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Document Control Desk
Information and Records Management Branch
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FROM: Jack E. Rosenthal, Chief
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of Operational Data

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SUBJECT: LOSS OF SPENT FUEL POOL COOLING PRA: MODEL AND RESULTS (INEL-96/0334) — APPENDIX A-D

Attached is Appendix A to the above report prepared, under contract, by staff at the Idaho National Engineering Laboratory. The original report was forwarded to you on September 10, 1996. Please submit the Appendix to NUDOCS and Central Files, and make it available to the public.

Attachment: As stated

cc w/o enclosure: E. Hayden, OPA

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APPENDIX A - SPENT FUEL POOL MODEL

This appendix summarizes the event tree/fault tree developed in this study to analyze spent fuel pool risk for a variety of plant configurations and operating practices. The following sections discuss the modeling approach, the key model features, the initiating events treated, the event trees for sequences leading to pool heatup and event trees for post heatup sequences, and system fault trees. Appendix B discusses the quantification of basic events, Appendix C discusses the human reliability analysis, and Appendix D provides the key modeling assumptions.

A.1 Modeling Approach

This study is aimed at the quantitative evaluation of loss of spent fuel pool cooling (SFPC) scenarios up to the point of pool boiling and the qualitative evaluation of the risk associated with these scenarios. The risk stems from three groups of scenarios: those that involve the active fuel in the core, those that involve the spent fuel in the spent fuel pool, and those that involve both. The models developed in this study address all three groups.

It is useful to note that, with respect to scenarios that can affect the core, the modeling approach employed is analogous to that used in the analysis of the so-called external events (e.g., internal fires). This approach divides the accident scenario analysis into three portions: a) the quantitative hazard analysis (e.g., the frequency of fires of a given size in a given location), b) the equipment fragility analysis (e.g., the conditional probability of damage to a given set of equipment, given the fire), and c) the plant response analysis (e.g., the conditional probability of core damage, given the loss of the given set of equipment). In simplified mathematical form,

$$CDF = \sum_{j} \lambda_j \phi_{ed|j} \phi_{cd|j,ed} \qquad (A.1)$$

where λ_j is the frequency of hazard scenario j, $\phi_{ed|j}$ is the conditional probability of equipment damage, given hazard scenario j, and $\phi_{cd|j,ed}$ is the conditional probability of core damage, given equipment damage and hazard scenario j.

In this study, it can be seen that λ_j corresponds to the near boiling frequency (NBF) associated with a given scenario; this is assessed quantitatively. The term $\phi_{ed|j}$, on the other hand, is not quantified in this work. (This term is highly dependent on the particular geometry, equipment layout, and ventilation conditions for the plant being analyzed. Furthermore, the analysis of heat and mass transport needed to support quantification is beyond the scope of this limited study.) Qualitative issues affecting the likelihood of equipment damage are discussed in the main body of this report. The term $\phi_{cd|j,ed}$ is not treated in this work, but can be quantified using the internal events model for the plant in question, as long as the likelihood of operator errors is not drastically affected by the spent fuel pool boiling event.

A.2 Key Features

The SAPHIRE Version 5.0 [A.1] software package is used to implement the event/tree fault tree model documented in this appendix. The fault tree linking approach employed by SAPHIRE ensures that shared equipment dependencies between top events (e.g., due to common support systems) are properly treated. Other dependencies (e.g., sequence-dependent human error probabilities) are treated using the SAPHIRE capability to employ user-defined rules for assigning different fault trees to different event sequences.

Note that the models described in the following sections are based largely on the Susquehanna plant, a two-unit boiling water reactor with two spent fuel pools, a SFPC system powered off of a non-safety bus and cooled by non-safety service water, residual heat removal (RHR) assist cooling as backup to the SFPC system, and a safety-related emergency service water system to provide makeup when normal pool makeup is unavailable or inadequate. The event tree models are expected to be generic enough to allow analysis of a variety of other plant configurations. (For example, they can treat plants where the fuel pools are not cross-tied, as they are at Susquehanna.) However, the success criteria and the fault trees developed are appropriate to Susquehanna.

A.3 Initiating Events and Cases

The initiating events modeled are derived from the master logic diagram shown in Figure A.1, comparison with the list of initiating events treated in Ref. A.2, and comparison with the list of initiating events treated in Refs. A.2 and A.3. The classes of initiating events treated in this study are as follows:

- Loss of Spent Fuel Pool Cooling System (LOSFP)

  This event includes loss of the SFPC system due to hardware failures and human errors. It also includes system loss due to loss of cooling to the SFPC heat exchangers and due to internal flooding and fires.

