A.2 LER Nos. 265/93-010 and -012

Event Description: Emergency Power System Unavailable

Date of Event: April 22, 1993

Plant: Quad Cities 2

A.2.1 Summary

During a surveillance test on April 22, 1993, the Quad Cities swing diesel generator cooling water pump (DGCWP) breaker locked-up on antipump protection. The licensee determined that the potential for lock-up existed since the initial plant startup if the pump power source was aligned to Unit 2. A 1992 modification ensured that the cooling water pump would be powered from Unit 2 if a loss-of-offsite power (LOOP) occurred on that unit. Unavailability of cooling water for ~ 5 to 10 min is sufficient to damage the DG.

About one month earlier, inadequate bearing oil level had been found in the Unit 2 dedicated diesel cooling water pump, the result of an incorrectly reassembled oiler. The pump would have been expected to fail if it had been required to run for more than a short period of time. The Unit 2 emergency power system was vulnerable to failure for a 7-month period beginning in August 1992.

The conditional core damage probability estimated for the event is 6.0×10^{-5}. The relative significance of this event compared to other potential events at Quad Cities 2 is shown in Fig. A.2.1.

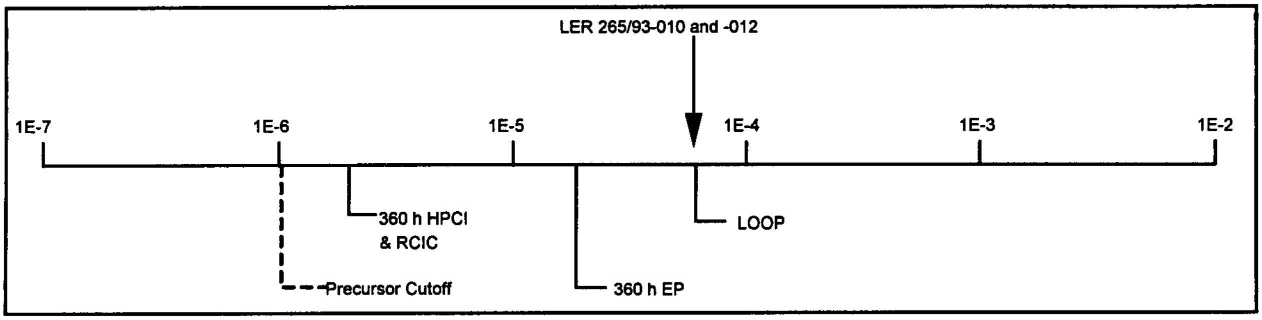

Fig. A.2.1 Relative event significance of LER Nos. 265/93-010 and -012 compared with other potential events at Quad Cities 2

A.2.2 Event Description

A.2.2.1 1/2 DGCWP Failure

On April 22, 1993, Quad Cities 2 was shut down and performing 4-kV bus 23-1 Undervoltage Functional Test QOS-6500-4. During the performance of this surveillance test, the 1/2 (swing) DGCWP failed to start as required. The pump was manually started at the DG ~ 2 min later by repositioning the feed power selector switch for the pump.

The 1/2 DGCWP breaker had locked-up on antipump protection. The licensee determined that the potential for lock-up of the 1/2 DGCWP if its power source was aligned to Unit 2 had existed since the initial design of the plant. However, before April 1992, the control logic aligned the 1/2 DGCWP to Unit 1 if power was

available to the Unit 1 bus, even if the 1/2 DG was aligned to supply power to Unit 2. An undervoltage logic modification in April 1992 revised the control logic for the 1/2 DGCWP so that the pump would receive power from the same bus that the 1/2 DG was powering, which ensured that the lock-up condition would occur in the event of a LOOP on Unit 2. Postmodification testing failed to identify the lock-up problem. A similar problem existed if the 1/2 DGCWP was powered from Unit 1, but only if the power selector switch was aligned to Unit 1 bus 18. Normally this switch is set to the "normal" position, which aligns 1/2 DGCWP power to the 1/2 DG powered-bus.

In the event of a LOOP on Unit 2, the 1/2 DG would be expected to start and load but would fail after ~ 5 min because of the loss of cooling water caused by the locked-up 1/2 DGCWP. A loss of DG cooling is not specifically annunciated in the control room—receipt of panel 902-8 annunciator A-4, "Diesel Generator 1/2 Trouble" would require operator response in the DG room. An operator is routinely dispatched to the DG rooms following an auto-start at Quad Cities. In the DG room, annunciator C-3, "Diesel Cooling Water Pump Failure or Diesel Cooling Water Pump Locked Out" would be alarmed. Its alarm procedure requires the 1/2 DGCWP to be manually started. Based on training, the operator would be expected to accomplish this by repositioning the pump feed power selector switch to the "Bus 28-1" position. Quad Cities procedures prohibit tripping a DG that has autostarted; recovery must, therefore, be accomplished by restoring cooling water flow before the DG overheats.

A.2.2.2 Unit 2 DGCWP Failure

On March 25, 1993, the Unit 2 dedicated DG (2 DG) had been taken out of service for scheduled maintenance. Four days later an operator questioned the height of the oiler for the 2 DGCWP. Upon disassembly of the pump, approximately one tablespoon of oil was found in the oil reservoir. This was the expected level based on the height of the oiler. The bearing retainer ring, which provides spaces between the ball bearings, was found in pieces. The races and ball bearings were intact, but the bearing and pump shaft had apparent heat damage, and the balls were coated with a heavy, grease-like film.

