December 17, 1997

Mr. Ted C. Feigenbaum
Executive Vice President and
Chief Nuclear Officer
North Atlantic Energy Service Company
c/o Mr. Terry L. Harpster
P.O. Box 300
Seabrook, NH 03874

SUBJECT: REVIEW OF PRELIMINARY ACCIDENT SEQUENCE PRECURSOR ANALYSIS OF OPERATIONAL CONDITION AT SEABROOK

Dear Mr. Feigenbaum:

Enclosed for your information is a copy of the final Accident Sequence Precursor (ASP) analysis of the operational condition discovered at Seabrook that was reported in Licensee Event Report (LER) No. 50-443/96-003. This final analysis (Enclosure 1) was prepared by our contractor at the Oak Ridge National Laboratory (ORNL), based on review and evaluation of your comments on the preliminary analysis and comments received from the NRC staff and from our independent contractor, Sandia National Laboratories (SNL). Enclosure 2 contains our responses to your specific comments. Our review of your comments employed the criteria contained in the material which accompanied the preliminary analysis. The results of the final analysis indicate that this event is a precursor for 1996.

Please contact me at (301) 415-1427 if you have any questions regarding the enclosures. We recognize and appreciate the effort expended by you and your staff in reviewing and providing comments on the preliminary analysis.

Sincerely,

Original signed by:

Craig W. Smith, Project Manager
Project Directorate I-3
Division of Reactor Projects - I/II
Office of Nuclear Reactor Regulation

Docket No. 50-443

Enclosures: As stated

cc w/Encls: See next page

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LER No. 443/96-003

Event Description: Turbine-driven emergency feedwater pump unavailable because of a mechanical seal failure

Date of Event: May 21, 1996

Plant: Seabrook

Licensee Comments

Reference: Letter from Ted C. Feigenbaum, Executive Vice President and Chief Nuclear Officer – North Atlantic Energy Service Corporation, to U. S. Nuclear Regulatory Commission, "Comments on Preliminary Accident Sequence Precursor Analysis of an Operational Condition at Seabrook Station," October 3, 1997.

Comment 1: *Event Description*: Paragraph 1, Sentence 5 should be replaced by: "The outboard seal gland was making contact with the top of the shaft sleeve and the throttle bushing inside diameter."

Paragraph 1, add the following after Sentence 6: "The inboard seal gland had 0.007 in. clearance between the top of the shaft sleeve and the throttle bushing inside diameter."

Paragraph 2, Sentence 1 should read: ". . . the mechanical seals of the motor-driven . . . discovered the outboard mechanical seal to have a similar position, along . . ."

Paragraph 2, last Sentence should be replaced by: "The inspection revealed that the burnishing identified on the outboard mechanical seal of the MDEFW pump was consistent with normal rubbing experienced during pump startup. The system engineer concluded that the MDEFW pump was capable of performing it's design function based on the review of the as-found clearance data."

Paragraph 3, Sentence 3 should read: ". . . between the throttle bushing seal (secondary seal) and the shaft sleeve. There was never any contact with the primary seal."

Response 1: The proposed editorial changes enhance the description of the event. All of the suggested changes were made.

Enclosure 1

Comment 2: Paragraph 2, Sentence 2 [*Modeling Assumptions*] refers to the wear on the MDEFW pump as being "similar" to that of the TDEFW pump. The wear on the MDEFW pump was due to normal rubbing experienced during pump starts and was not similar to that found on the TDEFW pump. However, it was concluded that the MDEFW pump seal was susceptible to the same mechanical rubbing as experienced on the TDEFW pump.

Response 2: The adjustment to the common-cause failure probability was based on the description of the event given in the LER (LER No. 443/96-003 R01) that stated that "The inspection [of the MDEFW pump mechanical seals] concluded that similar alignments of the mechanical seals were observed on this pump. This suggests that the pump was susceptible to the same mechanical rubbing as experienced on the turbine-driven pump." The LER *Cause of Event* section also suggests that the mechanical seal failure on the TDEFW pump was partially attributable to a design deficiency that "also applies to the motor driven EFW pump mechanical seals." Additionally, the mechanical seal failure was partially attributed to an inadequate procedure (applicable to both pumps) that had not been updated to incorporate lessons learned from previous mechanical seal maintenance.

The reference to "similar" wear was incorrectly used to represent the above common-cause issues. The statement that the wear on the MDEFW pump is "similar" to the wear on the TDEFW pump resulting in an increased potential for a common-cause failure has been removed. The second sentence in the second paragraph in the *Modeling Assumptions* section now reads as

However, because the outboard mechanical seal on the MDEFW pump was (1) positioned similar to that of the TDEFW pump, (2) subject to the same design deficiency, and (3) subject to the same inadequate maintenance procedure that resulted in the TDEFW pump failure, the potential for a common-cause EFW pump failure increased.

