B.4 LER No. 272/96-002

Event Description: Charging pump suction valves from the RWST potentially unavailable because of pressure locking

Date of Event: January 10, 1996

Plant: Salem 1 and 2

B.4.1 Event Summary

During an evaluation for potential pressure locking and thermal binding in power-operated gate valves, as required by Generic Letter (GL) 95-07 (Ref. 1), personnel determined that the following valves on both units were subject to pressure locking (see Fig. B.4.1) (Ref. 2):

Valves SJ1 and SJ2	Valves on the refueling water storage tank (RWST) supply line to the charging/safety injection pump suction
Valves 1SJ113 and 2SJ113	Valves on the cross-tie connection from the suction of the charging pumps to the suction of the safety injection (SI) pumps
Valves 1CS2 and 2CS2	Isolation valves on the containment spray header

Pressure locking of valves SJ1 and SJ2 could prevent these valves from opening when required for safety injection. Pressure locking of valves 1SJ113 and 2SJ113 could prevent these valves from opening if required during the recirculation phase of a loss-of-coolant accident (LOCA). Pressure locking of valves 1CS2 and 2CS2 could impact the containment spray function before the recirculation phase of a LOCA.

In addition, valves PR6 and PR7, power-operated relief valve (PORV) block valves, were determined to be susceptible to thermal binding. Thermal binding of these block valves could render the associated PORVs unavailable for feed-and-bleed operations if the block valves were to be closed before an accident condition.

Both units were shut down and defueled at the time of the evaluation. This analysis assumes the susceptible valves could impact the plant response to a small-break LOCA, a steam generator tube rupture (SGTR), a PORV lifting and failing to reseat, and a reactor coolant pump seal package failure. An increase in the core damage probability (CDP) for a 1-year period of 5.8×10^{-6} was calculated over a nominal value for the same period of 3.0×10^{-5}. This increase in the CDP is applicable to each unit.

B.4.2 Event Description

On January 10, 1996, both units were shut down and defueled. At that time, Public Service Electric and Gas Company determined that the RWST supply valves to the charging/SI pump suction, the valves on the cross tie connection from the suction of the charging pumps to the suction of the SI pumps, and the containment spray header isolation valves on both units were subject to pressure locking. Additionally, the PORV block valves on both units were determined to be subject to thermal binding.

Pressure locking occurs when the fluid in the valve bonnet is at a higher pressure than the adjacent piping at the time of the valve opening. The two most likely scenarios for elevating the pressure in the valve bonnet relative to the pressure in the valve system are the following:

1. Thermal pressure locking (or bonnet heatup) can occur when an incompressible fluid is trapped in the valve bonnet (e.g., during valve closure), followed by heating up the volume in the bonnet. The bonnet heatup scenarios include heating the valve bonnet by an increase in the temperature of the environment during an accident, heat up because of an increase in the temperature of the process fluid on either side of the valve, etc. (Normal ambient temperature variation is not considered because it occurs over a long time and pressure changes tend to be alleviated through extremely small amounts of leakage. Further, operating experience shows that normal temperature variations are not a source of pressure locking events.)

2. Hydraulic pressure locking (or pressure-trapping) can occur when an incompressible fluid is trapped in the valve bonnet, followed by depressurization of the adjacent piping before valve opening. Examples of hydraulic pressure locking scenarios include back-leakage past check valves and system operating pressures that are higher than the system pressure when the valve is required to open.

Pressure locking is of concern because the pressure in the space between the two discs of a gate valve can become pressurized above that assumed when sizing the valve's motor operator. This could prevent the valve operator from opening the valve when required.

Thermal binding is a phenomenon in which temperature changes of the valve's internal components cause the valve stem to expand after closure. This results in a higher required opening thrust that may be above the opening thrust assumed when sizing the valve motor operator.

The original plant designs at Salem 1 and 2 did not account for pressure locking and thermal binding effects. In 1977, plant personnel modified double-disc gate valves based on recommendations by Westinghouse. In 1986, a review of flexible wedge gate valves in response to INPO SOER 84-7 determined that the valves listed in this licensee event report (LER) were not susceptible to pressure locking or thermal binding. The more stringent requirements of GL 95-07 reversed this earlier conclusion for the previously listed valves.

