## B.10 LER No. 389/95-005

Event Description: Failure of one emergency diesel generator with common-cause failure implications

Date of Event: November 20, 1995

Plant: St. Lucie, Unit 2

### B.10.1 Event Summary

The 2A Emergency Diesel Generator (EDG) failed to start with the unit shutdown in Mode 6 following routine 18-month preventive maintenance. Several relay sockets were identified to be loose and were replaced. The 2A EDG subsequently failed a 24-h test run because of loose socket connections, and 48 of 54 relay sockets were replaced. The 2B EDG was determined to be subject to failure because of a common cause. The unavailability of the 2A EDG and the increased potential for a common cause failure of the 2B EDG affects the Unit 2 response to a loss of offsite power (LOOP). The estimated conditional core damage probability (CCDP) for this event is $1.4 \times 10^{-5}$. The nominal core damage probability (CDP) for the same period is $9.9 \times 10^{-7}$. Hence, the importance (CCDP–CDP) for this event is $1.3 \times 10^{-5}$.

### B.10.2 Event Description

Unit 2 entered a refueling outage on October 9, 1995. On November 3, 1995, the 2A EDG failed to start following routine 18-month preventive maintenance. The shutdown relay socket was found to have a cracked solder joint and was replaced. On November 4, 1995, the 2A EDG was paralleled with the grid. The load was unstable, and the 2A EDG was unloaded and secured. The relay controlling governor operation was identified to have a loose socket connection, causing a high resistance at the connection. All 54 relays were tested in place, and two additional loose sockets were identified and replaced. The 2A EDG was started and loaded for a 24-h surveillance run. Approximately 17 h into the run, a loss of remote control occurred, and the EDG was shutdown. A failed solder joint connection was identified on the load control relay socket. All 54 relay sockets were removed from the 2A EDG and inspected. A total of 48 sockets were replaced with new sockets, and the 2A EDG was returned to service.

On November 20, 1995, the 2B EDG was removed from service for routine 18-month preventive maintenance. A single, inadequate relay socket connection was identified, and all 54 relay sockets were replaced as a precaution. The inspection of the 2B EDG indicated the possibility of a common-cause failure of the 2B EDG.

### B.10.3 Additional Event-Related Information

The 1A and 1B EDG critical relays were removed and replaced. The removed relay sockets showed no signs of degradation. The orientation of the relays relative to the EDGs on Unit 1 was different than on Unit 2. Therefore, the 1A and 1B EDGs were determined not to be at increased risk of common-cause failure

resulting from the 2A EDG failure. Subsequent vibration readings in the vicinity of the relay panels on the 1A EDG and 2B EDG supported this conclusion.

## B.10.4 Modeling Assumptions

The 2A EDG failure was discovered during Mode 6 operation. However, the failure could have occurred with the unit in Mode 1 operation. Therefore, the event was analyzed as though the EDG failure occurred at power. The 2A EDG had successfully completed the previous monthly surveillance, so a failure period of 15 days was assumed.

A conditional assessment for 360 h (15 days) was performed with the 2A EDG failure probability (EPS-DGN-FC-DGA) set to TRUE. Because the 2A EDG was failed, the common-cause failure probability for the diesel generators (EPS-DGN-CF-AB) was set to the Beta factor for the Unit 2 EDGs. This accounts for the increased probability of the 2B EDG failing from a common cause as a result of the failure of the 2A EDG. The basic event representing the probability of not recovering the EDGs, if failed, in the short term, EPS-XHE-NOREC, was set to TRUE to reflect the expected inability to recover from the observed failures.

LOOP probabilities for offsite power recovery (accounted for in basic events OEP-XHE-NOREC-BD and OEP-XHE-NOREC-SL) and the probability of a reactor coolant pump (RCP) seal loss-of-coolant accident (LOCA) following a postulated station blackout were developed based on data distributions in NUREG-1032, *Evaluation of Station Blackout Accidents at Nuclear Power Plants*. The capability to provide power to Unit 2 from Unit 1 via a blackout cross-tie was simulated using a lognormal distribution of the operator response. The lognormal parameters were combined with the methodology described in the document *Revised LOOP Recovery and PWR Seal LOCA Models*, ORNL/NRC/LTR-89/11, to produce LOOP parameters that accounted for use of the blackout cross-tie for a plant-centered LOOP.