Comment 3: Sequence 39 [revised analysis sequence 41] from the Figure 1 "Dominant core damage sequence for LER No. 443/96-003" is the risk-dominant sequence in the NRC analysis. This sequence is a station blackout with failure of the turbine-driven EFW pump. In this sequence, no credit is given for recovery of electric power, presumably due to the assumption that "45 min were available before steam generator dry out would occur, leading to core damage."

Seabrook has performed analyses of this specific analysis, using the MAAP code, with comparisons to the RELAP code results. These codes show that, for this sequence, the time to steam generator dry out is about 1.5 h, with core uncovery at 2.0 h, and core overheating at 2.2 h. As a result, substantial time is available for electric power recovery. In addition, the recovery curves have their highest slope from 0 to 2 h, indicating that a few additional minutes of recovery can be significant for recovery probability. The probability for failure to recover off-site power in 1.5 h is approximately 0.25 and the probability for failure to recover at least one of two EDGs in 1.5 h is 0.65. The overall nonrecovery probability for electric power is 0.25 × 0.65 = 0.16. This factor should be used in calculating the Station Blackout with EFW failure sequence.

Response 3: The assumption that "45 min were available before a steam generator dry out would occur" was used to derive a failure probability for the operator action to realign the start-up feedwater pump power supply breakers to the A EDG (basic event EFW-XHE-XM-BRKR). Based on this comment, the probability of this basic event occurring was revised from 0.16 to 0.056 to account for 90 min until a steam generator dry out occurs. If power was not recovered within 30 min, a station blackout and concurrent loss of EFW sequence was assumed to continue to core damage, as in the original modeling of the event.

However, because an additional 60 min might be available to the operators, the model was revised. A new basic event that represents recovering ac power before a steam generator dry out under blackout conditions concurrent with a loss of EFW was added to the model (basic event OEP-XHE-NOREC-SB). The probability that a source of electric power could be restored within 1.5 h given that it was not recovered within 30 min (basic event OEP-XHE-NOREC-SB) was calculated to be 0.29. Values for the probability of short-term and long-term electric power recovery for a LOOP following a postulated station blackout (SBO) were developed based on data distributions contained in NUREG-1032, *Evaluation of Station Blackout Accidents at Nuclear Power Plants* (Ref. 3 in the analysis). Based on this data distribution, the probability that a LOOP is recovered in the short term is 0.53 and is factored into the LOOP initiating event frequency. This results in an overall nonrecovery probability for electric power in the revised model of 0.53 × 0.29 = 0.15, which is approximately the same as the value presented in the licensee comment above.

The net effect of this model change is that the dominant sequence remains the same, but the increase in the CDP over the 3,875-h period is reduced from 1.2×10^{-4} to 4.6×10^{-5}.

Comment 4: North Atlantic agrees with the analysis conclusion that during a LOOP event without the MDEFW pump and TDEFW pump available, a heavy reliance is placed on operator action to maintain secondary cooling. North Atlantic licensed and non-licensed operators are routinely trained on shifting the start-up feedwater pump to the emergency feedwater alignment evolution. North Atlantic is confident that the operators would have been able to successfully complete this evolution during accident conditions utilizing the existing emergency procedure guidance and the specific training on this evolution. However, for this event, the engineering review of the MDEFW pump seal as-found data concluded that the MDEFW pump would have performed its required safety function, for the required mission time.

Response 4: The knowledge and training of the operators are recognized. The human error probabilities used in operations involving the alignment and use of the start-up feedwater pump are consistent with accepted error probabilities in operating other safety related equipment using existing emergency operating procedures.

The MDEFW pump was not modeled as failed. The independent failure probability of the MDEFW pump to start and run for the required mission time ($p = 3.9 \times 10^{-3}$ for basic event EFW-MDP-FC-1B) was not altered from the base case. However, for the reasons discussed in the response to comment 2, the common-cause failure potential for the EFW pumps was increased from 3.8×10^{-4} to 8.8×10^{-2} (basic event EFW-PMP-CF-EFW).

Comment 5: North Atlantic engineering personnel concluded that the TDEFW pump would not have been able to perform its safety function for the required mission time (24h) because of the improper installation of the seal. This conclusion was based on discussions with the pump manufacturer and engineering judgement. The exact time that the TDEFW pump became inoperable could not be conclusively determined since the pump successfully completed two prior surveillance runs without any indications of problems related to the mechanical seal degradation. The system engineer evaluated the damage to the seal and conservatively determined that the pump had been inoperable since the mechanical seals were worked on during the November–December 1995 refueling outage.

Response 5: The following sentences were added to the first paragraph of the *Analysis Results* section to address the uncertainty over when the TDEFW pump actually became inoperable: "This is a conservative estimate because the TDEFW pump was satisfactorily tested twice (a total run time of ~1–2 h) during the unavailability period (3,875 h). Therefore, the TDEFW pump likely would have operated for a limited period (less than the mission time of 24 h) during the first part of the unavailability period, which would mitigate the calculated CDP."