Licensee personnel determined that valves SJ1 and SJ2 were subject to the "pressure-trapping" effect. A maximum bonnet pressure of 96 psig was estimated based on quarterly surveillance testing that recirculated water from the residual heat removal (RHR) pump discharge to the RWST suction line where SJ1 and SJ2 are located. The licensee indicated that once this increased bonnet pressure was established, no mechanism

existed for the pressure to be relieved (assumption used in response to GL 95-07). At degraded voltage conditions, the licensee could not guarantee sufficient thrust would be generated by the motor operator to overcome the bonnet pressure. This would result in a loss of high head injection, though the charging pumps would be available for high-pressure recirculation.[3]

Valves 1SJ113 and 2SJ113 were determined to be subject to both the "pressure-trapping" effect and "bonnet heatup." The maximum bonnet pressure was estimated to be 1.55 MPa (225 psig). Again, once this increased bonnet pressure was established, no mechanism existed for the pressure to be relieved. The "bonnet heatup" occurs in the first 2 min following the initiation of the hot-leg recirculation phase of a LOCA. The "pressure-trapping" is the result of surveillance testing.

Valves 1CS2 and 2CS2 were determined to be subject to the "pressure-trapping" effect. A maximum bonnet pressure was estimated at 1.72 MPa (250 psig) as a result of surveillance testing of the containment spray pumps immediately upstream of the valves. Pump start on a containment high pressure may relieve the high pressure on the upstream side of the disc and allow the valves to open.

Valves PR6 and PR7 were determined to be subject to thermal binding. These valves are normally open at power unless they are cycled for surveillance testing or a fault is on the PORV.

B.4.3 Additional Event-Related Information

The charging system (CVC) consists of two centrifugal charging pumps and one positive displacement pump. On an SI signal, the centrifugal charging pumps provide for high head safety injection. If valves SJ1 and SJ2 fail closed, the safety injection function of the charging pumps is defeated. However, assuming the charging pumps were throttled back following the failure of SJ1 and SJ2 before damage from a loss of suction, they would still be capable of providing service in the (piggyback) recirculation mode. The two safety injection pumps provide for intermediate head safety injection. Failure of valves SJ1 and SJ2 does not impact this mode of injection into the reactor coolant system (RCS).

Piggyback recirculation to the charging system and the SI system is provided separately by the individual RHR pumps. The A RHR pump provides for piggyback recirculation to the SI pump suction header. The B RHR pump provides for piggyback recirculation to the CVC suction header. Valves 1SJ113 and 2SJ113 are in parallel and connect the CVC and SI suction headers together. This connection provides an alternate path for recirculation to either the CVC or SI system should the primary path fail. Therefore, failure of both SJ113 valves does not fail piggyback recirculation without an additional failure occurring.

The containment spray system takes suction from the RWST and delivers spray flow to the containment via valves 1CS2 and 2CS2. A failure of these valves to open would preclude containment spray using the containment spray pumps. Downstream of the CS2 valves, a connection from the discharge of the RHR pumps exists to provide containment spray in the recirculation phase of a LOCA. This path would be unaffected by a failure of the CS2 valves. Additionally, five containment cooler units will limit the design basis pressure increase in containment, assuming all five units operate without failure.

B.4.4 Modeling Assumptions

Valves SJ1 and SJ2 were considered to be unavailable because of pressure locking following a small-break LOCA (SLOCA). The charging pumps or the SI pumps are required to protect the core during a SLOCA. Because the pressure locking mechanism was assumed to be from "pressure-trapping," the condition was assumed to have existed for 1 year following surveillance testing that recirculated higher pressure water back to the RWST. Basic event CVC-MOV-CC-SUCT represents the combination of SJ1 and SJ2 failing closed, so this event was set to "TRUE" (failed). The common cause failure of SJ1 and SJ2 was removed by setting basic event CVC-MOV-CF-SUCT to "FALSE" (not possible).