## B.10.5 Analysis Results

The estimated CCDP for the 360-h period that the 2A EDG was unavailable is $1.4 \times 10^{-5}$. Because the nominal CDP for the same period is $9.9 \times 10^{-7}$, the importance is also $1.3 \times 10^{-5}$. The dominant core damage sequence, highlighted as sequence number 41 on the LOOP event tree in Fig. B.10.1 contributes approximately 37% to the CCDP estimate. Sequence 41 involves:

- a LOOP,
- the successful trip of the reactor,
- the failure of emergency power, and
- the failure of the auxiliary feedwater system.

Definitions and probabilities for selected basic events are shown in Table B.10.1. The conditional probabilities associated with the highest probability sequences for the condition assessment are shown in Table B.10.2. The sequence logic associated with the sequences listed in Table B.10.2 are given in Table B.10.3. Table B.10.4 describes the system names associated with the dominant sequences for the condition assessment. Minimal cut sets associated with the dominant sequences for the condition assessment are listed in Table B.10.5.

## B.10.6 References

1. LER 389/95-005, Rev 0, "2A Emergency Diesel Generator Relay Socket Failures Due to High Cycle Fatigue," December 20, 1995.

2. ORNL/NRC/LTR-89/11, *Revised LOOP Recovery and PWR Seal LOCA Models,* August 1989.

3. Florida Power and Light Company, *St. Lucie Unit 2 Final Safety Analysis Report.*

4. NUREG 1032, *Evaluation of Station Blackout Accidents at Nuclear Power Plants.*

5. *Revised LOOP Recovery and PWR Seal LOCA Models*, ORNL/NRC/LTR-89/11, August 1989.

