Final Precursor Analysis

Accident Sequence Precursor Program – Office of Nuclear Regulatory Research

Susquehanna, Unit 1	Manual Reactor Scram due to Leakage from the Circulating Water System and Subsequent Flooding of the Condenser Bay	
Event Date: 07/16/2010	**LER:** 387/10-003-01 **IRs:** 50-387/10-04, 50-387/10-08	**ΔCDP =** 4×10^{-6}

EVENT SUMMARY

Brief Event Description. On July 16, 2010, at approximately 1520, Unit 1 received a condenser bay flood alarm. Plant operators verified that flooding was occurring into the 656' elevation of the condenser bay. Reactor power was reduced to 40 percent via control rod insertions and a recirculation runback. Operator attempts to isolate condenser waterboxes remotely were unsuccessful. Unit 1 was subsequently manually scrammed, main steam isolation valves (MSIVs) were shut, and the main condenser was isolated so that the circulating water (CW) system could be shutdown. Concurrently, plant operators manually closed waterbox isolation valves and isolated the leak.

Plant response following the manual reactor scram was not as expected. The integrated control system (ICS) feedwater level control (FWLC) is designed to switch to single element control on low main steam flow. Due to steam condensation and flashing on the flow instrument, measured main steam flow remained above the transition point and ICS FWLC remained in three element control. The effect of this was that while feedwater (FW) Pumps B and C automatically switched to the idle mode and the level setpoint set-down occurred as expected, FW Pump A underwent demand oscillations prior to its transition to discharge pressure mode. Inventory continued to be added to the reactor vessel until level reached the high level turbine trip setpoint and peaked at 55 inches. Exceeding the setpoint resulted in a trip of all FW pump turbines, the high-pressure coolant injection (HPCI) turbine, the reactor core isolation cooling (RCIC) turbine, and the main turbine. It took approximately 14 minutes for reactor vessel water level to steam down less than the trip setpoint. Once level was restored below the setpoint, HPCI and RCIC were manually reinitiated for pressure and level control respectively.

Additional details are provided in References 1, 2, and 3.

Key Event Details. The following event details are significant to the modeling of this event analysis:

- A reactor scram and subsequent loss of condenser heat sink occurred due to circulating water leak. Operators manually scrammed the plant and isolated the condenser by shutting the MSIVs and closed the waterbox isolation valves locally. No recovery of the condenser is credited in this analysis.

- HPCI and RCIC both tripped on high reactor vessel water level. Operators could restore these two pumps to operation when reactor vessel water level dropped below the trip set point (operators were successful at restarting HPCI and RCIC during the event).

Additional Event Information. The following event details are provided as additional information about the event. This additional information was not factored in the modeling of this analysis due to the negligible risk impact.

- In an attempt to dewater the turbine building, operations personnel transferred water from the condenser area to the condensate storage tank (CST) berm using temporary pumping equipment. However, the procedure provided no guidance as to a maximum level that should be transferred to the berm to limit interactions with other safety-related equipment. On July 17, 2010, the inspectors informed PPL that water was entering the buildings housing the 'B' and 'D' Emergency Diesel Generators through conduit and a junction box (which contained instrumentation cables associated with suction transfer of HPCI and RCIC from the CST to the suppression pool). It was determined that the switches and associated unscheduled junction boxes in the berm had been submerged when water was transferred from the condenser area and that these switches and associated junction boxes were not qualified for submergence.

  On July 20, 2010, RCIC swapped its suction from the CST to the suppression pool, with CST level at 24% (transfer should occur at a level of 7.5%). It was subsequently determined that the short-term failure mechanism of the level switches controlling the Technical Specifications (TS) required function was a simulated low-level condition (i.e., a fail-safe condition that ensures that the TS safety function is preserved).

ANALYSIS RESULTS

Change in Core Damage Probability. The conditional core damage probability (CCDP) for this event is 3.7×10^{-6}.

