C.7 LER No. 304/94-002

Event Description: Unavailability of Turbine-Driven Auxiliary Feedwater Pump and Emergency Diesel Generator

Date of Event: March 7, 1994

Plant: Zion Unit 2

C.7.1 Summary

During a refueling outage, with Unit 2 in hot shutdown, operators were performing a surveillance test on the turbine-driven auxiliary feedwater (TDAFW) pump and an endurance test on the 2B emergency diesel generator (EDG). During the tests, the TDAFW pump tripped on "overspeed," and the EDG experienced frequency swings and was manually tripped. An operator also observed an increase in lube oil and jacket water cooler temperatures for the EDG before it was manually tripped. The cause of the TDAFW pump trip could not be determined. The EDG frequency swings were caused by a blown fuse, and the elevated lube oil and jacket water cooler temperatures were caused by zebra mussel shells in the lube oil and jacket water coolers for EDG 2B. The conditional core damage probability estimated for this event is 2.3×10^{-5}.

C.7.2 Event Description

Zion Unit 2 was performing several tests required to conclude a refueling outage. During a surveillance test on the TDAFW pump, the pump tripped at 0533 hours on March 7, 1994. The cause of the TDAFW pump trip could not be determined. An endurance test of the 2B EDG was also being performed. During the endurance test, the EDG experienced frequency swings, and lube oil and jacket water cooler temperatures increased. The EDG was manually tripped at 0618 hours on March 7, 1994. It was later determined that the frequency swings were caused by a blown fuse, and the increased coolant temperatures were caused by zebra-mussel shells in the lube oil and jacket water coolers. The zebra mussels were from the fire protection header that was used to supply EDG cooling during a dual-unit service water outage.

The zebra-mussel shells were cleaned from EDG 2B, and the blown fuse was replaced. The coolers for the 0 EDG and the 2A EDG were inspected and few or no shells were found. The 1A and 1B EDGs were not inspected, but testing was performed to verify that the EDGs were operable.

C.7.3 Additional Event-Related Information

The auxiliary feedwater (AFW) system consists of two 200% capacity subsystems. One subsystem utilizes two 100% capacity motor-driven pumps that are powered from separate engineered safety features (ESF) buses. Each motor-driven pump supplies a header, which in turn supplies all four of the steam generators (SGs). The TDAFW pump supplies all four of the SGs. Steam to drive the TDAFW pump is supplied from either SG 2A or SG 2D.

There are three safety-related buses for each unit. There are three sources of power for each bus—a normal feed from the respective unit's transformers, a cross-tie to the opposite unit, and an emergency diesel generator. There are five diesel generators—two for Unit 1, two for Unit 2, and one common diesel that can serve one bus on both units. If a safety injection signal is present, the common diesel generator will align to the unit with the safety injection signal. If a safety injection signal is absent, the common diesel generator is capable of supplying power to the associated electrical bus of each unit simultaneously.

C.7.4 Modeling Assumptions

Although this event occurred during a refueling outage, it was modeled assuming it could have occurred with the plant at power. The fuse failure that rendered the EDG inoperable could have occurred at any time. The failure mechanism for the TDAFW pump could not be determined, but is was assumed that the failure could also have occurred at any time. The zebra mussel shells could have been introduced during a short outage, and the plant could have been returned to a power condition prior to performing an endurance run of the EDG. Therefore, this event was modeled as if it occurred during power operation.

It was assumed that the EDG 2B was inoperable for one-half of its 30-day surveillance period. It was assumed that the EDG surveillance tests performed every 30 days would have run the EDG long enough to detect the degraded cooling condition. It was also assumed that the TDAFW pump would have tripped on "overspeed" during this period. The equipment powered by the 2B EDG would be unavailable during a LOOP event prior to restoration of offsite power.

This event was modeled as an unavailability of the 2B EDG and the TDAFW pump for a period of 15 days (360 h). The TDAFW pump failure to start and run probability (AFW-TDP-FC-1C) was set to 1.0 (TRUE) to reflect its condition, and the operator nonrecovery probability was set to 0.04 because recovery was considered to be proceduralized and could have been performed from the control room. Note, this value is the default value and is nearly identical to the probability used for the failure of auxiliary feedwater. The 2B EDG failure probability (EPS-DGN-FC-1B) was set to 1.0 (TRUE). The emergency power system was treated as a three-train system because of the common diesel. Common-cause failure probabilities are estimated using the MGL model. In this model, the nominal common-cause basic event for a three-train system is $Q \times \beta \times \gamma$. If one train suffers a random failure and the other trains are exposed to this failure mechanism, then the common-cause basic event becomes $\beta \times \gamma$. Therefore, the common-cause failure probability becomes 2.7×10^{-2} (0.1×0.27). The initiating event frequency for all initiators was calculated for a 360-h period.