LER No. 443/96-003

Event Description: Turbine-driven emergency feedwater pump unavailable because of a mechanical seal failure

Date of Event: May 21, 1996

Plant: Seabrook

Event Summary

Seabrook was at 100% power when personnel were performing a scheduled operating test on the turbine-driven emergency feedwater (TDEFW) pump. The pump was manually tripped after sparks were observed coming out of its outboard mechanical seal. The sparks were ultimately attributed to the improper installation of the mechanical seal assembly during the previous refueling outage in November–December 1995 (Ref. 1, 2). This long-term unavailability of the TDEFW pump (3,875 h) would have affected the units' response to a loss of offsite power (LOOP) or a transient event. The estimated increase in the core damage probability (CDP) over the 5-month period for this event (i.e., the importance) is 4.6×10^{-5}. The base probability of core damage (the CDP) for the same period is 3.0×10^{-5}.

Event Description

Seabrook was at 100% power on May 21, 1996, when personnel started the TDEFW pump for its scheduled quarterly surveillance test. The operator tripped the pump locally during the test after sparks were observed emanating from the outboard mechanical seal area of the pump. The mechanical seal was disassembled and inspected. The sparks were the result of mechanical interference within the seal assembly. The outboard seal gland was making contact with the top of the shaft sleeve and the throttle bushing inside diameter. The sparks were caused because the shaft sleeve rubbed against the inside diameter of the throttle bushing, causing a 0.005-in. gouge in the shaft sleeve and the chipping of the throttle bushing. The inboard seal gland had a 0.007-in. clearance between the top of the shaft sleeve and the throttle bushing inside diameter. Licensee personnel concluded that because of the improper installation of the seal, the TDEFW pump would not have been able to perform its safety function for the required mission time (24 h) since the November–December 1995 refueling outage. However, the exact time that the TDEFW pump became inoperable could not be conclusively determined since the pump had successfully completed two prior surveillance runs without any indications of problems related to the mechanical seal degradation.

After repairing the TDEFW pump, personnel inspected the mechanical seals of the motor-driven emergency feedwater (MDEFW) pump and discovered the outboard mechanical seal to have a similar position, along with the corresponding indications of mechanical rubbing. The MDEFW pump outboard mechanical seal gland had a 0.0035-in. clearance between the shaft sleeve and the top of the throttle bushing inside diameter. The MDEFW pump throttle bushing was not chipped like the throttle bushing was on the TDEFW pump. The inspection revealed that the burnishing identified on the outboard mechanical seal of the MDEFW pump was consistent with normal rubbing experienced during pump startup. The system engineer concluded that the MDEFW pump was capable of performing its design function based on the review of the as-found clearance data.

The design clearances and tolerances of the TDEFW pump's mechanical seals were insufficient to prevent damage during operation unless the installation technique used noncustomary methods (i.e., use of dial indicators and feeler gauges). The design permitted the allowable tolerances to be greater than the available clearance. Hence, the design did not preclude the interference between the throttle bushing seal (secondary seal) and the shaft sleeve. There was never any contact with the primary seal. This design deficiency also applies to the MDEFW pump mechanical seals. Contributing to this event was the failure to adequately incorporate previous knowledge regarding seal installation into maintenance procedures or training. As a result, maintenance personnel were unaware of a prior seal failure (in 1987) or the need to take precision measurements to verify the proper installation of the seal assembly.

Additional Event-Related Information

The emergency feedwater (EFW) system consists of two 100% capacity trains that feed a common discharge header (Ref. 3). One train uses the TDEFW pump, and the other train uses the MDEFW pump. All four steam generators can be fed by either EFW pump. The TDEFW pump is supplied steam from the A and B steam generators. The MDEFW pump is powered from 4160V emergency bus E6 supported by the B emergency diesel generator (EDG).

Seabrook also maintains a start-up feedwater pump with a capacity approximately equivalent to the combined capacity of both EFW pumps (Ref. 3). The start-up feedwater pump can be started from the control room, except during a LOOP. Two normally closed motor-operated valves (MOVs) must be opened to establish feedwater flow. Following a LOOP, the normal power source to the start-up feedwater pump is not supplied power from an emergency bus. Therefore, the normal breaker alignment for the start-up feedwater pump must be altered from 4160V bus 4 to 4160V emergency bus E5 (emergency bus E5 is powered by the A EDG). The normal and alternate start-up feedwater pump breakers are key-interlocked, requiring one breaker to be racked out before the interlock key can be removed. The interlock key is required to rack-in the alternate source breaker (from bus E5) to the start-up feedwater pump.