  Note that in principle, the loss of heat exchanger cooling, internal flooding, and internal fires should be treated as separate initiating events, since these causes for loss of SFPC might also affect other parts of the plant. (At Susquehanna, heat exchanger cooling is normally provided by a non-safety service water system.) These events are intentionally grouped with direct losses of SFPC because of the limited scope of this study, and because the results of Ref. A.2 indicate that, at least in the case of Susquehanna, the contributions to risk from the loss of service water and internal flooding initiators are relatively small.

- Loss of Offsite Power (LOOP)

  In this analysis, the LOOP event includes the extended LOOP and station blackout (SBO) events.

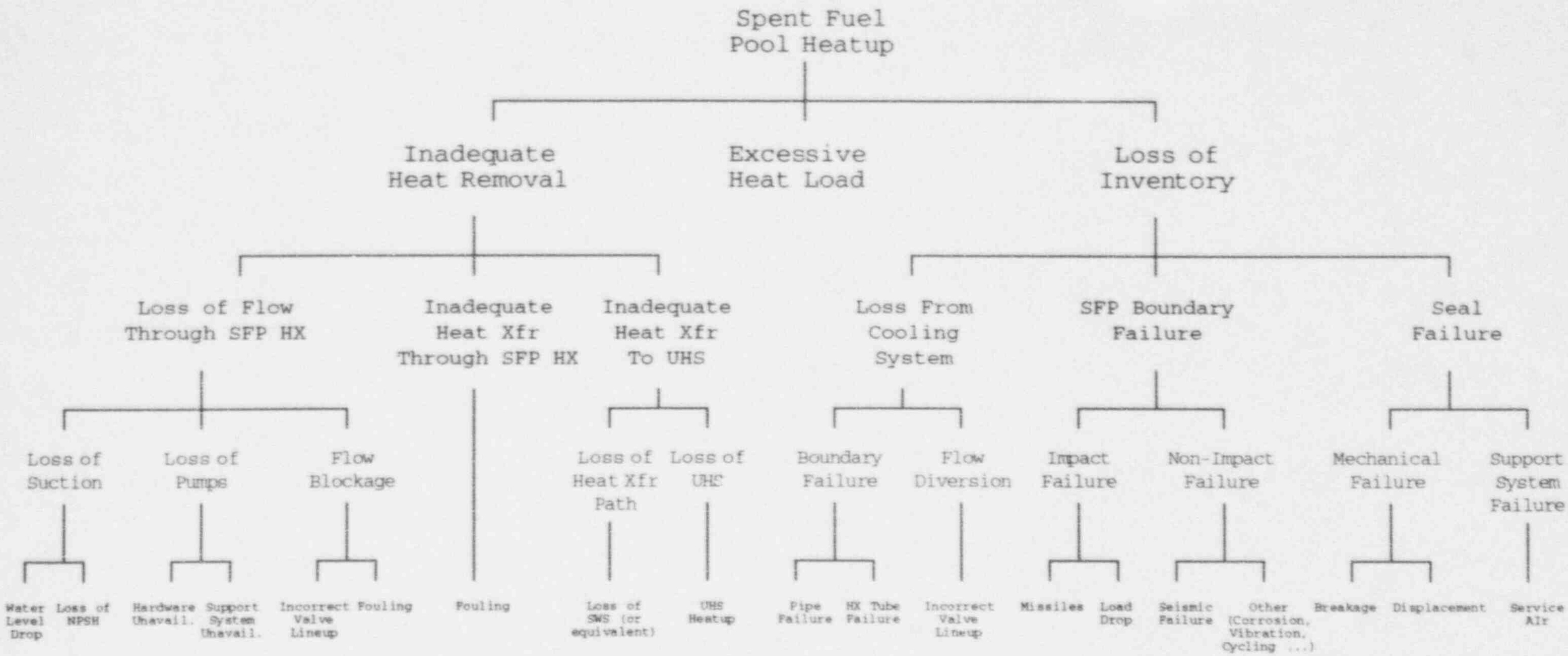


Figure A.1 - Master Logic Diagram for Spent Fuel Pools

- Loss of Spent Fuel Pool Inventory (LINVR)

  This event includes losses of inventory from leaks/breaks from the failure of piping or gates/seals. Only leaks/breaks for which the outgoing flow rate exceeds the normal makeup flow rate are considered. Losses of inventory due to structural failure of the spent fuel pool boundary (e.g., due to missiles, heavy load drops, thermal stresses) are not treated. This category of events may need to be re-examined, depending on the quantitative results of the models documented in this study.

- Loss of Primary Coolant (PLOCA)

  This event covers pipe break LOCAs in an operating unit and special outage-associated LOCAs (both "J" LOCAs, i.e., connected system LOCAs, and "K" LOCAs, i.e., maintenance-induced LOCAs) in a unit undergoing refueling. LOCAs during operation are of potential concern because they can, for some plant designs, lead to an automatic trip of the SFPC system, and because they create a demand for the RHR system, which serves as an alternate cooling system for the spent fuel pool. In the case of the J and K LOCAs, the event provides a potential means for quickly draining the spent fuel pool down to the bottom of the transfer gate.