The Accident Sequence Precursor (ASP) Program acceptance threshold is a CCDP of 1×10^{-6} or the CCDP equivalent of an uncomplicated reactor trip with a non-recoverable loss of secondary plant systems (e.g., feed water and condensate), whichever is greater. This CCDP equivalent for Susquehanna, Unit 1 is 1.1×10^{-6}.

Dominant Sequence. The dominant accident sequence, Loss of Condenser Heat Sink (LOCHS) 44 (CCDP = 3.3×10^{-6}) contributes 87% of the total internal events CCDP. Additional sequences that contribute greater than 1% of the total internal events CCDP are provided in Appendix A.

The dominant sequence is shown graphically in Figure B-1 in Appendix B. The events and important component failures in LOCHS Sequence 44 are:

- Loss of condenser heat sink transient occurs,
- Reactor trip succeeds,
- Safety relief valves reclose (if challenged),
- High-pressure injection (HPCI and RCIC) fails, and
- RCS depressurization fails.

SAPHIRE 8 Report. The SAPHIRE 8 Worksheets (Appendix A) provide the following:

- Summary of conditional event changes, including base and change case probabilities/frequencies.

- Event tree dominant results
- Dominant sequences (including CCDPs).
- Sequence logic for all dominant sequences.
- Referenced fault trees (including definitions).
- Cutset report for each dominant sequence.
- Referenced events (including definitions and probabilities for key basic events)

MODELING ASSUMPTIONS

Analysis Type. The Revision 8.17 of the Susquehanna, Unit 1 Standardized Plant Analysis Risk (SPAR) Model created in September 2010 was used for this event analysis. This event was modeled as a loss of condenser heat sink initiating event with complications.

Analysis Rules. The ASP program uses Significance Determination Process results for degraded conditions when available. However, the ASP Program performs independent initiating event analysis when an initiator occurs.

Key Modeling Assumptions. The following modeling assumptions and associated basic event modifications were required for this event analysis:

- The probability of IE-LOCHS (*Initiating Event- Loss of Condenser Heat Sink*) was set to 1.0; all other initiating event frequencies were set to zero.

- The basic events HCI-MULTIPLE-INJECT (*Probability of Multiple HPCI Injections*) and RCI-RESTART (*Restart of RCIC is Required*) were set to TRUE because both the HPCI and RCIC pumps tripped automatically due high reactor vessel water level and were restarted manually by operators.

REFERENCES

1. Susquehanna Steam Electric Station, Unit 1, "LER 387/10-003-001 – Unit 1 Manual Reactor Scram due to Leakage from the Unit 1 Circulating Water System and Subsequent Flooding of the Unit 1 Condenser Bay," dated September 14, 2010.

2. U.S. Nuclear Regulatory Commission, "Susquehanna Steam Electric Station – NRC Integrated Inspection Report 05000387/2010004 and 05000388/2010004; Preliminary White Finding," dated November 12, 2010

3. U.S. Nuclear Regulatory Commission, "Susquehanna Steam Electric Station – NRC Inspection Report 05000387/2010008 and 05000388/2010008; Final Significance Determination of White Finding with Assessment Follow-up," dated December 16, 2010.

Appendix A: SAPHIRE 8 Worksheets

Summary of Conditional Event Changes

Event	Description	Cond. Value	Nominal Value
HCI-MULTIPLE-INJECT	PROBABILITY OF MULTIPLE HPCI INJECTIONS	True	1.500E-1
IE-LOCHS	LOSS OF CONDENSER HEAT SINK[a]	1.000E+0	2.000E-1
RCI-RESTART	RESTART OF RCIC IS REQUIRED	True	1.500E-1

a. All other initiating events frequencies were set to zero.

Dominant Sequence Results

Only items contributing at least 1.0% to the total CCDP are displayed.