Large-break and medium-break LOCAs are not currently modeled by the Integrated Reliability and Risk Analysis System (IRRAS). These larger LOCAs are predicted to remove all decay heat out of the break location. Therefore, accumulator response and the progression to the recirculation mode are the key elements in a large-break or medium-break LOCA event tree. Those responses are not significantly impacted by the valve failures reported in the LER. Thus, no effort was made to model these accident conditions.

Similar to valves SJ1 and SJ2, valves 1SJ113 and 2SJ113 were considered to be unavailable because of pressure locking following a SLOCA. These valves were not specifically modeled in IRRAS; therefore, a basic event representing the probability of failure of 1SJ113 and 2SJ113 was added (HPR-MOV-CC-HPI) with a base failure probability of 9.0×10^{-6} to the high-pressure recirculation (HPR) and HPR-L [loss of offsite power (LOOP)] fault trees. This basic event was added via an "or" gate with a new basic event (HPR-HPI-FM-CVC or HPR-CVC-FM-HPI) representing the success of the recirculation flow path elements in the opposite RHR train. Subsequently, basic event HPR-MOV-CC-HPI was set to TRUE (failed).

The PORV block valves (PR6 and PR7) were not considered for the analysis. These valves are subject to thermal binding that can be mitigated over time. Additionally, these valves would need to be closed at the initiation of an accident to impact the ability of the unit to conduct feed-and-bleed operations. The Salem individual plant examination (IPE) indicates that the probability of PR6 or PR7 being closed could range as high as 3.2×10^{-5} (Ref. 4). When combined with the probability of an accident condition requiring feed-and-bleed, consideration of a PORV block valve failure becomes insignificant for analysis purposes. Additionally, the Salem final safety analysis report (FSAR) does not take credit for the PORV block valves mitigating the severity of any accident.[5]

It was assumed that the failure of the containment spray valves would not impact the probability of core damage. The licensee considered that the containment spray pump start following an SI signal would likely relieve pressure on 1CS2 and 2CS2, allowing these valves to open. Furthermore, several alternatives appear to be available to reduce containment pressure if required.

The IRRAS response to an SGTR is modified. Previously, a loss of the high-pressure injection (HPI) function led directly to core damage. The possibility of lowering RCS pressure below the steam generator safety valve set point within 30 min is allowed following the loss of HPI capability by adding a basic event PCS-XHE-DEPR-30. Based on the operator burden under a short time constraint, a failure probability of 0.1 is assigned to the new basic event, PCS-XHE-DEPR-30.

The basic event for the probability that an operator fails to switch the auxiliary feedwater (AFW) system water supply to a backup source (AFW-XHE-XA-CST) was lowered from 4.0×10^{-2} to 1.0×10^{-3}. This change was based on the size of the normal AFW water supply (200,000 gal) and the added time this would allow an operator to switch to a backup source of water.

B.4.5 Analysis Results

This event is most sensitive to a SLOCA sequence, which accounts for 81% of the increase in the CDP for the 1-year period analyzed. An overall increase of 5.8×10^{-6} in the CDP was calculated. This is above the base probability for core damage (the CDP) for the same period of 3.0×10^{-5}. The dominant core damage sequence, highlighted as sequence number 06 on the event tree in Fig. B.4.2, involves:

- an SLOCA,
- the successful trip of the reactor,
- the successful operation of the AFW system, and
- the failure of the HPI system (SI pumps) combined with the initial injection phase failure of the CVC system.

The next most significant sequence involves an SGTR and contributes 13% of the total increase in the CDP. This sequence also leads to core damage based on a failure of the HPI system and a failure to depressurize the RCS in a timely manner. Loss of HPI is the primary failure mechanism involved in all of the most dominant core damage sequences.

The first sequence that involves a failure of HPR or the failure of valves 1SJ113 and 2SJ113 is LOOP sequence number 10. This sequence contributes less than 1% to the total increase in the CDP. Therefore, the only significant valve failure related to this analysis from the LER involves the pressure locking of valves SJ1 and SJ2.

Definitions and probabilities for selected basic events are shown in Table B.4.1. The conditional probabilities associated with the highest probability sequences are shown in Table B.4.2. Table B.4.3 lists the sequence logic associated with the sequences listed in Table B.4.2. Table B.4.4 describes the system names associated with the dominant sequences. Minimal cut sets associated with the dominant sequences are shown in Table B.4.5.