Modeling Assumptions

Even though previous surveillance tests were successfully completed, the licensee concluded that the TDEFW pump would not have been able to perform its safety function for the required mission time (24 h) since the November–December 1995 refueling outage (Ref. 1, 2). Hence, the TDEFW pump was considered inoperable, and its failure probability was adjusted to 1.0 (TRUE) for a 3,875 h condition assessment. The 3,875 h condition assessment is based on the TDEFW pump being required from the end of the outage on December 9, 1995, until the discovery of the mechanical seal failure on May 2' 1996. Two days (48 h) were subtracted from the total number of hours that the TDEFW pump was unavailable to account for a reactor trip in January.

The licensee indicated that the MDEFW pump would have performed its safety function for the required mission time. However, because the outboard mechanical seal on the MDEFW pump was (1) positioned similar to that of the TDEFW pump, (2) subject to the same design deficiency, and (3) subject to the same inadequate maintenance procedure that resulted in the TDEFW pump failure, the potential for a common-cause EFW pump failure increased. The EFW common-cause factor was developed based on data distributions for mixed-pump types contained in INEL-94-0064, *Common-Cause Failure Data Collection and Analysis System* (Ref. 4, Table 9-19: Alpha Factor Distribution Summary – All AFW Types Fail to Start, CCCG = 2, α_2 = 0.0884). Because α_2 is equivalent to the β factor of the multiple Greek letter method used in the Integrated Reliability and Risk Analysis System (IRRAS) models, the common-cause failure probability of the EFW system pumps (EFW-PMP-CF-EFW) was adjusted from 3.8×10^{-4} to 8.84×10^{-2} based on the common-cause failure potential.

The utility has conducted computer simulations of a station blackout with a concurrent failure of EFW at Seabrook. This simulation has shown that under these conditions, the time to steam generator dry out is about 90 min. As a result, substantial time is available for electric power recovery. This potential was modeled by the addition of a basic event (OEP-XHE-NOREC-SB) that is considered under the OP-SBO top event (OP-2H) on the LOOP event tree (Fig. 1). Top Event OP-SBO is substituted for the OP-2H top event whenever emergency power and EFW are failed.

The Seabrook *Individual Plant Examination* (IPE) indicates that the start-up feedwater pump is a backup source of feedwater for the EFW system. To credit the use of the start-up feedwater pump, a basic event was added to the IRRAS model for the Seabrook plant based on the IPE value for a failure of the start-up feedwater pump to start and run (Ref. 5, Table 7.9-1) or a failure of the associated valves to open (basic event EFW-MDP-FC-SFP). Because an operator is required to open two normally closed MOVs to establish flow from the start-up feedwater system, another basic event was added to account for the failure of the operator to manipulate the required MOVs (EFW-XHE-XM-SFP). Finally, during a LOOP, an operator must realign the supply breaker for the start-up feedwater pump to the A EDG. A basic event was therefore added to represent the failure of an operator to complete this realignment (EFW-XHE-XM-BRKR). This last basic event was based on the assumption that it would take an operator approximately 15 min, following a LOOP, to perform the activity and that approximately 90 min were available before a steam generator dry out would occur, leading to core damage. A lognormal distribution was used to calculate the failure probability for EFW-XHE-XM-BRKR.

The operator nonrecovery probability for the EFW system during a LOOP (EFW-XHE-NOREC-L) was adjusted from 0.26 to 0.80 because this action is not independent from other operator actions. The operator must first realign the supply breaker for the start-up feedwater pump to the A EDG (EFW-XHE-XM-BRKR). If the operator fails to realign this breaker, the start-up feedwater pump would not be available in a LOOP scenario (LOOP sequence 17). Further, if the operator does indeed fail to realign this breaker, it is more likely that the operator will fail to recover the EFW system during a LOOP. Finally, during a station blackout (SBO), the only source of EFW is the TDEFW pump; therefore, with the TDEFW pump unavailable, there is no opportunity to recover EFW. Based on this, the operator nonrecovery factor during a SBO (EFW-XHE-NOREC-EP) was set to "TRUE" (recovery not possible).

Analysis Results

The increase in the CDP during a 3,875-h period for this event is 4.6×10^{-5}. The nominal CDP for the same period is 3.0×10^{-5}. This is a conservative estimate because the TDEFW pump was satisfactorily tested twice (a total run time of ~1–2 h) during the unavailability period (3,875 h). Therefore, the TDEFW pump likely would have operated for a limited period (less than the mission time of 24 h) during the first part of the unavailability period, which would mitigate the calculated CDP. The dominant core damage sequence for this event (sequence 41 on Fig. 1) involves

- a postulated LOOP,
- a successful reactor trip,
- a failure of emergency power,
- a failure of emergency feedwater, and
- a failure to restore electric power prior to steam generator dry out.

This SBO sequence (sequence 41 on Fig. 1) accounts for 56% of the total contribution to the increase in the CDP. The next most dominant sequence (sequence 17 on Fig. 1) contributes 22% to the total increase in the CDP. This sequence involves a LOOP with the success of emergency power, a failure of EFW, and a failure of feed-and-bleed decay heat removal.