EVENT TREE	SEQUENCE	CCDP	% CONTRIBUTION	DESCRIPTION
LOCHS	44	3.270E-6	87.2%	/RPS, /SRV, HPI, DEP
LOCHS	14	2.682E-7	7.2%	/RPS, /SRV, /HPI, SPC, /DEP, CDS, /LPI, CSS, PCSR, CVS, LI08
LOCHS	47-06-16	1.415E-7	3.8%	RPS, /PPR, /RRS, PCS1, /SLC, /NX, /TAF, DE2
Total		**3.749E-6**	**100.0%**	

Referenced Fault Trees

Fault Tree	Description
CDS	CONDENSATE
CSS	CONTAINMENT SPRAY
CVS	CONTAINMENT VENTING
DE2	MANUAL REACTOR DEPRESS
DEP	MANUAL REACTOR DEPRESS
HPI	HIGH PRESSURE INJECTION (HPCI or RCIC)
LI08	LATE INJECTION
PCS1	POWER CONVERSION SYSTEM
PCSR	POWER CONVERSION SYSTEM RECOVERY
RPS	REACTOR SHUTDOWN
SPC	SUPPRESSION POOL COOLING

Cutset Report - LOCHS 44

Only items contributing at least 1% to the total are displayed.

#	CCDP	TOTAL%	CUTSET
	3.270E-6	100	Displaying 171 of 171 Cutsets.
1	1.200E-6	36.69	IE-LOCHS,ADS-XHE-XM-MDEPR,HCI-MOV-CC-IVFRO,HCI-XHE-XL-INJECT,RCI-TDP-FS-RSTRT,RCI-XHE-XL-RSTRT
2	6.000E-7	18.35	IE-LOCHS,ADS-XHE-XM-MDEPR,HCI-MOV-CC-IVFRO,HCI-XHE-XL-INJECT,RCI-TDP-TM-TRAIN
3	4.200E-7	12.84	IE-LOCHS,ADS-XHE-XM-MDEPR,HCI-MOV-CC-IVFRO,HCI-XHE-XL-INJECT,RCI-TDP-FS-TRAIN
4	2.461E-7	7.53	IE-LOCHS,ADS-XHE-XM-MDEPR,HCI-MOV-CC-IVFRO,HCI-XHE-XL-INJECT,RCI-TDP-FR-TRAIN
5	1.200E-7	3.67	IE-LOCHS,ADS-XHE-XM-MDEPR,HCI-TDP-TM-TRAIN,RCI-TDP-FS-RSTRT,RCI-XHE-XL-RSTRT
6	7.185E-8	2.2	IE-LOCHS,ADS-XHE-XM-MDEPR,HCI-XHE-XO-ERROR1,RCI-XHE-XO-ERROR
7	7.000E-8	2.14	IE-LOCHS,ADS-XHE-XM-MDEPR,HCI-TDP-FS-TRAIN,RCI-TDP-FS-RSTRT,RCI-XHE-XL-RSTRT
8	6.000E-8	1.83	IE-LOCHS,ADS-XHE-XM-MDEPR,HCI-MOV-CC-IVFRO,HCI-XHE-XL-

#	CCDP	TOTAL%	CUTSET
			INJECT,RCI-MOV-CC-INJEC
9	6.000E-8	1.83	IE-LOCHS,ADS-XHE-XM-MDEPR,HCI-MOV-CC-IVFRO,HCI-XHE-XL-INJECT,RCI-XHE-XO-ERROR
10	4.570E-8	1.4	IE-LOCHS,DCP-BDC-CF-ALL
11	4.200E-8	1.28	IE-LOCHS,ADS-XHE-XM-MDEPR,HCI-TDP-TM-TRAIN,RCI-TDP-FS-TRAIN
12	4.102E-8	1.25	IE-LOCHS,ADS-XHE-XM-MDEPR,HCI-TDP-FR-TRAIN,RCI-TDP-FS-RSTRT,RCI-XHE-XL-RSTRT
13	3.500E-8	1.07	IE-LOCHS,ADS-XHE-XM-MDEPR,HCI-TDP-FS-TRAIN,RCI-TDP-TM-TRAIN

Cutset Report - LOCHS 14
Only items contributing at least 1% to the total are displayed.