The 2 DGCWP bearing degradation was caused by the incorrect reassembly of the oiler piping during pump maintenance in January 1992. Although the pump bearing oil level was very low and the bearing showed evidence of heat damage, the 2 DGCWP was run and successfully passed its surveillance tests through February 16, 1993. This included a 56-h run between August 5–7, 1992, and six 2.5-h monthly surveillance tests.

Unit 2 entered a refueling outage on March 6, 1993. The emergency power system was vulnerable to failure if required to operate for longer than the limited 2 DGCWP lifetime from August 1992.

A.2.3 Additional Event-Related Information

A simplified diagram of the emergency power system at Quad Cities is provided in Fig. A.2.2. Three DGs provide emergency power to the two units: the 1 DG provides power to Unit 1 bus 14-1, the 2 DG provides power to Unit 2 bus 24-1, and the 1/2 DG provides power to either Unit 1 bus 13-1 or Unit 2 bus 23-1 in the event of a LOOP on Unit 1 or Unit 2, respectively. In the event of a dual-unit LOOP with a loss-of-coolant accident (LOCA) on one unit, the 1/2 DG provides power to the unit with the LOCA. In the event of a dual-unit LOOP without a LOCA, the 1/2 DG powers the unit that first suffers the LOOP. Unit 1 bus 14-1 and Unit 2 bus 24-1 can be cross-tied by closing two normally open breakers.

Two 250-V dc and two 125-V dc batteries are shared between both units. The 250-V dc batteries primarily power large loads, such as dc-powered pumps and valves, while the 125-V dc batteries provide control power to components such as circuit breakers. Each battery is sized to power its respective loads for 4 h.

Normally, Unit 1 batteries are charged using power from bus 14-1 (via bus 19); Unit 2 batteries are charged from bus 24-1 (via bus 29). An alternate charger can be powered from buses 13-1 and 23-1 and can charge either unit's battery. The 480-V ac buses that power the battery chargers on each unit can also be cross-tied.

In addition to high pressure coolant injection (HPCI) and reactor core isolation cooling (RCIC), Quad Cities can utilize a shared safe shutdown makeup pump (SSMP) to provide high-pressure makeup in the event of a loss of feedwater (FW). The motor-driven pump is capable of supplying 400 gal/min at essentially all reactor pressures. It is powered from safe shutdown bus 31, which is supplied from Unit 1 bus 14-1 (preferentially) or Unit 2 bus 24-1, and can provide makeup to either of the two units. The pump and associated valves can be operated from the control room. Utilization of the SSMP requires opening a test return valve, starting the pump, opening the injection valve, and closing the test return valve. The SSMP would be used if both HPCI and RCIC failed.

Thermal-hydraulic analyses performed in support of the individual plant examination (IPE) indicated that RCIC or the SSMP, in addition to HPCI and FW, can provide sufficient makeup to prevent core damage in the event of a single stuck-open relief valve.

Additional information concerning this event is provided in NRC inspection report 50-254/93016; 50-265/93-016 dated June 9, 1993.

A.2.4 Modeling Assumptions

The event was modeled as a potential LOOP during the 7-month (211-d) period in which both DGCWPs were vulnerable to failure. Consistent with information provided by the licensee, the analysis assumed that the 1/2 DGCWP breaker would lock-up on antipump protection if a LOOP occurred at Unit 2 at any time following the undervoltage logic modification in April 1992. The analysis also assumed that the 2 DGCWP was vulnerable to failure due to low bearing oil level following the successful 56-h run on August 7, 1992. After that, the 2 DGCWP was run 2.5 h each month until February 16, 1993, for DG surveillance testing. Following the February 16, 1993, test, the oil level was assumed to be inadequate, and the pump was assumed to be failed. The average lifetime of the 2 DGCWP in the 7-month period is, therefore, 7.5 h. The emergency power system would fail, on average, 7.5 h after a postulated LOOP; battery depletion would occur 4 h later unless power was recovered to the battery chargers.

Due to the nature of the DGCWP failures, no restoration of emergency power through DG recovery was assumed possible. Cooling water would have to be restored to the 1/2 DG within ~ 5 to 10 min of receipt of the control room 1/2 DG trouble alarm to prevent damage to the DG. At this time, both DGs would be running and powering their safety-related buses. Although an operator is dispatched to the EDGs following auto-start and could reach the 1/2 DG room in 10 min under these circumstances, diagnosis and recovery of cooling water within that time was considered unlikely.* Failure of the 2 DG after the 2 DGCWP fails from lack of bearing oil was also considered nonrecoverable.

The analysis considered potential plant-centered LOOPs that would impact only Unit 2 and potential grid- and weather-related LOOPs that would impact both units. Although multiple-unit, plant-centered LOOPs have been historically observed, their impact is small compared to grid- and weather-related LOOPs.

*In "Electric Power Recovery Models," J. W. Read and K. N. Fleming, *Proceedings of the International Topical Meeting on Probabilistic Safety Assessment, PSA '93*, January 26-29, 1993, the probability of first operator arrival at a failed DG is estimated. For times up to 10 min, this probability is 0.26 (p_{fail} = 0.74). In the dominant sequence for this event (developed later), the EDG is also failed. This failure would compete with the 1/2 EDG for response/recovery resources.

Recovery of power to Unit 2 buses was assumed to occur following recovery of offsite power. Recovery of power to bus 24-1 was also assumed to be possible from Unit 1 bus 14-1 through closure of normally open breakers 1421 and 2429.