An alternate study investigating the conditional core damage probability (CCDP) associated with the reactor trip that occurred in January with the unavailable TDEFW pump was conducted. The TDEFW pump failure probability (EFW-TDP-FC-1A) was set to "TRUE" (failed). Using the same material assumptions as those made for the previous condition assessment, the CCDP for this initiating event is 4.0×10^{-6}. The dominant core damage sequence involves a failure to trip the reactor and a failure of the EFW system.

Definitions and probabilities for selected basic events are shown in Table 1. The conditional probabilities associated with the highest probability sequences are shown in Table 2. Table 3 lists the sequence logic associated with the sequences listed in Table 2. Table 4 describes the system names associated with the dominant sequences. Minimal cut sets associated with the dominant sequences are shown in Table 5.

Acronyms

ATWS	anticipated transient without scram
CCDP	conditional core damage probability
CDP	core damage probability
EDG	emergency diesel generator
EFW	emergency feedwater system
IPE	integrated plant examination
IRRAS	Integrated Reliability and Risk Analysis System
LOOP	loss of offsite power
MDEFW	motor-driven EFW (pump)
MFW	main feedwater
MOV	motor-operated valve

PORV	power-operated relief valve
SBO	station blackout
TDEFW	turbine-driven EFW (pump)

References

1. LER 443/96-003, Rev. 0, "Emergency Feedwater Pump Mechanical Seal Failure," June 21, 1996.

2. LER 443/96-003, Rev. 1, "Emergency Feedwater Pump Mechanical Seal Failure," September 12, 1996.

3. Seabrook Nuclear Station, *Final Safety Analysis Report*.

4. Marshall and R[illegible]uson, *Common-Cause Failure Data Collection and Analysis System*, INEL-94/0064, December 1995.