#	CCDP	TOTAL%	CUTSET
	2.682E-7	100	Displaying 31 of 31 Cutsets.
1	2.500E-7	93.23	IE-LOCHS,CFAILED,CVS-XHE-XM-VENT,RHR-XHE-XM-ERROR
2	4.644E-9	1.73	IE-LOCHS,CFAILED,CVS-XHE-XM-VENT,RHR-MDP-CF-START
3	3.785E-9	1.41	IE-LOCHS,CFAILED,CVS-XHE-XM-VENT,RHR-MOV-CF-HXBPS

Cutset Report - LOCHS 47-06-16
Only items contributing at least 1% to the total are displayed.

#	CCDP	TOTAL%	CUTSET
	1.415E-7	100	Displaying 29 of 29 Cutsets.
1	1.700E-8	12.01	IE-LOCHS,ADS-XHE-XM-MDEPR2,RPS-SYS-FC-PSOVS
2	1.360E-8	9.61	IE-LOCHS,ADS-SRV-CC-VALV1,RPS-SYS-FC-PSOVS
3	1.360E-8	9.61	IE-LOCHS,ADS-SRV-CC-VALV2,RPS-SYS-FC-PSOVS
4	1.360E-8	9.61	IE-LOCHS,ADS-SRV-CC-VALV3,RPS-SYS-FC-PSOVS
5	1.360E-8	9.61	IE-LOCHS,ADS-SRV-CC-VALV4,RPS-SYS-FC-PSOVS
6	1.360E-8	9.61	IE-LOCHS,ADS-SRV-CC-VALV5,RPS-SYS-FC-PSOVS
7	1.360E-8	9.61	IE-LOCHS,ADS-SRV-CC-VALV6,RPS-SYS-FC-PSOVS
8	3.800E-9	2.68	IE-LOCHS,ADS-XHE-XM-MDEPR2,RPS-SYS-FC-RELAY
9	3.040E-9	2.15	IE-LOCHS,ADS-SRV-CC-VALV1,RPS-SYS-FC-RELAY
10	3.040E-9	2.15	IE-LOCHS,ADS-SRV-CC-VALV2,RPS-SYS-FC-RELAY
11	3.040E-9	2.15	IE-LOCHS,ADS-SRV-CC-VALV3,RPS-SYS-FC-RELAY
12	3.040E-9	2.15	IE-LOCHS,ADS-SRV-CC-VALV4,RPS-SYS-FC-RELAY
13	3.040E-9	2.15	IE-LOCHS,ADS-SRV-CC-VALV5,RPS-SYS-FC-RELAY
14	3.040E-9	2.15	IE-LOCHS,ADS-SRV-CC-VALV6,RPS-SYS-FC-RELAY
15	2.500E-9	1.77	IE-LOCHS,ADS-XHE-XM-MDEPR2,RPS-SYS-FC-CRD
16	2.000E-9	1.41	IE-LOCHS,ADS-SRV-CC-VALV1,RPS-SYS-FC-CRD
17	2.000E-9	1.41	IE-LOCHS,ADS-SRV-CC-VALV2,RPS-SYS-FC-CRD
18	2.000E-9	1.41	IE-LOCHS,ADS-SRV-CC-VALV3,RPS-SYS-FC-CRD
19	2.000E-9	1.41	IE-LOCHS,ADS-SRV-CC-VALV4,RPS-SYS-FC-CRD
20	2.000E-9	1.41	IE-LOCHS,ADS-SRV-CC-VALV5,RPS-SYS-FC-CRD
21	2.000E-9	1.41	IE-LOCHS,ADS-SRV-CC-VALV6,RPS-SYS-FC-CRD