B.4.6 References

1. NRC Generic Letter 95-07, "Pressure Locking and Thermal Binding of Safety-Related Power-Operated Gate Valves," August 17, 1995.

2. LER 272/96-002, Rev. 1, "Motor Operated Gate valves Susceptible to Pressure Locking and Thermal Binding," February 9, 1996.

3. Telephone conversation between Dennis Hassler and Bob Lewis, Salem Generating Station, and R. J. Belles and M. D. Muhlheim, Oak Ridge National Laboratory, February 13, 1997.

4. *Salem Generating Station Individual Plant Examination*, July 1993.

5. *Salem Generating Station Updated Final Safety Analysis Report*, Volume 3.

Figure removed during SUNIS review.

Fig. B.4.1 Composite drawing of the emergency core cooling system at Salem 2

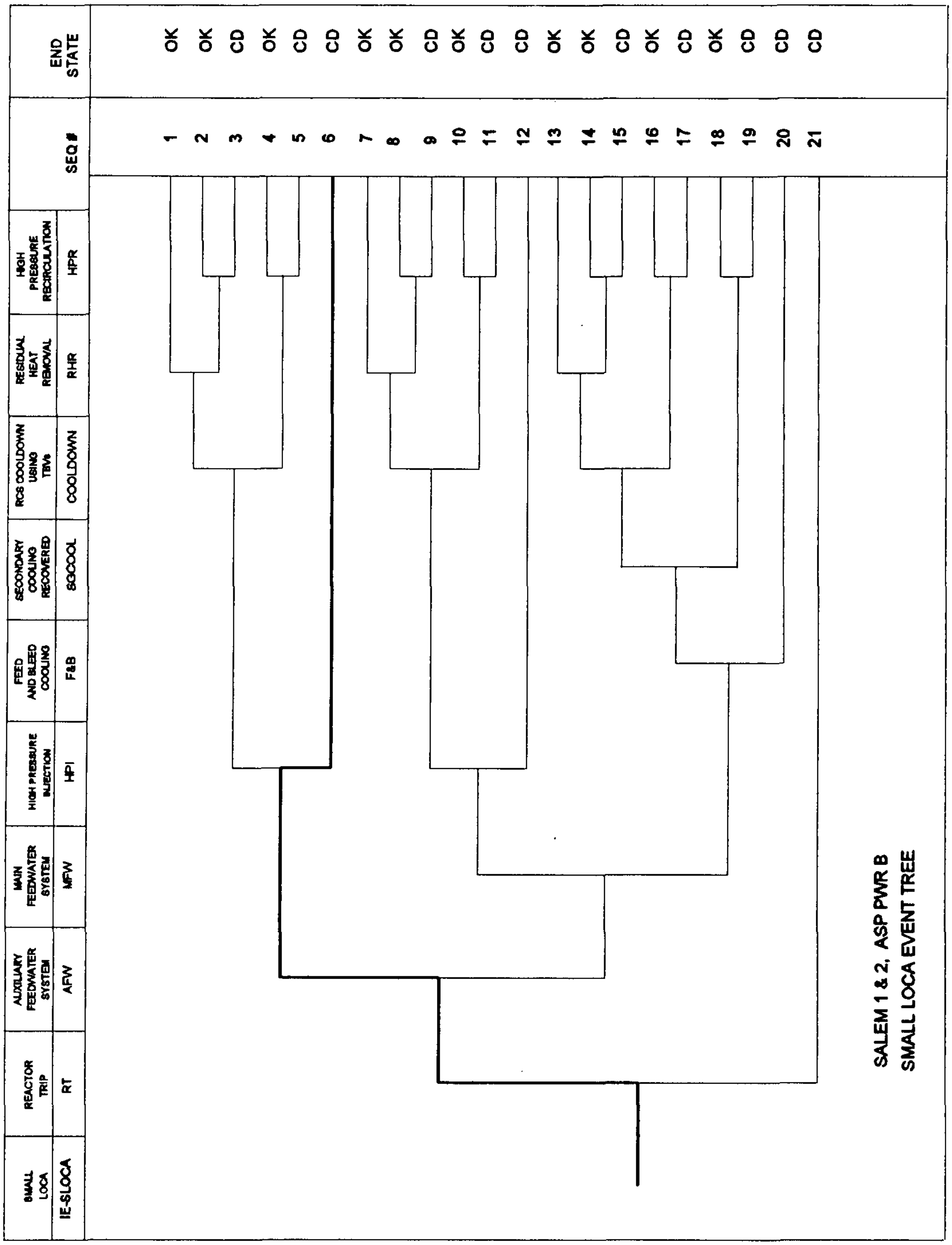

Fig. B.4.2. Dominant core damage sequence for LER No. 272/96-002.

Table B.4.1. Definitions and Probabilities for Selected Basic Events for LER No. 272/96-002

Event name	Description	Base probability	Current probability	Type	Modified for this event
IE-LOOP	Initiating Event–LOOP	8.5 E-006	8.5 E-006		No
IE-SGTR	Initiating Event–SGTR	1.6 E-006	1.6 E-006		No
IE-SLOCA	Initiating Event–SLOCA	1.0 E-006	1.0 E-006		No
IE-TRANS	Initiating Event–Transient (TRANS)	5.3 E-004	5.3 E-004		No
AFW-PMP-CF-ALL	Common-Cause Failure of AFW Pumps	2.8 E-004	2.8 E-004		No
AFW-XHE-NOREC	Operator Fails to Recover the AFW System	2.6 E-001	2.6 E-001		No
AFW-XHE-XA-CST	Operator Fails to Initiate Backup Water Supply	4.0 E-002	1.0 E-003		Yes
CVC-MOV-CC-SUCT	CVC RWST Suction MOVs Fail to Open (SJ1 and SJ2)	1.1 E-004	1.0 E+000	TRUE	Yes
CVC-MOV-CF-SUCT	CVC-HPI RWST Suction Fails to Open (SJ1 and SJ2) CCF	2.6 E-004	2.6 E-004	FALSE	Yes
HPI-MDP-CF-ALL	Common-Cause Failure of HPI Motor-Driven Pumps	7.8 E-004	7.8 E-004		No