C.7.5 Analysis Results

The conditional core damage probability estimated for this event is 2.3×10^{-5}. The dominant sequence highlighted on the event tree in Figure C.7.1 involves a postulated LOOP, a successful reactor trip, failure of emergency power, a PORV lift and successful reseat, recovery of AFW, and failure to recover offsite power prior to core uncovery following a reactor coolant pump seal LOCA. If the zebra mussels were judged not to be a common cause failure, then the CCDP would be 7×10^{-6}.

Definitions and probabilities for selected basic events are shown in Table C.7.1. The conditional probabilities associated with the highest probability sequences are shown in Table C.7.2. Table C.7.3 lists the sequence logic associated with the sequences listed in Table C.7.2. Table C.7.4 describes the system names associated with the dominant sequences. Cutsets associated with each sequence are shown in Table C.7.5.

C.7.6 Reference

1. LER 304/94-002, Revision 1, "Exceeded Limiting Condition for Operation 3.7.2 Action e for Placing Unit in Mode 4 with a Turbine-Driven and Motor-Driven AFW Pump Inoperable," July 25, 1994.

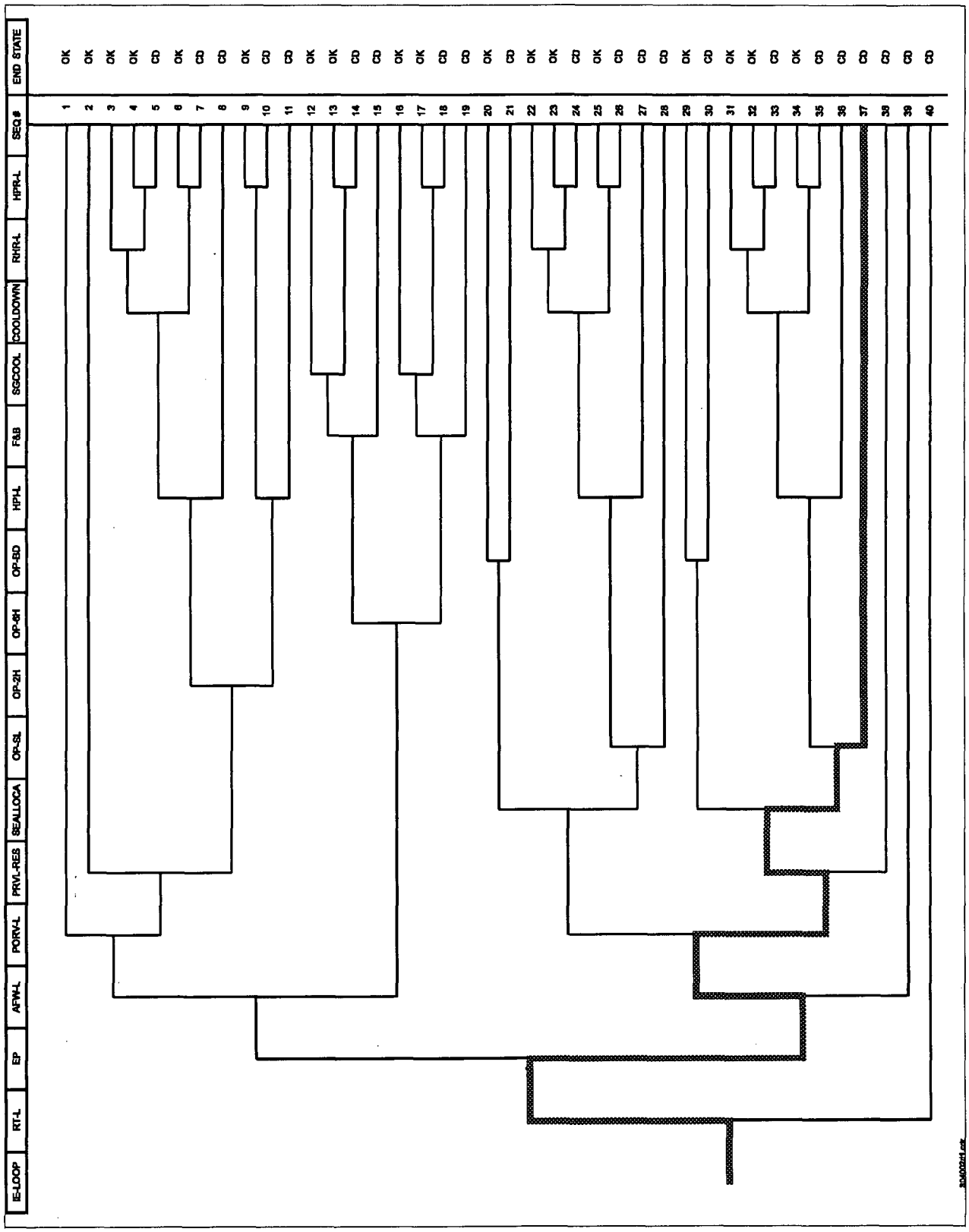

Figure C.7.1. Dominant core damage sequence for LER 304/94-002.