The ASP model frequency for LOOP and the probabilities of failing to recover offsite power in the short-term and before battery depletion were modified using the models described in *Revised LOOP Frequency and PWR Seal LOCA Models*, ORNL/NRC/LTR-89/11, August 1989. These models are based on the data distributions described in *Evaluation of Station Blackout Accidents at Nuclear Power Plants*, NUREG-1032, June 1988.

For operational events involving unavailabilities, such as this event, the ASP program estimates the core damage probability for the event by calculating the probability of core damage during the unavailability period conditioned on the failures observed during the event, and subtracting a base-case probability for the same period, assuming plant equipment performs nominally. Because potential plant-centered LOOPs were addressed separately from potential grid- and weather-related LOOPs in this analysis, the ASP computer code could not be used to perform this differential calculation. Instead, the ASP code was used to calculate the probability of core damage given the conditions observed during the event and a postulated LOOP. This probability was then multiplied by the probability of a LOOP during the 211-d multiple DG unavailability. The nominal core damage probability was estimated in the same way. For this analysis, subtracting the nominal core damage probability did not significantly affect the overall results. Because of this, those calculations are not included here.

The analysis addressed the potential use of the SSMP, RCIC, and containment venting in providing core protection for certain sequences at Quad Cities. The SSMP was considered the primary backup for HPCI and RCIC. Because the pump can be operated from the control room, it was assumed that no effort would be made to recover HPCI or RCIC before using the SSMP. Two motor-operated valves plus the pump itself must be remote-manually operated for SSMP success. A failure probability of 0.04 was estimated, based on nominal failure probabilities used in the ASP Program (0.01 for pumps and motor-operated valves) and an assumed operator error probability of 0.01. This operator error probability is typically used for failure to utilize the control rod drive (CRD) pumps for reactor pressure vessel makeup following HPCI and RCIC failure (see Appendix A, Sect. A.3.2 and Table A.14, *Precursors to Potential Severe Core Damage Accidents: 1992, A Status Report*, NUREG/CR-4674, Vol. 17). At Quad Cities, however, the operators are directed to use the CRD pumps only if HPCI, RCIC, and the SSMP all fail. (This would require the operator error probability associated with the CRD pumps to be increased from the nominal ASP value. However, because of the observed DG unavailabilities, CRD pump availability for injection does not impact this analysis, and the CRD branch failure probability was not revised.) Sequences with successful SRV closure and HPCI and RCIC failure were modified to include failure of the SSMP by multiplying their sequence probabilities by p(SSMP).

To address the potential use of RCIC or the SSMP to provide core cooling in the event of a single stuck-open relief valve, the conditional probabilities for sequences involving a stuck-open safety-relief valve with HPCI failure were multiplied by

$$p(\text{two or more SRVs open} \mid \text{one SRV open}) + p(\text{RCIC}) \times p(\text{SSMP}).$$

Because only one SRV is manually opened at Quad Cities for most transients, $p(\text{two or more SRVs open} \mid \text{one SRV open}) \sim 0$.

The existing ASP model was modified to include the potential use of venting for decay heat removal in the event that both the shutdown cooling and suppression pool cooling modes of RHR fail. This was done by

revising sequences involving failure of both RHR cooling modes to also include failure to vent the containment. The probability of failing to vent was assumed to be dominated by human error. A probability of 0.01 is utilized for sequences in which the injection source operates at low pressure and the source of water is separate from the suppression pool.

For sequences in which the injection source takes suction from the suppression pool (such as LPCS or LPCI), an alternate injection source, the CRD pumps or RHR service water, must be aligned for injection following venting. Venting is considered much less reliable in such cases, and an operator error probability of 0.5 was utilized (see NRR Daily Events Evaluation Manual, 1-275-03-336-01, January 31, 1992). Because of the expected delay in recovering ac power in this event, HPCI was assumed to have transferred to the suppression pool prior to venting.

Case 1. Plant-Centered LOOP at Unit 2. For a postulated plant-centered LOOP at Unit 2 only, offsite power remains available at Unit 1. Power can be recovered to bus 24-1 after the failure of the 2 DG by recovering offsite power or by closing the cross-tie from Unit 1 bus 14-1. Because of the shared dc system at Quad Cities, dc power will remain available for instrumentation even after the Unit 2 batteries are depleted (on average 11.5 h after the postulated LOOP in this event, if offsite power is not recovered by then). Because the SSMP is preferentially powered from Unit 1, it will also be available without operator action to align a power source.

The frequency of plant-centered LOOP and the probability of failing to recover offsite power in the short-term and before battery depletion were estimated to be 8.5×10^{-2}/y, 0.50, and 1.3×10^{-6}, respectively. Because one train of Unit 2 instrumentation is powered from the Unit 1 batteries, sequences involving SSMP success will not proceed to core damage when the Unit 2 batteries are depleted.

As described previously, ac power can also be recovered to bus 24-1 through closure of cross-tie breakers 1421 and 2429. The probability of failing to perform this action before battery depletion was assumed to be 0.12 (ASP nonrecovery class R3, see Appendix A, Sect. A.1 to the 1992 precursor report). This value was chosen because recovery appeared possible in the required time from the control room, but was not considered routine (the value chosen for this failure probability for this case is considered a bounding probability and does not impact the final analysis results).