HPI-MDP-FC-1A	HPI Train A Fails	3.9 E-003	3.9 E-003		No
HPI-MDP-FC-1B	HPI Train B Fails	3.9 E-003	3.9 E-003		No
HPI-MOV-OC-SUCT	HPI Suction Valves Fail (SJ30)	1.4 E-004	1.4 E-004		No
HPI-XHE-NOREC	Operator Fails to Recover the HPI System	8.4 E-001	8.4 E-001		No
HPI-XHE-XM-FB	Operator Fails to Initiate Feed-and-Bleed Cooling	1.0 E-002	1.0 E-002		No
HPR-CVC-FM-HPI	HPR path to CVC from HPI Fails (excludes failure of SJ113 valves)	7.0 E-003	7.0 E-003	NEW	Yes
HPR-CVC-FM-HPI	HPR path to HPI from CVC Fails (excludes failure of SJ113 valves)	7.0 E-003	7.0 E-003	NEW	Yes
HPR-MOV-CC-HPI	Failure of SJ113 Suction Cross-Connect Valves	9.0 E-006	1.0 E+000	NEW/ TRUE	Yes

Table B.4.1. Definitions and Probabilities for Selected Basic Events for LER No. 272/96-002 (Continued)

Event name	Description	Base probability	Current probability	Type	Modified for this event
MFW-SYS-TRIP	MFW System Trips	2.0 E-001	2.0 E-001		No
MFW-XHE-NOREC	Operator Fails to Recover MFW	3.4 E-001	3.4 E-001		No
PCS-XHE-DEPR-30	Operator Fails to Depressurize RCS Within 30 Minutes (SGTR-Loss of HPI)	1.0 E-001	1.0 E-001	NEW	Yes
PPR-MOV-OO-BLK1	PORV 1 Block Valve Fails to Close	3.0 E-003	3.0 E-003		No
PPR-MOV-OO-BLK2	PORV 2 Block Valve Fails to Close	3.0 E-003	3.0 E-003		No
PPR-SRV-CC-1	PORV 1 Fails to Open on Demand	3.0 E-002	3.0 E-002		No
PPR-SRV-CC-2	PORV 2 Fails to Open on Demand	3.0 E-002	3.0 E-002		No
PPR-SRV-CO-TRAN	PORVs Open During Transient	4.0 E-002	4.0 E-002		No
PPR-SRV-OO-1	PORV 1 Fails to Reclose After Opening	3.0 E-002	3.0 E-002		No
PPR-SRV-OO-2	PORV 2 Fails to Reclose After Opening	3.0 E-002	3.0 E-002		No
PPR-XHE-NOREC	Operator Fails to Close PORVs or Block Valves	1.1 E-002	1.1 E-002		No