5. Seabrook Nuclear Station, *Individual Plant Examination*.

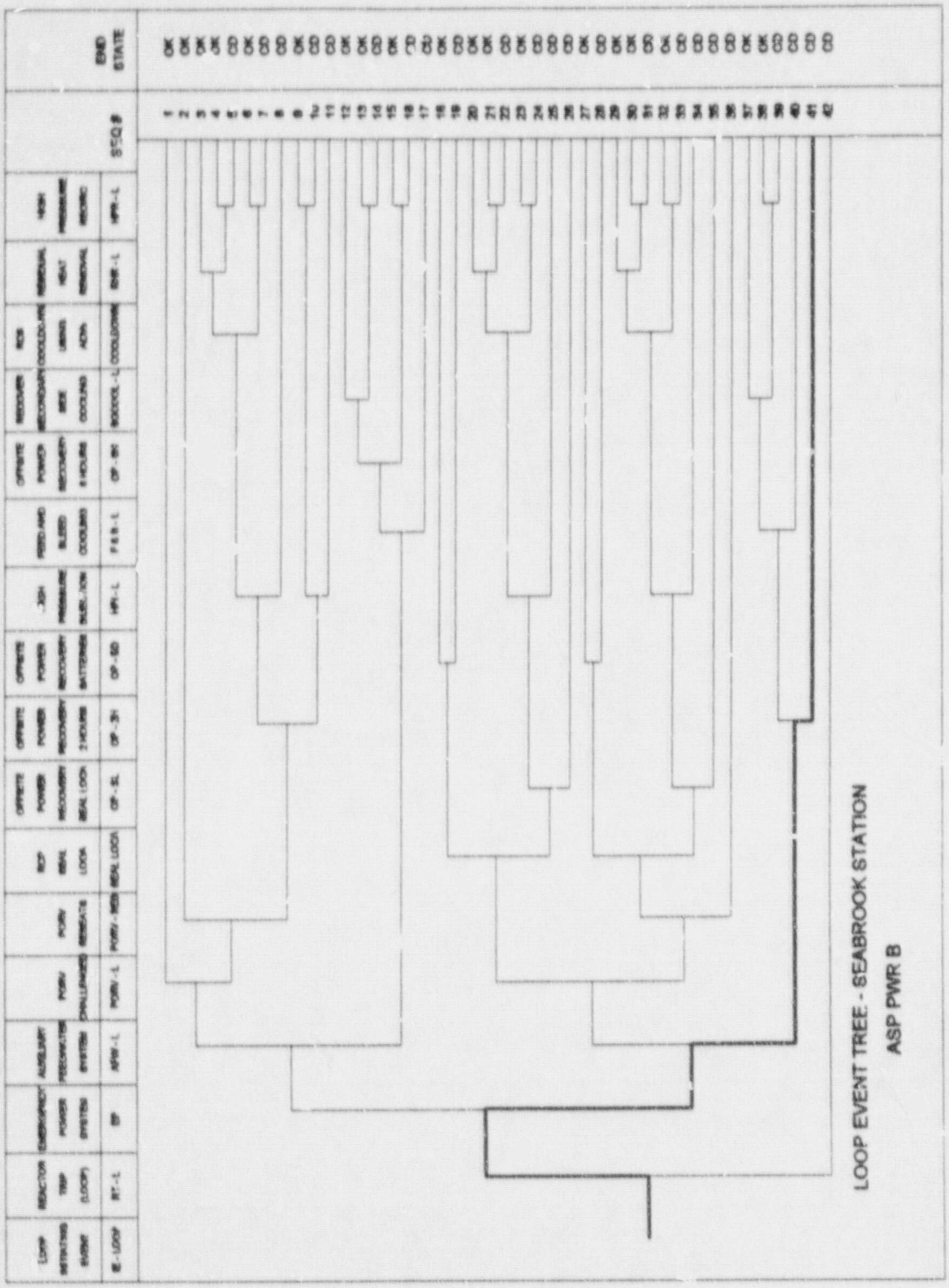

Fig. 1 Dominant core damage sequence for LER No. 443/96-003.

Table 1. Definitions and Probabilities for Selected Basic Events for LER No. 443/96-003

Event name	Description	Base probability	Current probability	Type	Modified for this event
IE-LOOP	Initiating Event–LOOP	8.6 E-006	8.6 E-006		No
IE-SGTR	Initiating Event–Steam Generator Tube Rupture	1.6 E-006	1.6 E-006		No
IE-SLOCA	Initiating Event–Small Loss-of-Coolant Accident (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
EFW-MDP-FC-1B	EFW Motor-Driven Pump Fails	3.9 E-003	3.9 E-003		No
EFW-MDP-FC-SFP	Start-up Feedwater Pump Fails	2.1 E-002	2.1 E-002	NEW	No
EFW-PMP-CF-EFW	Common-Cause Failure of EFW Pumps (Excludes Start-up Feedwater Pump)	3.8 E-004	8.8 E-002		Yes
EFW-TDP-FC-1A	EFW Turbine-Driven Pump Fails	3.9 E-002	1.0 E+000	TRUE	Yes
EFW-XHE-NOREC	Operator Fails to Recover EFW	2.6 E-001	2.6 E-001		No
EFW-XHE-NOREC-EP	Operator Fails to Recover EFW During a Station Blackout	3.4 E-001	1.0 E+000	TRUE	Yes
EFW-XHE-NOREC-L	Operator Fails to Recover EFW During a LOOP	2.6 E-001	8.0 E-001		Yes
EFW-XHE-NEC-ATW	Operator Fails to Recover EFW During an ATWS	1.0 E+000	1.0 E+000		No
EFW-XHE-XM-BRKR	Operator Fails to Realign Start-up Feedwater Pump Supply Breaker	5.6 E-002	5.6 E-002	NEW	No
EFW-XHE-XM-SFP	Operator Fails to Open Start-up Feedwater Pump MOVs	1.0 E-002	1.0 E-002	NEW	No
EPS-DGN-CF-ALL	Common-Cause Failure of EDGs	1.6 E-003	1.6 E-003		No
EPS-DGN-FC-1A	A EDG Fails	4.2 E-002	4.2 E-002		No
EPS-DGN-FC-1B	B EDG Fails	4.2 E-002	4.2 E-002		No
EPS-XHE-NOREC	Operator Fails to Recover Emergency Power	8.0 E-001	8.0 E-001		No
HPI-MDP-FC-1B	HPI Pump B Fails	3.9 E-003	3.9 E-003		No

Table 1. Definitions and Probabilities for Selected Basic Events for LER No. 443/96-003

Event name	Description	Base probability	Current probability	Type	Modified for this event
HPI-XHE-NOREC-L	Operator Fails to Recover the HPI System During a LOOP	8.4 E-001	8.4 E-001		No
HPI-XHE-XM-FB	Operator Fails to Initiate Feed-and-Bleed	1.0 E-002	1.0 E-002		No
HPI-XHE-XM-FBL	Operator Fails to Initiate Feed-and-Bleed During LOOP	1.0 E-002	1.0 E-002		No
MFW-SYS-TRIP	Main Feedwater (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
OEP-XHE-NOREC-SB	Operator Fails to Recover Electric Power Before Steam Generator Dry out	2.9 E-001	2.9 E-001	NEW	No
PPR-SRV-CC-1	Power-Operated Relief Valve (PORV) 1 Fails to Open on Demand	6.3 E-003	6.3 E-003		No
PPR-SRV-CC-2	PORV 2 Fails to Open on Demand	6.3 E-003	6.3 E-003		No
RPS-NONREC	Nonrecoverable Reactor Protection System Failures	2.0 E-005	2.0 E-005		No
RPS-REC	Recoverable RCS Failures	4.0 E-005	4.0 E-005		No
RPS-XHE-XM-SCRAM	Operator Fails to Manually Trip the Reactor	1.0 E-002	1.0 E-002		No

Table 2. Sequence Conditional Probabilities for LER No. 443/96-003

Event tree name	Sequence number	Conditional core damage probability (CCDP)	Core damage probability (CDP)	Importance (CCDP-CDP)	Percent contribution[a]
LOOP	41	2.6 E-005	3.4 E-007	2.5 E-005	55.6
LOOP	17	1.0 E-005	4.5 E-008	9.9 E-006	21.5
TRANS	21-8	5.1 E-006	7.7 E-008	5.0 E-006	10.9
TRANS	20	2.3 E-006	1.4 E-008	2.3 E-006	5.0
LOOP	40	2.0 E-006	2.6 E-008	2.0 E-006	4.3
Total (all sequences)		**7.6 E-005**	**3.0 E-005**	**4.6 E-005**	

[a]Percent contribution to the total importance.