Modifications to blackout sequence conditional probabilities indicated on the Conditional Core Damage Probability Calculation sheets to reflect the above considerations for this case follow:

Sequence	p(LOOP)	p(RCIC)	p(SSMP)	p(vent)
65	0.07	n/a	n/a	0.5
66	0.07	included	n/a	0.5
67	0.07	included	0.04	n/a
68	0.07	n/a	n/a	0.5
69	0.07	0.042	0.04	n/a
83	invalid sequence*			

*Sequence 83 is not a valid sequence because one train of Quad Cities batteries is charged from Unit 1. Provided power is available to charge the Unit 1 batteries, one train of dc power will remain available at Unit 2 for instrumentation and control functions.

For the dominant sequences shown on the calculation sheets, the above modifications result in the following revised probabilities:

Sequence	Calculation sheet probability	Revised probability
65	2.6×10^{-6}	9.1×10^{-8}
66	5.1×10^{-8}	1.8×10^{-9}
67	4.2×10^{-4}	1.2×10^{-6}
68	2.6×10^{-8}	9.1×10^{-10}
69	1.0×10^{-4}	1.2×10^{-8}
83	7.8×10^{-8}	0*

*Sequence 83 is not a valid sequence because one train of Quad Cities batteries is charged from Unit 1. Provided power is available to charge the Unit 1 batteries, one train of dc power will remain available at Unit 2 for instrumentation and control functions.

The conditional probability estimated for this case is 1.3×10^{-6}.

Case 2a. Dual-unit LOOP with 1 DG Success. For a postulated dual-unit LOOP (primarily grid- and weather-related LOOPs), offsite power is unavailable to both units. The potential availability and unavailability of the 1 DG must be separately considered to correctly address the potential use of the SSMP and recovery of bus 24-1 from bus 14-1.

For this subcase, 1 DG is assumed to have started and provided power to bus 14-1. Because bus 14-1 is powered, power is available to the SSMP and for recovery of bus 24-1 via the cross-tie, similar to case 1. The same failure probability, 0.12, was utilized for failure to power bus 24-1 via the cross-tie. However, unlike case 1, in which offsite power is assumed to exist at bus 14-1, considerable care would be required to shed loads before closing the cross-tie breakers and then to selectively repower bus 14-1 and 24-1 loads to prevent tripping the 1 DG.

For a dual-unit LOOP, the 1/2 DG will power bus 13-1 or 23-1, depending on which first experiences a loss of power (assuming a LOCA does occur simultaneously). If bus 13-1 experiences the LOOP first, the 1/2 DG will be available to power that bus, and it may be possible to power bus 23-1 from the 1/2 DG. However, this analysis assumed that the 1/2 DG would fail due to loss of cooling water flow when its output was transferred from bus 13-1 to 23-1, because the 1/2 DGCWP would also switch to Unit 2 and lock out.

The frequency of a dual-unit LOOP with 1 DG successful ($p_{DG\ success}$ = 0.95) and the probability of failing to recover offsite power in the short-term and before battery depletion were estimated to be 1.6×10^{-2}/year, 0.66, and 0.23, respectively, using the approach described for case 1. Because one train of Unit 2 instrumentation is powered from the Unit 1 batteries, sequences involving SSMP success will not proceed to core damage when the Unit 2 batteries are depleted.

Modifications to blackout sequence conditional probabilities indicated on the Conditional Core Damage Probability Calculation sheets to reflect the above considerations for this subcase follow:

Sequence	p(LOOP)	p(RCIC)	p(SSMP)	p(vent)
65	0.013	n/a	n/a	0.5
66	0.013	included	n/a	0.5
67	0.013	included	0.04	n/a
68	0.013	n/a	n/a	0.5
69	0.013	0.042	0.04	n/a
83	invalid sequence*			

*Sequence 83 is not a valid sequence because one train of Quad Cities batteries is charged from Unit 1. Provided power is available to charge the Unit 1 batteries, one train of dc power will remain available at Unit 2 for instrumentation and control functions.

For the dominant sequences shown on the calculation sheets, the above modifications result in the following revised probabilities:

Sequence	Calculation sheet probability	Revised probability
65	3.3×10^{-6}	2.2×10^{-8}
66	6.5×10^{-8}	4.2×10^{-10}
67	5.4×10^{-4}	2.8×10^{-7}
68	3.3×10^{-8}	2.2×10^{-10}
69	1.3×10^{-4}	2.8×10^{-9}
83	1.8×10^{-2}	0*

*Sequence 83 is not a valid sequence because one train of Quad Cities batteries is charged from Unit 1. Provided power is available to charge the Unit 1 batteries, one train of dc power will remain available at Unit 2 for instrumentation and control functions.

The conditional probability estimated for this subcase is 3.1×10^{-7}..

Case 2b. Dual-unit LOOP with 1 DG Failure. This subcase assumes that the 1 DG fails to provide power to bus 14-1. Because bus 14-1 is not powered, the SSMP is unavailable to provide makeup to the core and the cross-tie cannot be used to restore power to bus 24-1.

As in case 2a, the 1/2 DG may be available for powering battery chargers and RHR pumps if bus 13-1 experiences the LOOP before bus 23-1. Because it is equally likely that the LOOP will occur first on either bus, the probability that the 1/2 DG will fail to provide power is 0.55 (assuming a nominal DG failure probability of 0.05). The probability of failing to recover offsite power before battery depletion was multiplied by this factor to address the potential availability of the 1/2 DG to power instrumentation and control loads via the Unit 1/2 battery chargers.

The frequency of a dual-unit LOOP with 1 DG failed ($p_{DG\ fail}$ = 0.05) and the probability of failing to recover offsite power in the short-term and before battery depletion were estimated to be 8.5×10^{-4}/year, 0.66, and 0.23, respectively, using the approach described in Case 1.