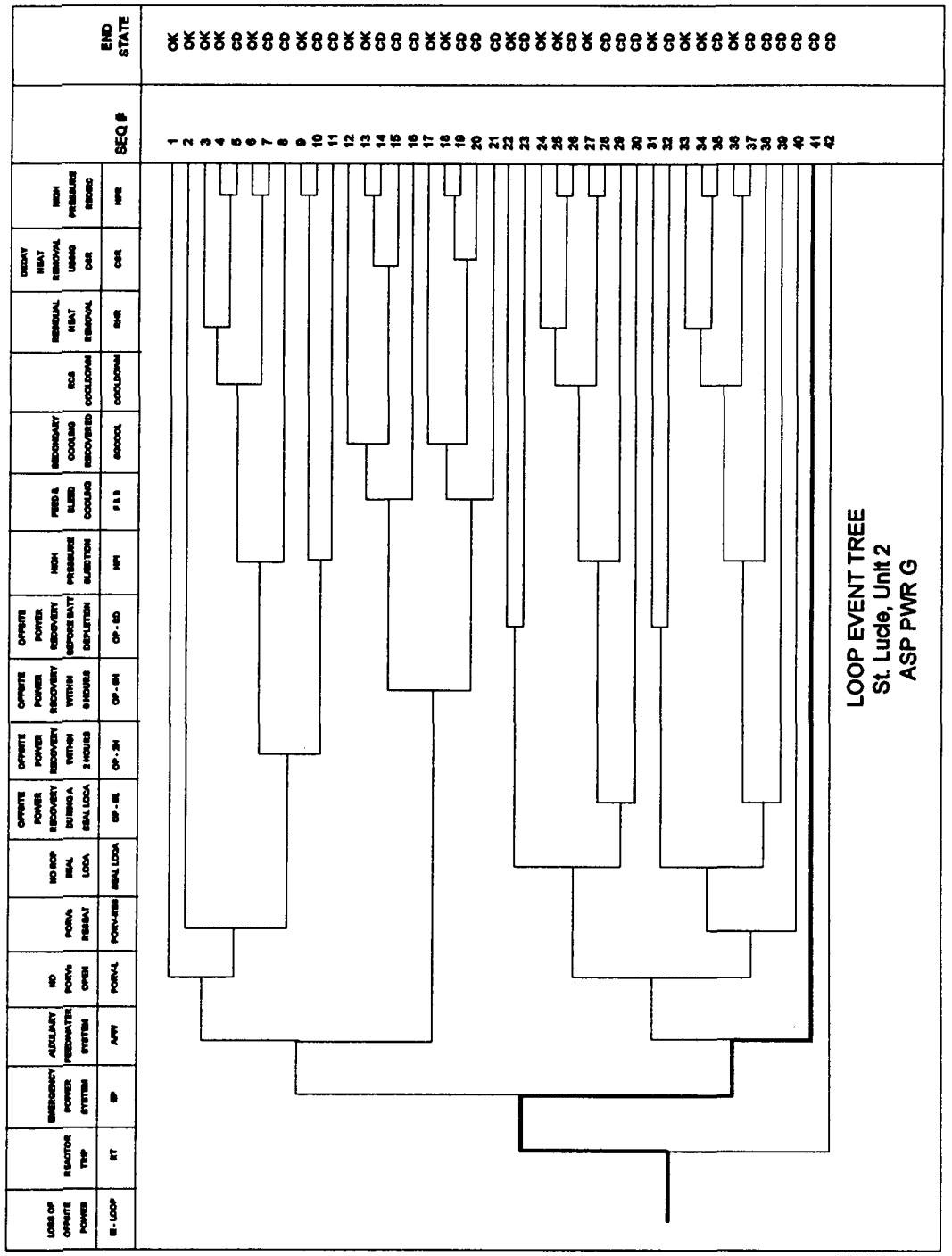


Fig. B.10.1. Dominant core damage sequence given a LOOP for LER 389/95-005.

**Table B.10.1. Definitions and Probabilities for Selected Basic Events for LER No. 389/95-005**

| Event name | Description | Base probability | Current probability | Type | Modified for this event |
|---|---|---|---|---|---|
| AFW-TDP-FC-1C | Auxiliary Feedwater (AFW) Turbine-Driven Pump 1C Failure | 3.2E-002 | 3.2E-002 | | No |
| AFW-XHE-NOREC-EP | Operator Fails to Recover AFW during a Station Blackout (SBO) | 3.4E-001 | 3.4E-001 | | No |
| AFW-XHE-XA-CST2E | Operator Fails to Initiate Backup Water Source | 1.0E-003 | 1.0E-003 | | No |
| EPS-DGN-CF-AB | Common-Cause Failure of Diesel Generators | 1.6E-003 | 3.8E-002 | | Yes |
| EPS-DGN-FC-DGA | Diesel Generator A Failure | 4.2E-002 | 1.0E+000 | TRUE | Yes |
| EPS-DGN-FC-DGB | Diesel Generator B Failure | 4.2E-002 | 4.2E-002 | | No |
| EPS-XHE-NOREC | Operator Fails to Recover Emergency Power | 8.0E-001 | 1.0E+000 | TRUE | Yes |
| OEP-XHE-NOREC-BD | Operator Fails to Recover Off-Site Power Before Battery Depletion | 8.8E-003 | 8.8E-003 | | No |
| OEP-XHE-NOREC-SL | Operator Fails to Recover Off-Site Power Before Seal LOCA | 5.4E-001 | 5.4E-001 | | No |
| PPR-SRV-CO-SBO | Safety Relief Valves Open During a SBO | 3.7E-001 | 3.7E-001 | | No |
| PPR-SRV-OO-1 | Power Operated Relief Valve (PORV) 1 Fails to Reclose After Opening | 2.0E-003 | 2.0E-003 | | No |
| PPR-SRV-OO-2 | PORV 2 Fails to Reclose After Opening | 2.0E-003 | 2.0E-003 | | No |
| PPR-XHE-NOREC-L | Operator Fails to Close Block Valves | 1.1E-002 | 1.1E-002 | | No |
| RCS-MDP-LK-SEALS | RCP Seals Fail Without Cooling and Injection | 7.4E-003 | 7.4E-003 | | No |

