/95-002.