Modifications to blackout sequence conditional probabilities indicated on the Conditional Core Damage Probability Calculation sheets to reflect the above considerations for this subcase follow:

Sequence	p(LOOP)	p(RCIC)	p(SSMP)	p(vent)
65	7.0×10^{-4}	n/a	n/a	0.5
66	7.0×10^{-4}	included	n/a	0.5
67	7.0×10^{-4}	included	unavail	n/a
68	7.0×10^{-4}	n/a	n/a	0.5
69	7.0×10^{-4}	0.042	unavail	n/a
83	7.0×10^{-4}	n/a	n/a	n/a

For the dominant sequences shown on the calculation sheets, the previous modifications result in the following revised probabilities:

Sequence	Calculation sheet probability	Revised probability
65	3.0×10^{-6}	1.1×10^{-9}
66	5.9×10^{-8}	2.1×10^{-11}
67	4.9×10^{-4}	3.5×10^{-7}
68	3.0×10^{-8}	1.1×10^{-11}
69	1.2×10^{-4}	3.5×10^{-9}
83	8.3×10^{-2}	5.8×10^{-5}

The conditional probability estimated for this subcase is 5.8×10^{-5}.

Combining the probabilities for cases 1, 2a, and 2b results in an estimated overall conditional core damage probability of 6.0×10^{-5}.

A.2.5 Analysis Results

The conditional core damage probability estimated for this event is 6.0×10^{-5}. The dominant core damage sequence, highlighted on the event tree shown in Fig. A.2.3, involves a postulated dual-unit LOOP (primarily grid- or weather-related) with subsequent failure of all three Quad Cities DGs (see case 2b, sequence 83), and failure to recover offsite power before battery depletion. In the dominant sequence, the 1/2 DG is postulated to fail due to a loss of cooling water following its alignment to Unit 2 (the postulated dual-unit LOOP affects Unit 2 first), the 2 DG also fails due to loss of cooling water after its DGCWP bearing oil is depleted, and the 1 DG fails for unspecified reasons (random failure).

The core damage probability for the event is strongly influenced by the probability of the dominant sequence. The next highest conditional probability sequence has a probability of 1.2×10^{-6} and involves a postulated LOOP at Unit 2 only, with failure of high-pressure injection before recovery of ac power. The dominant

sequence probability is dictated by the LOOP probability distributions described in NUREG-1032 and assumptions concerning the expected lifetime of the 2 DGCWP.

The continued availability of dc power from the Unit 1 batteries in Cases 1 and 2a significantly affects the results of the analysis. Because Unit 1 dc power remains available in these cases, the potential use of the bus 14-1–24-1 cross-tie does not contribute to the analysis results.

The potential use of the SSMP also influences the results of the analysis. Consideration of the SSMP along with the shared dc system, without consideration of RCIC and containment venting, results in a core damage probability estimate within 2% of the value calculated for the event. Assumptions concerning the potential use of RCIC following a stuck-open relief valve and containment venting have essentially no impact on the analysis results.