**Table B.10.2. Sequence Conditional Probabilities for LER No. 389/95-005**

| Event tree name | Sequence name | Conditional core damage probabiliy (CCDP) | Core damage probability (CDP) | Importance (CCDP-CDP) | Percent contribution[b] |
|---|---|---|---|---|---|
| LOOP | 41 | 5.3E-006 | 1.7E-007 | 5.1E-006 | 38.6 |
| LOOP | 23 | 4.1E-006 | 1.3E-007 | 3.9E-006 | 29.5 |
| LOOP | 30 | 1.8E-006 | 6.3E-008 | 1.8E-006 | 13.6 |
| LOOP | 32 | 1.5E-006 | 5.1E-008 | 1.4E-006 | 10.6 |
| LOOP | 39 | 6.9E-007 | 2.3E-008 | 6.7E-007 | 5.0 |
| LOOP | 40 | 3.4E-007 | 7.7E-010 | 3.4E-007 | 2.5 |
| **Total (all sequences)[a]** | | **1.4E-005** | **9.9E-007** | **1.3E-005** | |

[a] This analysis represents the conditional core damage probability because of the long-term unavailability (15 days) of the 2A EDG and the increased potential for common cause failure of the 2B EDG.
[b] Percent contribution to the total Importance.

**Table B.10.3. Sequence Logic for Dominant Sequences for LER No. 389/95-005**

| Event tree name | Sequence name | Logic |
|---|---|---|
| LOOP | 41 | /RT-L, EP, AFW-L-EP |
| LOOP | 23 | /RT-L, EP, /AFW-L, /PORV-SBO, /SEALLOCA, OP-BD |
| LOOP | 30 | /RT-L, EP, /AFW-L, /PORV-SBO, SEALLOCA, OP-SL |
| LOOP | 32 | /RT-L, EP, /AFW-L, PORV-SBO, /PRVL-RES, /SEALLOCA, OP-BD |
| LOOP | 39 | /RT-L, EP, /AFW-L, PORV-SBO, /PRVL-RES, SEALLOCA, OP-SL |
| LOOP | 40 | /RT-L, EP, /AFW-L, PORV-SBO, PRVL-RES |

**Table B.10.4. System Names for LER No. 389/95-005**

| System name | Logic |
|---|---|
| AFW-L | No or Insufficient AFW Flow During a LOOP event |
| AFW-L-EP | No or Insufficient AFW Flow During SBO |
| EP | Failure of Both Trains of Emergency Power |
| OP-BD | Operator Fails to Recover Off-Site Power Before Battery Depletion |
| OP-SL | Operator Fails to Recover Off-Site Power Before Core Uncovery Following a Seal LOCA on a RCP |
| PORV-SBO | PORVs Open During a SBO |
| PRVL-RES | PORVs and Block Valves Fail to Reseat |
| RT-L | Reactor Fails to Trip During a LOOP |
| SEALLOCA | RCP Seals Fail During a LOOP |