Table B.4.2. Sequence Conditional Probabilities for LER No. 272/96-002

Event tree name	Sequence name	Conditional core damage probability (CCDP)	Core damage probability (CDP)	Importance (CCDP-CDP)	Percent contribution[a]
SLOCA	06	4.8 E-006	4.2 E-008	4.8 E-006	82.1
SGTR	08	7.8 E-007	6.9 E-009	7.8 E-007	13.3
TRANS	08	8.6 E-008	7.5 E-010	8.5 E-008	1.4
TRANS	20	1.7 E-006	1.7 E-006	6.0 E-008	1.0
Total (all sequences)		**3.6 E-005**	**3.0 E-005**	**5.8 E-006**	

[a]Percent contribution to the total importance.

Table B.4.3. Sequence Logic for Dominant Sequences for LER No. 272/96-002

Event tree name	Sequence name	Logic
SLOCA	06	/RT, /AFW, HPI
SGTR	08	/RT, /AFW, HPI, RCS-HPI
TRANS	08	/RT, /AFW, PORV, PORV-RES, HPI
TRANS	20	/RT, AFW, MFW, F&B

Table B.4.4. System Names for LER No. 272/96-002

System name	Logic
AFW	No or Insufficient AFW Flow
F&B	Failure to Provide Feed-and-Bleed Cooling
HPI	No or Insufficient HPI Flow
MFW	Failure of the MFW System
PORV	PORVs Open During Transient
PORV-RES	PORVs Fail to Reseat
RCS-HPI	Failure to Depressurize RCS<SG Relief Within 30 Min (HPI Fails)
RT	Reactor Fails to Trip During Transient

Table B.4.5. Conditional Cut Sets for Higher Probability Sequences for LER No. 272/96-002

Cut set number	Percent contribution[a]	Change in CCDP (Importance)[b]	Cut sets[c]
SLOCA Sequence 06		4.8 E-006	
1	83.3	4.0 E-006	CVC-MOV-CC-SUCT, HPI-MDP-CF-ALL, HPI-XHE-NOREC
2	15.0	7.2 E-007	CVC-MOV-CC-SUCT, HPI-MOV-OC-SUCT, HPI-XHE-NOREC
3	1.6	7.8 E-008	CVC-MOV-CC-SUCT, HPI-MDP-FC-1A, HPI-MDP-FC-1A, HPI-XHE-NOREC
SGTR Sequence 08		7.8 E-007	
1	82.1	6.4 E-007	CVC-MOV-CC-SUCT, HPI-MDP-CF-ALL, HPI-XHE-NOREC, PCS-XHE-DEPR-30
2	14.1	1.1 E-007	CVC-MOV-CC-SUCT, HPI-MOV-OC-SUCT, HPI-XHE-NOREC, PCS-XHE-DEPR-30
3	1.5	1.2 E-008	CVC-MOV-CC-SUCT, HPI-MDP-FC-1A, HPI-MDP-FC-1A, HPI-XHE-NOREC, PCS-XHE-DEPR-30
TRANS Sequence 08		8.5 E-008	
1	32.9	2.8 E-008	PPR-SRV-CO-TRAN, PPR-SRV-OO-2, PPR-XHE-NOREC, CVC-MOV-CC-SUCT, HPI-MDP-CF-ALL, HPI-XHE-NOREC
2	32.9	2.8 E-008	PPR-SRV-CO-TRAN, PPR-SRV-OO-1, PPR-XHE-NOREC, CVC-MOV-CC-SUCT, HPI-MDP-CF-ALL, HPI-XHE-NOREC
3	9.1	7.7 E-009	PPR-SRV-CO-TRAN, PPR-SRV-OO-2, PPR-MOV-OO-BLK2, CVC-MOV-CC-SUCT, HPI-MDP-CF-ALL, HPI-XHE-NOREC
4	9.1	7.7 E-009	PPR-SRV-CO-TRAN, PPR-SRV-OO-1, PPR-MOV-OO-BLK1, CVC-MOV-CC-SUCT, HPI-MDP-CF-ALL, HPI-XHE-NOREC
5	5.9	5.0 E-009	PPR-SRV-CO-TRAN, PPR-SRV-OO-2, PPR-XHE-NOREC, CVC-MOV-CC-SUCT, HPI-MOV-OC-SUCT, HPI-XHE-NOREC
6	5.9	5.0 E-009	PPR-SRV-CO-TRAN, PPR-SRV-OO-1, PPR-XHE-NOREC, CVC-MOV-CC-SUCT, HPI-MOV-OC-SUCT, HPI-XHE-NOREC
7	1.6	1.4 E-009	PPR-SRV-CO-TRAN, PPR-SRV-OO-2, PPR-MOV-OO-BLK2, CVC-MOV-CC-SUCT, HPI-MOV-OC-SUCT, HPI-XHE-NOREC
8	1.6	1.4 E-009	PPR-SRV-CO-TRAN, PPR-SRV-OO-1, PPR-MOV-OO-BLK1, CVC-MOV-CC-SUCT, HPI-MOV-OC-SUCT, HPI-XHE-NOREC