Referenced Events

Event	Description	Probability
ADS-SRV-CC-VALV1	ADS VALVE FAILS TO OPEN	8.000E-3
ADS-SRV-CC-VALV2	ADS VALVE FAILS TO OPEN	8.000E-3
ADS-SRV-CC-VALV3	ADS VALVE FAILS TO OPEN	8.000E-3

Event	Description	Probability
ADS-SRV-CC-VALV4	ADS VALVE FAILS TO OPEN	8.000E-3
ADS-SRV-CC-VALV5	ADS VALVE FAILS TO OPEN	8.000E-3
ADS-SRV-CC-VALV6	ADS VALVE FAILS TO OPEN	8.000E-3
ADS-XHE-XM-MDEPR	OPERATOR FAILS TO MANUALLY DEPRESSURIZE THE REACTOR	5.000E-4
ADS-XHE-XM-MDEPR2	OPERATOR FAILS TO DEPRESSURIZE THE REACTOR (ATWS)	1.000E-2
CFAILED	CONTAINMENT FAILURE CAUSES LOSS OF ALL INJECTION	5.000E-1
CVS-XHE-XM-VENT	OPERATOR FAILS TO VENT CONTAINMENT	1.000E-3
DCP-BDC-CF-ALL	4-OF-4 125 VDC BUSES FAIL FROM COMMON CAUSE	4.570E-8
HCI-MOV-CC-IVFRO	HPCI INJECTION VALVE FAILS TO REOPEN	1.500E-1
HCI-TDP-FR-TRAIN	HPCI PUMP TRAIN FAILS TO RUN GIVEN IT STARTED	4.102E-3
HCI-TDP-FS-TRAIN	HPCI PUMP FAILS TO START	7.000E-3
HCI-TDP-TM-TRAIN	HPCI TRAIN IS UNAVAILABLE BECAUSE OF MAINTENANCE	1.200E-2
HCI-XHE-XL-INJECT	OPERATOR FAILS TO RECOVER HPCI INJ. VALVE REOPENING	8.000E-1
HCI-XHE-XO-ERROR1	OPERATOR FAILS TO START/CONTROL HPCI INJECTION	1.437E-1
IE-LOCHS	LOSS OF CONDENSER HEAT SINK	1.000E+0
RCI-MOV-CC-INJEC	RCIC INJECTION VALVE CAUSES FAILURE TO START	1.000E-3
RCI-TDP-FR-TRAIN	RCIC PUMP FAILS TO RUN GIVEN THAT IT STARTED	4.102E-3
RCI-TDP-FS-RSTRT	RCIC FAILS TO RESTART GIVEN START AND SHORT-TERM RUN	8.000E-2
RCI-TDP-FS-TRAIN	RCIC PUMP FAILS TO START	7.000E-3
RCI-TDP-TM-TRAIN	RCIC TRAIN IS UNAVAILABLE BECAUSE OF MAINTENANCE	1.000E-2
RCI-XHE-XL-RSTRT	OPERATOR FAILS TO RECOVER RCIC FAILURE TO RESTART	2.500E-1
RCI-XHE-XO-ERROR	OPERATOR FAILS TO START/CONTROL RCIC INJECTION	1.000E-3
RHR-MDP-CF-START	RHR PUMPS FAIL FROM COMMON CAUSE TO START	9.288E-6
RHR-MOV-CF-HXBPS	RHR HTX BYPASS VALVES FAIL FROM COMMON CAUSE	7.570E-6
RHR-XHE-XM-ERROR	OPERATOR FAILS TO START/CONTROL RHR	5.000E-4
RPS-SYS-FC-CRD	CONTROL ROD DRIVE MECHANICAL FAILURE	2.500E-7
RPS-SYS-FC-PSOVS	HCU SCRAM PILOT SOVS FAIL	1.700E-6
RPS-SYS-FC-RELAY	TRIP SYSTEM RELAYS FAIL	3.800E-7