**Table B.10.5. Conditional Cut Sets for Higher Probability Sequences for LER No. 389/95-005**

| Cut set no. | Percent contribution | Conditional probability[a] | Cut sets[b] |
|---|---|---|---|
| **LOOP Sequence 41** | | 5.3E-006 | |
| 1 | 50.2 | 2.7E-006 | EPS-DGN-FC-DGA, EPS-DGN-FC-DGB, EPS-XHE-NOREC, AFW-TDP-FC-1C, AFW-XHE-NOREC-EP |
| 2 | 45.5 | 2.4E-006 | EPS-DGN-CF-AB, EPS-XHE-NOREC, AFW-TDP-FC-1C, AFW-XHE-NOREC-EP |
| 3 | 1.5 | 8.3E-007 | EPS-DGN-FC-DGA, EPS-DGN-FC-DGB, EPS-XHE-NOREC, AFW-XHE-XA-CST2E, AFW-XHE-NOREC-EP |
| 4 | 1.4 | 7.6E-007 | EPS-DGN-CF-AB, EPS-XHE-NOREC, AFW-XHE-XA-CST2E, AFW-XHE-NOREC-EP |
| **LOOP Sequence 23** | | 4.1E-006 | |
| 1 | 52.5 | 2.2E-006 | EPS-DGN-FC-DGA, EPS-DGN-FC-DGB, EPS-XHE-NOREC, OEP-XHE-NOREC-BD |
| 2 | 47.5 | 1.9E-006 | EPS-DGN-CF-AB, EPS-XHE-NOREC, OEP-XHE-NOREC-BD |
| **LOOP Sequence 30** | | 1.8E-006 | |
| 1 | 52.5 | 9.7E-007 | EPS-DGN-FC-DGA, EPS-DGN-FC-DGB, EPS-XHE-NOREC, RCS-MDP-LK-SEALS, OEP-XHE-NOREC-SL |
| 2 | 47.5 | 8.6E-007 | EPS-DGN-CF-AB, EPS-XHE-NOREC, RCS-MDP-LK-SEALS, OEP-XHE-NOREC-SL |
| **LOOP Sequence 32** | | 1.5E-006 | |
| 1 | 52.5 | 7.9E-007 | EPS-DGN-FC-DGA, EPS-DGN-FC-DGB, EPS-XHE-NOREC, PPR-SRV-CO-SBO, OEP-XHE-NOREC-BD |
| 2 | 47.5 | 7.2E-007 | EPS-DGN-CF-AB, EPS-XHE-NOREC, PPR-SRV-CO-SBO, OEP-XHE-NOREC-BD |
| **LOOP Sequence 39** | | 6.9E-007 | |
| 1 | 52.5 | 3.6E-007 | EPS-DGN-FC-DGA, EPS-DGN-FC-DGB, EPS-XHE-NOREC, PPR-SRV-CO-SBO, RCS-MDP-LK-SEALS, OEP-XHE-NOREC-SL |
| 2 | 47.5 | 3.3E-007 | EPS-DGN-CF-AB, EPS-XHE-NOREC, PPR-SRV-CO-SBO, RCS-MDP-LK-SEALS, OEP-XHE-NOREC-SL |

## Table B.10.5. Conditional Cut Sets for Higher Probability Sequences for LER No. 389/95-005

| Cut set no. | Percent contribution | Conditional probability[a] | Cut sets[b] |
|---|---|---|---|
| **LOOP Sequence 40** | | 3.4E-007 | |
| 1 | 48.9 | 1.7E-007 | EPS-DGN-CF-AB, EPS-XHE-NOREC, PPR-SRV-CO-SBO, PPR-SRV-OO-1 |
| 2 | 48.9 | 1.7E-007 | EPS-DGN-CF-AB, EPS-XHE-NOREC, PPR-SRV-CO-SBO, PPR-SRV-OO-2 |
| **Total (all sequences)** | | **1.4E-005** | |

[a]The conditional probability is determined by calculating the conditional probability for the period in which the condition existed. 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 $\lambda t$, where $\lambda$ is the frequency of the initiating event (given on a per-hour basis), and t is the duration time of the event (in this case, 360 h). This approximation is conservative for precursors made visible by the initiating event. The frequency of interest for this event is $\lambda_{LOOP} = 1.6 \times 10^{-5}$/h.

[b]Basic events EPS-DGN-FC-DGA and EPS-XHE-NOREC are TRUE type events which are not normally included in the output of fault tree reduction programs. These events have been added to aid in understanding the sequences to potential core damage associated with the event.