Fig. A.2.2 Simplified diagram of Quad Cities emergency power system

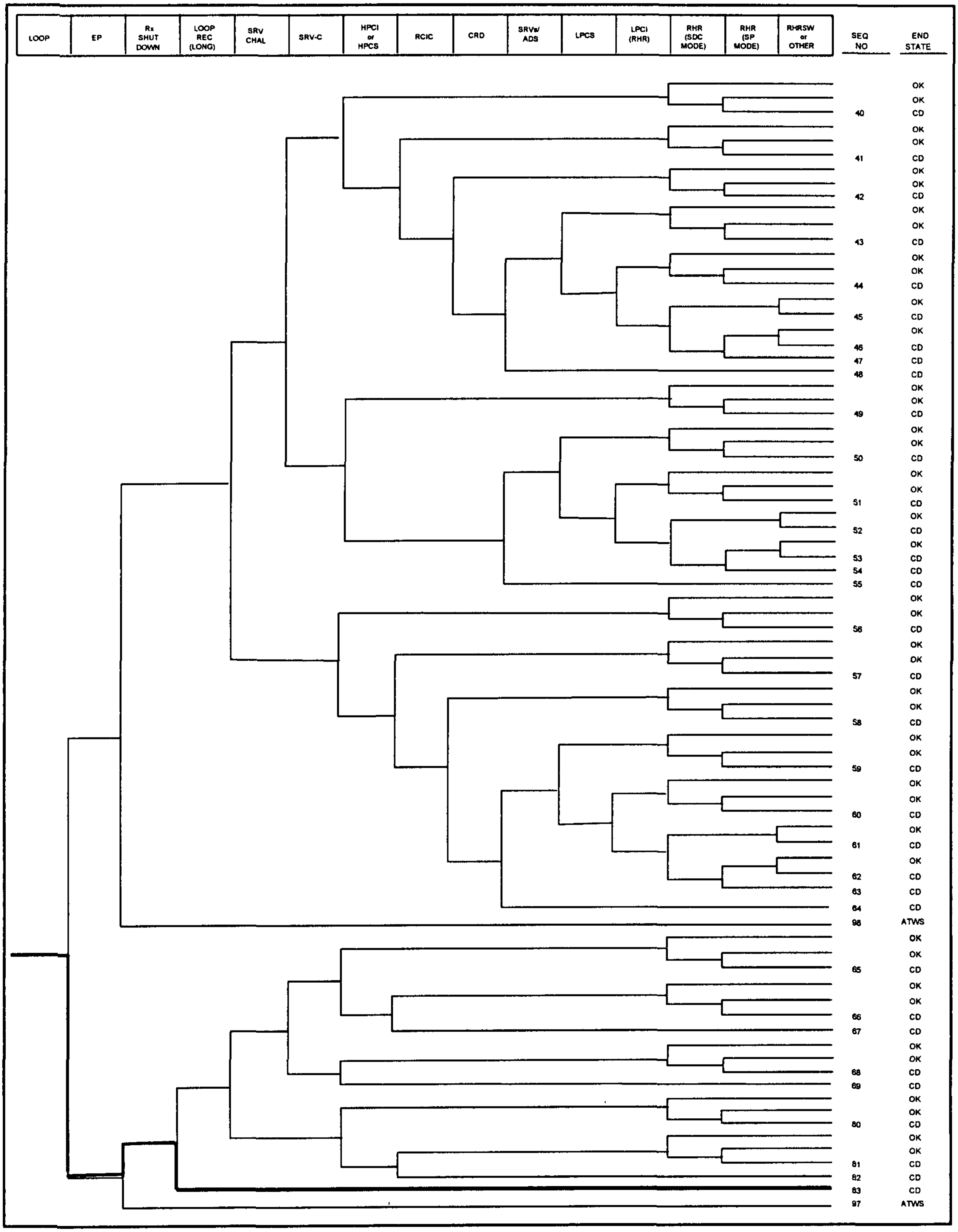

Fig. A.2.3 Dominant core damage sequence for LER Nos. 265/93-010 and -012

CONDITIONAL CORE DAMAGE PROBABILITY CALCULATIONS

Event Identifier: 265/93-010
Event Description: Emergency power system unavailable (case 1)
Event Date: 04/22/93
Plant: Quad Cities 2

INITIATING EVENT

NONRECOVERABLE INITIATING EVENT PROBABILITIES

LOOP	5.0E-01

SEQUENCE CONDITIONAL PROBABILITY SUMS

End State/Initiator	Probability
CD	
LOOP	5.3E-04(1)
Total	5.3E-04(1)
ATWS	
LOOP	1.5E-05
Total	1.5E-05

SEQUENCE CONDITIONAL PROBABILITIES (PROBABILITY ORDER)

	Sequence	End State	Prob	N Rec**
67	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close hpci rcic	CD	4.2E-04(1)	2.4E-01
69	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram srv.close hpci	CD	1.0E-04(1)	3.5E-01
65	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close -hpci rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	2.6E-06(1)	5.7E-02
83	LOOP EMERG.POWER -rx.shutdown/ep EP.REC	CD	7.8E-08(1)	6.0E-02
66	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close hpci -rcic rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	5.1E-08(1)	4.0E-02
68	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram srv.close -hpci rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	2.6E-08(1)	5.7E-02
97	LOOP EMERG.POWER rx.shutdown	ATWS	1.5E-05	5.0E-01

** nonrecovery credit for edited case

SEQUENCE CONDITIONAL PROBABILITIES (SEQUENCE ORDER)

	Sequence	End State	Prob	N Rec**
65	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close -hpci rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	2.6E-06	5.7E-02
66	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close hpci -rcic rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	5.1E-08	4.0E-02
67	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close hpci rcic	CD	4.2E-04	2.4E-01
68	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram srv.close -hpci rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	2.6E-08	5.7E-02
69	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram srv.close hpci	CD	1.0E-04	3.5E-01
83	LOOP EMERG.POWER -rx.shutdown/ep EP.REC	CD	7.8E-08	6.0E-02
97	LOOP EMERG.POWER rx.shutdown	ATWS	1.5E-05	5.0E-01

** nonrecovery credit for edited case

SEQUENCE MODEL: s:\asp\prog\models\bwrcseal.cmp
BRANCH MODEL: s:\asp\prog\models\quadcit2.sl1
PROBABILITY FILE: s:\asp\prog\models\bwr_csl1.pro

No Recovery Limit

BRANCH FREQUENCIES/PROBABILITIES

Branch	System	Nonrecov	Opr Fail
trans	5.3E-04	1.0E+00	
LOOP	1.6E-05 > 1.6E-05	5.3E-01 > 5.0E-01(2)	
Branch Model: INITOR			
Initiator Freq:	1.6E-05		
loca	3.3E-06	5.0E-01	
rx.shutdown	3.0E-05	1.0E+00	
rx.shutdown/ep	3.5E-04	1.0E+00	
pcs/trans	1.7E-01	1.0E+00	
srv.chall/trans.-scram	1.0E+00	1.0E+00	
srv.chall/loop.-scram	1.0E+00	1.0E+00	
srv.close	1.0E-02	1.0E+00	
EMERG.POWER	2.9E-03 > 1.0E+00	8.0E-01 > 1.0E+00(2)	
Branch Model: 1.OF.2			
Train 1 Cond Prob:	5.0E-02 > Failed(2)		
Train 2 Cond Prob:	5.7E-02 > Failed(2)		
EP.REC	4.9E-02 > 1.3E-06	1.0E+00 > 1.2E-01(2)	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	4.9E-02 > 1.3E-06(2)		
fw/pcs.trans	2.9E-01	3.4E-01	
fw/pcs.loca	4.0E-02	3.4E-01	
hpci	2.9E-02	7.0E-01	
rcic	6.0E-02	7.0E-01	
crd	1.0E-02	1.0E+00	1.0E-02
srv.ads	3.7E-03	7.1E-01	1.0E-02
lpcs	3.0E-03	3.4E-01	
lpci(rhr)/lpcs	1.0E-03	7.1E-01	
rhr(sdc)	2.1E-02	3.4E-01	1.0E-03
rhr(sdc)/-lpci	2.0E-02	3.4E-01	1.0E-03
rhr(sdc)/lpci	1.0E+00	1.0E+00	1.0E-03
rhr(spcool)/rhr(sdc)	2.0E-03	3.4E-01	
rhr(spcool)/-lpci.rhr(sdc)	2.0E-03	3.4E-01	
rhr(spcool)/lpci.rhr(sdc)	9.3E-02	1.0E+00	
rhrsw	2.0E-02	3.4E-01	2.0E-03