Table C.7.1. Definitions and probabilities for selected basic events for LER 304/94-002

Event name	Description	Base probability	Current probability	Type	Modified for this event
AFW-TDP-FC-1C	AFW Turbine Driven Pump Fails	3.9E-002	1.0E+000	TRUE	Y
AFW-XHE-NOREC-EP	Operator Fails to Recover AFW During Station Blackout	3.4E-001	4.0E-002		Y
AFW-XHE-NOREC-L	Operator Fails to Recover AFW System During LOOP	2.6E-001	4.0E-002		Y
EPS-DGN-CF-ALL	Common Cause Failure of Diesel Generators	1.0E-003	3.7E-003		Y
EPS-DGN-FC-10	Diesel Generator 0 Fails	3.7E-002	3.7E-002		N
EPS-DGN-FC-1A	Diesel Generator 1A Fails	3.7E-002	3.7E-002		N
EPS-DGN-FC-1B	Diesel Generator 1B Fails	3.8E-002	1.0E+000	TRUE	Y
EPS-XHE-NOREC	Operator Fails to Recover Emergency Power	8.0E-001	8.0E-001		N
HPI-MOV-OO-RWST	HPI RWST Isolation MOV Fails	3.0E-003	3.0E-003		N
HPR-MOV-CC-RHRB	RHR Train B Discharge MOV Fails	3.0E-003	3.0E-003		N
HPR-MOV-CC-SMPB	Failure of Sump MOV SI-8811B	3.0E-003	3.0E-003		N
HPR-XHE-NOREC-L	Operator Fails to Recover HPR System During LOOP	1.0E+000	1.0E+000		N
IE-LOOP	Loss-of-Offsite Power Initiating Event	8.6E-006	3.1E-003		Y
IE-SGTR	Steam Generator Tube Rupture Initiating Event	1.6E-006	5.9E-004		Y
IE-SLOCA	Small Loss of Coolant Accident Initiating Event	1.0E-006	3.6E-004		Y
IE-TRANS	Transient Initiating Event	5.3E-004	1.7E-001		Y
OEP-XHE-NOREC-BD	Operator Fails to recover offsite power before battery depletion	3.1E-002	3.1E-002		N
OEP-XHE-NOREC-SL	Operator Fails to Recover Offsite Power (Seal LOCA)	5.7E-001	5.7E-001		N
PPR-SRV-OO-1	PORV 1 Fails to Reclose After Opening	3.0E-002	3.0E-002		N
PPR-SRV-OO-2	PORV 2 Fails to Reclose After Opening	3.0E-002	3.0E-002		N
RCS-MDP-LK-SEALS	RCP Seals Fail Without Cooling and Injection	2.7E-001	2.7E-001		N
RHR-MDP-FC-1B	RHR Train B Fails	4.0E-003	4.0E-003		N
RHR-MOV-CF-RWST	Common Cause Failure of RHR/RWST MOVs	2.6E-004	2.6E-004		N

Table C.7.1. Definitions and probabilities for selected basic events for LER 304/94-002 (cont.)

Event name	Description	Base probability	Current probability	Type	Modified for this event
RHR-MOV-OO-RWSTA	RHR/RWST Isolation MOV 8812A Fails to Close	3.0E-003	3.0E-003		N
RHR-MOV-OO-RWSTB	RHR/RWST Isolation MOV 8812B Fails to Close	3.0E-003	3.0E-003		N
RHR-XHE-NOREC	Operator Fails to Recover the RHR System	1.0E+000	1.0E+000		N
RHR-XHE-NOREC-L	Operator Fails to Recover the RHR System During LOOP	1.0E+000	1.0E+000		N

Table C.7.2. Sequence conditional probabilities for LER 304/94-002

Event tree name	Sequence name	Conditional core damage probability (CCDP)	Core damage probability (CDP)	Importance (CCDP-CDP)	%Contribution
LOOP	37	1.0E-005	1.2E-006	9.6E-006	46.2
LOOP	38	4.2E-006	1.7E-007	4.0E-006	18.0
LOOP	39	2.8E-006	1.8E-007	2.6E-006	12.0
LOOP	30	2.1E-006	5.1E-008	2.1E-006	9.3
LOOP	05	1.7E-006	1.7E-007	1.5E-006	7.4
Total (all sequences)		2.3E-005	2.4E-006	2.1E-005	