Table B.4.5. Conditional Cut Sets for Higher Probability Sequences for LER No. 272/96-002 (Continued)

Cut set number	Percent contribution[a]	Change in CCDP (Importance)[b]	Cut sets[c]
Trans Sequence 20		6.0 E-008	
1	60.0	3.6 E-008	AFW-XHE-XA-CST, AFW-XHE-NOREC, MFW-SYS-TRIP, MFW-XHE-NOREC , CVC-MOV-CC-SUCT, HPI-MDP-CF-ALL, HPI-XHE-NOREC
2	16.7	1.0 E-008	AFW-PMP-CF-ALL, AFW-XHE-NOREC, MFW-SYS-TRIP, MFW-XHE-NOREC , CVC-MOV-CC-SUCT, HPI-MDP-CF-ALL, HPI-XHE-NOREC
3	11.3	6.8 E-009	AFW-XHE-XA-CST, AFW-XHE-NOREC, MFW-SYS-TRIP, MFW-XHE-NOREC , CVC-MOV-CC-SUCT, HPI-MOV-OC-SUCT, HPI-XHE-NOREC
Total (all sequences)		**5.8 E-006**	

[a]Percent contribution to the sequence total importance.

[b]The change in conditional probability (importance) is determined by calculating the conditional probability for the period in which the condition existed, and subtracting the conditional probability for the same period but with plant equipment assumed to be operating nominally. The conditional probability for each cut set within a sequence is determined by multiplying the probability that the portion of the sequence that makes the precursor visible (e.g., the system with a failure is demanded) will occur during the duration of the event by the probabilities of the remaining basic events in the minimal cut set. This can be approximated by $1 - e^{-p}$, where p is determined by multiplying the expected number of initiators that occur during the duration of the event by the probabilities of the basic events in that minimal cut set. The expected number of initiators is given by λt, where λ is the frequency of the initiating event (given on a per-hour basis), and t is the duration time of the event. This approximation is conservative for precursors made visible by the initiating event. The frequencies of interest for this event are: $\lambda_{TRANS} = 5.3 \times 10^{-4}$/h, $\lambda_{LOOP} = 8.5 \times 10^{6}$/h, $\lambda_{SLOCA} = 1.0 \times 10^{-6}$/h, and $\lambda_{SGTR} = 1.6 \times 10^{-6}$/h.

[c]Basic event CVC-MOV-CC-SUCT is a type TRUE event. This type of event is not normally included in the output of the fault tree reduction process, but has been added to aid in understanding the sequences to potential core damage associated with the event.