Table 3. Sequence Logic for Dominant Sequences for LER No. 443/96-003

Event tree name	Sequence number	Logic
LOOP	41	/RT-L. EP, EFW-L-EP, OP-SBO
LOOP	17	/RT-L, /EP, EFW-L, F&B-L
TRANS	21-8	RT, /RCSPRESS, EFW-ATWS
TRANS	20	/RT, EFW, MFW, F&B
LOOP	40	/RT-L, EP, EFW-L-EP, /OP-SBO, F&B

Table 4. System Names for LER No. 443/96-003

System name	Logic
EFW	No or Insufficient EFW Flow
EFW-ATWS	No or Insufficient EFW Flow During an ATWS
EFW-L	No or Insufficient EFW Flow During a LOOP
EFW-L-EP	No or Insufficient EFW Flow During a Station Blackout
EP	Failure of Both Trains of Emergency Power
F&B	Failure to Provide Feed-and-Bleed Cooling
F&B-L	Failure to Provide Feed-and-Bleed Cooling During LOOP
MFW	Failure of the MFW System
OP-SBO	Operator Fails to Restore AC Power Before Steam Generator Dry out During a Station Blackout
RCSPRESS	Failure to Limit Reactor Coolant System Pressure to <3200 PSI
RT	Reactor Fails to Trip During Transient
RT-L	Reactor Fails to Trip During LOOP

Table 5. Conditional Cut Sets for Higher Probability Sequences for LER No. 443/96-002

Cut set number	Percent contribution	CCDP[a]	Cut sets[b]
LOOP Sequence 41		2.6 E-005	
1	52.4	1.4 E-005	EPS-DGN-FC-1A, EPS-DGN-FC-1B, EPS-XHE-NOREC, EFW-TDP-FC-1A, EFW-XHE-NOREC-EP, OEP-XHE-NOREC-SB
2	47.6	1.2 E-005	EPS-DGN-CF-ALL, EPS-XHE-NOREC, EFW-TDP-FC-1A, EFW-XHE-NOREC-EP, OEP-XHE-NOREC-SB
LOOP Sequence 17		1.0 E-005	
1	13.2	1.3 E-006	EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-XHE-XM-BRKR, EFW-XHE-NOREC-L, HPI-XHE-XM-FBL
2	9.5	9.4 E-007	EPS-DGN-FC-1A, /EPS-DGN-FC-1B, EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-XHE-NOREC-L, HPI-XHE-XM-FBL
3	8.3	8.3 E-007	EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-XHE-XM-BRKR, EFW-XHE-NOREC-L, PPR-SRV-CC-1
4	8.3	8.3 E-007	EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-XHE-XM-BRKR, EFW-XHE-NOREC-L, PPR-SRV-CC-2
5	6.0	6.0 E-007	/EPS-DGN-FC-1A, EPS-DGN-FC-1B, EFW-TDP-FC-1A, EFW-XHE-XM-BRKR, EFW-XHE-NOREC-L, HPI-XHE-XM-FBL
6	6.0	5.9 E-007	EPS-DGN-FC-1A, /EPS-DGN-FC-1B, EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-XHE-NOREC-L, PPR-SRV-CC-2
7	6.0	5.9 E-007	EPS-DGN-FC-1A, /EPS-DGN-FC-1B, EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-XHE-NOREC-L, PPR-SRV-CC-1
8	5.0	4.9 E-007	EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-MDP-FC-SFP, EFW-XHE-NOREC-L, HPI-XHE-XM-FBL
9	3.8	3.8 E-007	/EPS-DGN-FC-1A, EPS-DGN-FC-1B, EFW-TDP-FC-1A, EFW-XHE-XM-BRKR, EFW-XHE-NOREC-L, PPR-SRV-CC-1
10	3.8	3.8 E-007	/EPS-DGN-FC-1A, EPS-DGN-FC-1B, EFW-TDP-FC-1A, EFW-XHE-XM-BRKR, EFW-XHE-NOREC-L, PPR-SRV-CC-2
11	3.1	3.1 E-007	EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-MDP-FC-SFP, EFW-XHE-NOREC-L, PPR-SRV-CC-1
12	3.1	3.1 E-007	EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-MDP-FC-SFP, EFW-XHE-NOREC-L, PPR-SRV-CC-2
13	3.1	3.1 E-007	EPS-DGN-FC-1A, /EPS-DGN-FC-1B, EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-XHE-NOREC-L, HPI-MDP-FC-1B, HPI-XHE-NOREC-L