Appendix B: Key Event Tree

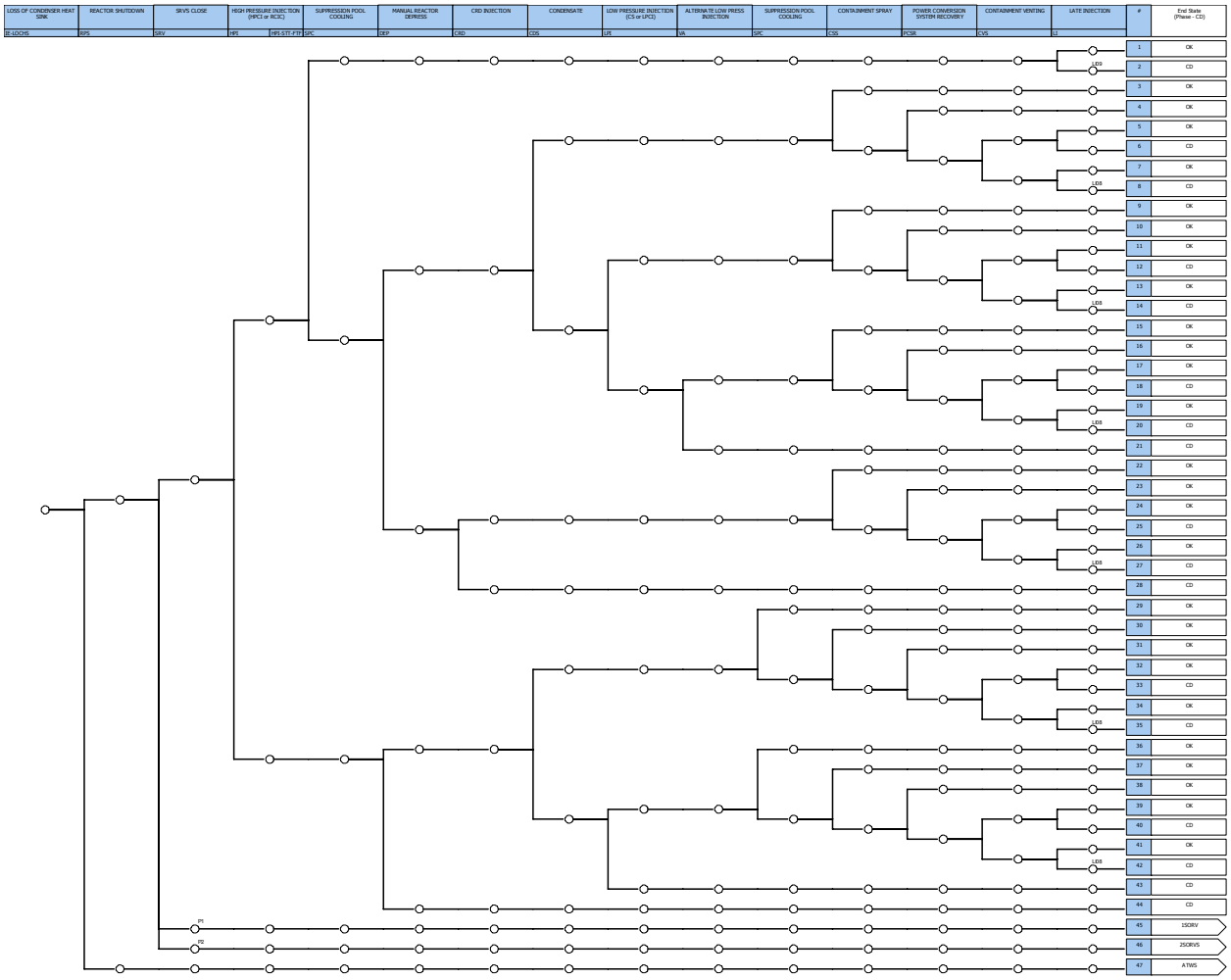

Figure B-1. Susquehanna, Unit 1 LOCHS event tree.