* branch model file
** forced

Notes:

1. See Modeling Assumptions for modifications to this sequence conditional probabilities.
2. See Modeling Assumptions for the development of this probability value.

CONDITIONAL CORE DAMAGE PROBABILITY CALCULATIONS

Event Identifier: 265/93-010
Event Description: Emergency power system unavailable (case 2a)
Event Date: 04/22/93
Plant: Quad Cities 2

INITIATING EVENT

NONRECOVERABLE INITIATING EVENT PROBABILITIES

LOOP	6.6E-01

SEQUENCE CONDITIONAL PROBABILITY SUMS

End State/Initiator	Probability
CD	
LOOP	1.9E-02(1)
Total	1.9E-02(1)
ATWS	
LOOP	2.0E-05
Total	2.0E-05

SEQUENCE CONDITIONAL PROBABILITIES (PROBABILITY ORDER)

	Sequence	End State	Prob	N Rec**
83	LOOP EMERG.POWER -rx.shutdown/ep EP.REC	CD	1.8E-02(1)	7.9E-02
67	LOOP EMERG.POWER -rx.shutdown/ep -EP,REC srv.chall/loop.-scram -srv.close hpci rcic	CD	5.4E-04(1)	3.2E-01
69	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram srv.close hpci	CD	1.3E-04(1)	4.5E-01
65	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close -hpci rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	3.3E-06(1)	7.4E-02
66	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close hpci -rcic rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	6.5E-08(1)	5.1E-02
68	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram srv.close -hpci rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	3.3E-08(1)	7.4E-02
97	LOOP EMERG.POWER rx.shutdown	ATWS	2.0E-05	6.6E-01

** nonrecovery credit for edited case

SEQUENCE CONDITIONAL PROBABILITIES (SEQUENCE ORDER)

	Sequence	End State	Prob	N Rec**
65	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close -hpci rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	3.3E-06	7.4E-02
66	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close hpci -rcic rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	6.5E-08	5.1E-02
67	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close hpci rcic	CD	5.4E-04	3.2E-01
68	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram srv.close -hpci rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	3.3E-08	7.4E-02
69	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram srv.close hpci	CD	1.3E-04	4.5E-01
83	LOOP EMERG.POWER -rx.shutdown/ep EP.REC	CD	1.8E-02	7.9E-02
97	LOOP EMERG.POWER rx.shutdown	ATWS	2.0E-05	6.6E-01

** nonrecovery credit for edited case

SEQUENCE MODEL: s:\asp\prog\models\bwrcseal.cmp
BRANCH MODEL: s:\asp\prog\models\quadcit2.sl1
PROBABILITY FILE: s:\asp\prog\models\bwr_csl1.pro

No Recovery Limit

BRANCH FREQUENCIES/PROBABILITIES

Branch	System	Non-Recov	Opr Fail
trans	5.3E-04	1.0E+00	
LOOP	1.6E-05 > 1.6E-05	5.3E-01 > 6.6E-01(2)	
Branch Model: INITOR			
Initiator Freq:	1.6E-05		
loca	3.3E-06	5.0E-01	
rx.shutdown	3.0E-05	1.0E+00	
rx.shutdown/ep	3.5E-04	1.0E+00	
pcs/trans	1.7E-01	1.0E+00	
srv.chall/trans.-scram	1.0E+00	1.0E+00	
srv.chall/loop.-scram	1.0E+00	1.0E+00	
srv.close	1.0E-02	1.0E+00	
EMERG.POWER	2.9E-03 > 1.0E+00	8.0E-01 > 1.0E+00(2)	
Branch Model: 1.OF.2			
Train 1 Cond Prob:	5.0E-02 > Failed(2)		
Train 2 Cond Prob:	5.7E-02 > Failed(2)		
EP.REC	4.9E-02 > 2.3E-01	1.0E+00 > 1.2E-01(2)	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	4.9E-02 > 2.3E-01(2)		
fw/pcs.trans	2.9E-01	3.4E-01	
fw/pcs.loca	4.0E-02	3.4E-01	
hpci	2.9E-02	7.0E-01	
rcic	6.0E-02	7.0E-01	
crd	1.0E-02	1.0E+00	1.0E-02
srv.ads	3.7E-03	7.1E-01	1.0E-02
lpcs	3.0E-03	3.4E-01	
lpci(rhr)/lpcs	1.0E-03	7.1E-01	
rhr(sdc)	2.1E-02	3.4E-01	1.0E-03
rhr(sdc)/-lpci	2.0E-02	3.4E-01	1.0E-03
rhr(sdc)/lpci	1.0E+00	1.0E+00	1.0E-03
rhr(spcool)/rhr(sdc)	2.0E-03	3.4E-01	
rhr(spcool)/-lpci.rhr(sdc)	2.0E-03	3.4E-01	
rhr(spcool)/lpci.rhr(sdc)	9.3E-02	1.0E+00	
rhrsw	2.0E-02	3.4E-01	2.0E-03

* branch model file
** forced

Notes:

1. See Modeling Assumptions for modifications to this sequence conditional probabilities.
2. See Modeling Assumptions for the development of this probability value.