Table 5. Conditional Cut Sets for Higher Probability Sequences for LER No. 443/96-003

Cut set number	Percent contribution	CCDP[a]	Cut sets[b]
TRANS Sequence 21-8		5.1 E-006	
1	70.2	3.6 E-006	RPS-NONREC, EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-XHE-NEC-ATW
2	16.8	8.6 E-007	RPS-NONREC, EFW-TDP-FC-1A, EFW-MDP-FC-SFP, EFW-XHE-NEC-ATW
3	7.9	4.1 E-007	RPS-NONREC, EFW-TDP-FC-1A, EFW-XHE-XM-SFP, EFW-XHE-NEC-ATW
4	3.1	1.6 E-007	RPS-NONREC, EFW-TDP-FC-1A, EFW-MDP-FC-1B, EFW-XHE-NEC-ATW
5	1.4	7.2 E-008	RPS-REC, RPS-XHE-XM SCRAM, EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-XHE-NEC-ATW
TRANS Sequence 20		2.3 E-006	
1	28.7	6.7 E-007	EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-MDP-FC-SFP, EFW-XHE-NOREC, MFW-SYS-TRIP, MFW-XHE-NOREC, HPI-XHE-XM-FB
2	18.1	4.2 E-007	EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-MDP-FC-SFP, EFW-XHE-NOREC, MFW-SYS-TRIP, MFW-XHE-NOREC, PPR-SRV-CC-2
3	18.1	4.2 E-007	EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-MDP-FC-SFP, EFW-XHE-NOREC, MFW-SYS-TRIP, MFW-XHE-NOREC, PPR-SRV-CC-1
4	13.6	3.2 E-007	EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-XHE-XM-SFP, EFW-XHE-NOREC, MFW-SYS-TRIP, MFW-XHE-NOREC, HPI-XHE-XM-FB
5	8.6	2.0 E-007	EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-XHE-XM-SFP, EFW-XHE-NOREC, MFW-SYS-TRIP, MFW-XHE-NOREC, PPR-SRV-CC-2
6	8.6	2.0 E-007	EFW-TDP-FC-1A, EFW-PMP-CF-EFW, EFW-XHE-XM-SFP, EFW-XHE-NOREC, MFW-SYS-TRIP, MFW-XHE-NOREC, PPR-SRV-CC-1
7	1.3	3.0 E-008	EFW-TDP-FC-1A, EFW-MDP-FC-1B, EFW-MDP-FC-SFP, EFW-XHE-NOREC, MFW-SYS-TRIP, MFW-XHE-NOREC, HPI-XHE-XM-FB

Table 5. Conditional Cut Sets for Higher Probability Sequences for LER No. 443/96-003

Cut set number	Percent contribution	CCDP[a]	Cut sets[b]
LOOP Sequence 40		2.0 E-006	
1	23.0	4.7 E-007	EPS-DGN-FC-1A, EPS-DGN-FC-1B, EPS-XHE-NOREC, EFW-TDP-FC-1A, EFW-XHE-NOREC-EP, HPI-XHE-XM-FBL
2	20.9	4.3 E-007	EPS-DGN-CF-ALL, EPS-XHE-NOREC, EFW-TDP-FC-1A, EFW-XHE-NOREC-EP, HPI-XHE-XM-FBL
3	14.5	3.0 E-007	EPS-DGN-FC-1A, EPS-DGN-FC-1B, EPS-XHE-NOREC, EFW-TDP-FC-1A, EFW-XHE-NOREC-EP, PPR-SRV-CC-1
4	14.5	3.0 E-007	EPS-DGN-FC-1A, EPS-DGN-FC-1B, EPS-XHE-NOREC, EFW-TDP-FC-1A, EFW-XHE-NOREC-EP, PPR-SRV-CC-2
5	13.2	2.7 E-007	EPS-DGN-CF-ALL, EPS-XHE-NOREC, EFW-TDP-FC-1A, EFW-XHE-NOREC-EP, PPR-SRV-CC-1
6	13.2	2.7 E-007	EPS-DGN-CF-ALL, EPS-XHE-NOREC, EFW-TDP-FC-1A, EFW-XHE-NOREC-EP, PPR-SRV-CC-2
Total (all sequences)		**7.6 E-005**	

[a]The CCDP 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 (3,875 h). 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, $\lambda_{LOOP} = 8.6 \times 10^{-6}$/h. The importance is determined by subtracting the CDP for the same period but with plant equipment assumed to be operating nominally.

[b]Basic events EFW-TDP-FC-1A and EFW-XHE-NOREC-EP are type TRUE events. These type of events are not normally included in the output of the fault tree reduction process but have been added to aid in understanding the sequences to potential core damage associated with the event.