Table C.7.3. Sequence logic for LER 304/94-002

Event tree name	Sequence name	Logic
LOOP	37	/RT-L, EP, /AFW-L-EP, PORV-L, /PORV-EP, SEALLOCA, OP-SL
LOOP	38	/RT-L, EP, /AFW-L-EP, PORV-L, PORV-EP
LOOP	39	/RT-L, EP, AFW-L-EP
LOOP	30	/RT-L, EP, /AFW-L-EP, PORV-L, /PORV-EP, /SEALLOCA, OP-BD
LOOP	05	/RT-L, /EP, /AFW-L, PORV-L, PRVL-RES, /OP-2H, /HPI-L, /COOLDOWN, RHR-L, HPR-L

Table C.7.4. System names for LER 304/94-002

System name	Description
AFW-L	No or Insufficient AFW Flow During LOOP
AFW-L-EP	No or Insufficient AFW Flow During Station Blackout
COOLDOWN	RCS CoolDown to RHR Pressure Using TBVs, etc.
EP	Failure of Both Trains of Emergency Power
HPI-L	No or Insufficient Flow From HPI System During LOOP
HPR-L	No or Insufficient HPR Flow During LOOP
OP-2H	Operator Fails to Recover Offsite Power Within 2 hrs
OP-BD	Operator Fails to Recover Offsite Power Before Battery Depletion
OP-SL	Operator Fails to Recover Offsite Power (Seal LOCA)
PORV-EP	PORVs Fail to Reclose (No Electric Power)
PORV-L	PORVs Open During LOOP
PRVL-RES	PORVs and Block Valves Fail to Reclose (EP Succeeds)
RHR-L	No or Insufficient Flow From RHR System During LOOP
RT-L	Reactor Fails to Trip During LOOP
SEALLOCA	RCP Seals Fail During LOOP

Table C.7.5. Conditional cut sets for higher probability sequences for LER 304/94-002

Cut set No.	% Contribution	Frequency	Cut sets
LOOP Seq: 37		1.1E-005	
1	94.9	1.0E-005	EPS-DGN-CF-ALL, EPS-XHE-NOREC,,OEP-XHE-NOREC-SL, RCS-MDP-LK-SEALS
2	5.0	5.4E-007	EPS-DGN-FC-1A, EPS-XHE-NOREC, OEP-XHE-NOREC-SL, RCS-MDP-LK-SEALS, EPS-DGN-FC-10
LOOP Seq: 38		4.2E-006	
1	47.4	2.0E-006	EPS-DGN-CF-ALL, EPS-XHE-NOREC, PPR-SRV-OO-2
2	47.4	2.0E-006	EPS-DGN-CF-ALL, EPS-XHE-NOREC, PPR-SRV-OO-1
LOOP Seq: 39		2.8E-006	
1	94.9	2.7E-006	AFW-XHE-NOREC-EP, EPS-DGN-CF-ALL, EPS-XHE-NOREC
2	5.0	1.4E-007	AFW-XHE-NOREC-EP, EPS-DGN-FC-1A, EPS-XHE-NOREC, EPS-DGN-FC-10
LOOP Seq: 30		2.2E-006	
1	94.9	2.1E-006	EPS-DGN-CF-ALL, EPS-XHE-NOREC, OEP-XHE-NOREC-BD
2	5.0	1.1E-007	EPS-DGN-FC-1A, EPS-XHE-NOREC, OEP-XHE-NOREC-BD, EPS-DGN-FC-10

Table C.7.5. Conditional cut sets for higher probability sequences for LER 304/94-002 (cont.)

Cut set No.	% Contribution	Frequency	Cut sets
LOOP Seq: 05		1.8E-006	
1	20.5	3.6E-007	/EPS-DGN-FC-1A, HPR-XHE-NOREC-L, PPR-SRV-OO-2, RHR-MDP-FC-1B, RHR-XHE-NOREC-L
2	15.3	2.7E-007	/EPS-DGN-FC-1A, HPR-XHE-NOREC-L, PPR-SRV-OO-2, RHR-XHE-NOREC-L, HPR-MOV-CC-RHRB
3	15.3	2.7E-007	/EPS-DGN-FC-1A, HPR-XHE-NOREC-L, PPR-SRV-OO-2, RHR-XHE-NOREC-L, RHR-MOV-OO-RWSTA
4	15.3	2.7E-007	/EPS-DGN-FC-1A, HPR-XHE-NOREC-L, PPR-SRV-OO-2, RHR-XHE-NOREC-L, HPI-MOV-OO-RWST
5	15.3	2.7E-007	/EPS-DGN-FC-1A, HPR-XHE-NOREC-L, PPR-SRV-OO-2, RHR-XHE-NOREC-L, HPR-MOV-CC-SMPB
Total (all sequences)		2.3E-005	