CONDITIONAL CORE DAMAGE PROBABILITY CALCULATIONS

Event Identifier: 265/93-010
Event Description: Emergency power system unavailable (case 2b)
Event Date: 04/22/93
Plant: Quad Cities 2

INITIATING EVENT

NONRECOVERABLE INITIATING EVENT PROBABILITIES

LOOP	6.6E-01

SEQUENCE CONDITIONAL PROBABILITY SUMS

End State/Initiator	Probability
CD	
LOOP	8.4E-02(1)
Total	8.4E-02(1)
ATWS	
LOOP	2.0E-05
Total	2.0E-05

SEQUENCE CONDITIONAL PROBABILITIES (PROBABILITY ORDER)

	Sequence	End State	Prob	N Rec**
83	LOOP EMERG.POWER -rx.shutdown/ep EP.REC	CD	8.3E-02(1)	3.6E-01
67	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close hpci rcic	CD	4.9E-04(1)	3.0E-01
69	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram srv.close hpci	CD	1.2E-04(1)	4.3E-01
65	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close -hpci rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	3.0E-06(1)	7.1E-02
66	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close hpci -rcic rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	5.9E-08(1)	4.9E-02
68	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram srv.close -hpci rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	3.0E-08(1)	7.1E-02
97	LOOP EMERG.POWER rx.shutdown	ATWS	2.0E-05	6.6E-01

** nonrecovery credit for edited case

SEQUENCE CONDITIONAL PROBABILITIES (SEQUENCE ORDER)

	Sequence	End State	Prob	N Rec**
65	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close -hpci rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	3.0E-06	7.1E-02
66	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close hpci -rcic rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sd c)	CD	5.9E-08	4.9E-02
67	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram -srv.close hpci rcic	CD	4.9E-04	3.0E-01
68	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram srv.close -hpci rhr(sdc)/-lpci rhr(spcool)/-lpci.rhr(sdc)	CD	3.0E-08	7.1E-02
69	LOOP EMERG.POWER -rx.shutdown/ep -EP.REC srv.chall/loop.-scram srv.close hpci	CD	1.2E-04	4.3E-01
83	LOOP EMERG.POWER -rx.shutdown/ep EP.REC	CD	8.3E-02	3.6E-01
97	LOOP EMERG.POWER rx.shutdown	ATWS	2.0E-05	6.6E-01

** nonrecovery credit for edited case

SEQUENCE MODEL: s:\asp\prog\models\bwrcseal.cmp
BRANCH MODEL: s:\asp\prog\models\quadcit2.sl1
PROBABILITY FILE: s:\asp\prog\models\bwr_csl1.pro

No Recovery Limit

BRANCH FREQUENCIES/PROBABILITIES

Branch	System	Nonrecov	Opr Fail
trans	5.3E-04	1.0E+00	
LOOP	1.6E-05 > 1.6E-05	5.3E-01 > 6.6E-01(2)	
Branch Model: INITOR			
Initiator Freq:	1.6E-05		
loca	3.3E-06	5.0E-01	
rx.shutdown	3.0E-05	1.0E+00	
rx.shutdown/ep	3.5E-04	1.0E+00	
pcs/trans	1.7E-01	1.0E+00	
srv.chall/trans.-scram	1.0E+00	1.0E+00	
srv.chall/loop.-scram	1.0E+00	1.0E+00	
srv.close	1.0E-02	1.0E+00	
EMERG.POWER	2.9E-03 > 1.0E+00	8.0E-01 > 1.0E+00(2)	
Branch Model: 1.OF.2			
Train 1 Cond Prob:	5.0E-02 > Failed(2)		
Train 2 Cond Prob:	5.7E-02 > Failed(2)		
EP.REC	4.9E-02 > 2.3E-01	1.0E+00 > 5.5E-01(2)	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	4.9E-02 > 2.3E-01(2)		
fw/pcs.trans	2.9E-01	3.4E-01	
fw/pcs.loca	4.0E-02	3.4E-01	
hpci	2.9E-02	7.0E-01	
rcic	6.0E-02	7.0E-01	
crd	1.0E-02	1.0E+00	1.0E-02
srv.ads	3.7E-03	7.1E-01	1.0E-02
lpcs	3.0E-03	3.4E-01	
lpci(rhr)/lpcs	1.0E-03	7.1E-01	
rhr(sdc)	2.1E-02	3.4E-01	1.0E-03
rhr(sdc)/-lpci	2.0E-02	3.4E-01	1.0E-03
rhr(sdc)/lpci	1.0E+00	1.0E+00	1.0E-03
rhr(spcool)/rhr(sdc)	2.0E-03	3.4E-01	
rhr(spcool)/-lpci.rhr(sdc)	2.0E-03	3.4E-01	
rhr(spcool)/lpci.rhr(sdc)	9.3E-02	1.0E+00	
rhrsw	2.0E-02	3.4E-01	2.0E-03

* branch model file
** forced

Notes:

1. See Modeling Assumptions for modifications to this sequence conditional probabilities.
2. See Modeling Assumptions for the development of this probability value.