- Seismic Events (EQE)

  This event covers seismically-induced losses of offsite power, SFPC piping integrity, and spent fuel pool boundary integrity. Two classes of earthquakes are treated: those with peak ground acceleration (PGA) between 0.2g and 0.6g, and those with PGA above 0.6g.

The specific initiating events addressed in this analysis are listed in Table A.1. Events occurring during refueling are treated differently than those that occur during operation. In the case of LOSFP and LOOP, distinctions are also drawn for events occurring during a 1/3 core offload refueling and those occurring during a full core offload refueling.

The following different plant configurations ("cases") are analyzed. Table A.2 presents a comparison of the cases considered in this study and those considered in Ref. A.2.

- Case 1 - Both units operating.

- Case 2 - Unit 2 operating, Unit 1 refueling (1/3 core offload).

- Case 3 - Unit 2 operating, Unit 1 refueling (full core offload).

Table A.1 - Initiating Event Frequencies (Instantaneous)

Initiating Event	Description	Frequency (/yr)	Source
LSFP1	Loss of SFPC system, Case 1	2.4E-2	Data (see App. B)
LSFP2	Loss of SFPC system, Case 2	2.8E-1	Data (see App. B)
LSFP3	Loss of SFPC system, Case 3	2.8E-1	Data (see App. B)
LP1	Loss of offsite power, Case 1	8.0E-2	Ref. A.4
LP2	Loss of offsite power, Case 2	8.0E-2	Ref. A.4
LP3	Loss of offsite power, Case 3	8.0E-2	Ref. A.4
LINVC	Large loss of inventory, Case 1	2.0E-3	Data (see App. B)
LINCS	Small loss of inventory, Case 1	5.0E-3	Data (see App. B)
LINVR	Large loss of inventory, Cases 2 and 3	2.0E-2	Data (see App. B)
LINRS	Small loss of inventory, Cases 2 and 3	3.0E-2	Data (see App. B)
PLOCA	Primary LOCA, Case 1	1.5E-2	Ref. A.5
PLOCR	Primary LOCA, Cases 2 and 3	1.2E-1	Ref. A.6, A.7 (see App. B)
EQE	Seismic event ($0.2g < PGA \leq 0.6g$)[a]	1.2E-4	Ref. A.8

[a]Earthquakes with PGA > 0.6g are for the purposes of this analysis, assumed to lead directly to core damage (with frequency 3.2E-6/yr).

Table A.2 - Mapping of INEL and Ref. A.2 Cases

	Both units operating	Unit 2 operating, Unit 1 refueling (1/3 core discharge)	Unit 2 operating, Unit 1 refueling (full core discharge)
INEL Case #	1	2	3
Ref. 3 Case #	1,2	3, 4, 5[a]	3,4,5

[a]Not clear if Ref. A.2 treats 1/3 core discharges

A.4 NBF Event Trees and Success Criteria

In general, the structure and level of detail of the NBF event trees are similar to those of the event trees presented in Ref. A.2. The three key differences are as follows.

1) Those trees that model initiators with potential direct impacts on the core (LOOP, seismic, PLOCA) include a top event (UNREC) indicating if recovery is uncomplicated. Assuming that operators are generally more concerned with the core than the spent fuel pool, a complicated recovery can inhibit the operators from devoting sufficient resources to deal with the spent fuel pool in a timely fashion. Appendix B provides the operational definition for complicated scenarios used in this analysis.

2) The trees explicitly allow for the possibility that operators will not respond to the initiating event until pool boiling occurs. This delay can be due to lack of awareness (e.g., failed instrumentation) or distraction (e.g., due to a complicated recovery). Note that the AEOD database includes a number of events in which operator response was delayed for many hours, although none were delayed to such an extent that pool boiling occurred.

3) The LOOP, seismic, and primary LOCA trees represent the possibility of "direct core damage" (i.e., core damage not due to the consequences of a spent fuel pool scenario) for complicated scenarios. The purpose of this treatment is to ensure that any final core damage frequency estimates developed from the results of this study do not double count risk contributing scenarios. (Thus, for example, station blackout scenarios which lead directly to core damage are not included in the NBF estimation, even though they could lead to pool boiling.)

This section contains the event trees for near boiling frequency (NBF), the top event definitions, and the success criteria associated with each top event. The event trees appear on the following pages:

The endstates for these trees are defined as follows:

OK Scenario recovery is successful

CD Core damage

FPIS1 Boiling; scenario involves loss of SFPC, spent fuel pool (SFP) level is not maintained

FPIS2 Near boiling of SFP; scenario involves late restoration of SFPC

FPIS3 Steaming; scenario involves use of alternate cooling system; SFP level is maintained

FPSF1 Combination of end states FPIS1 (boiling) and FPISF (flooding)

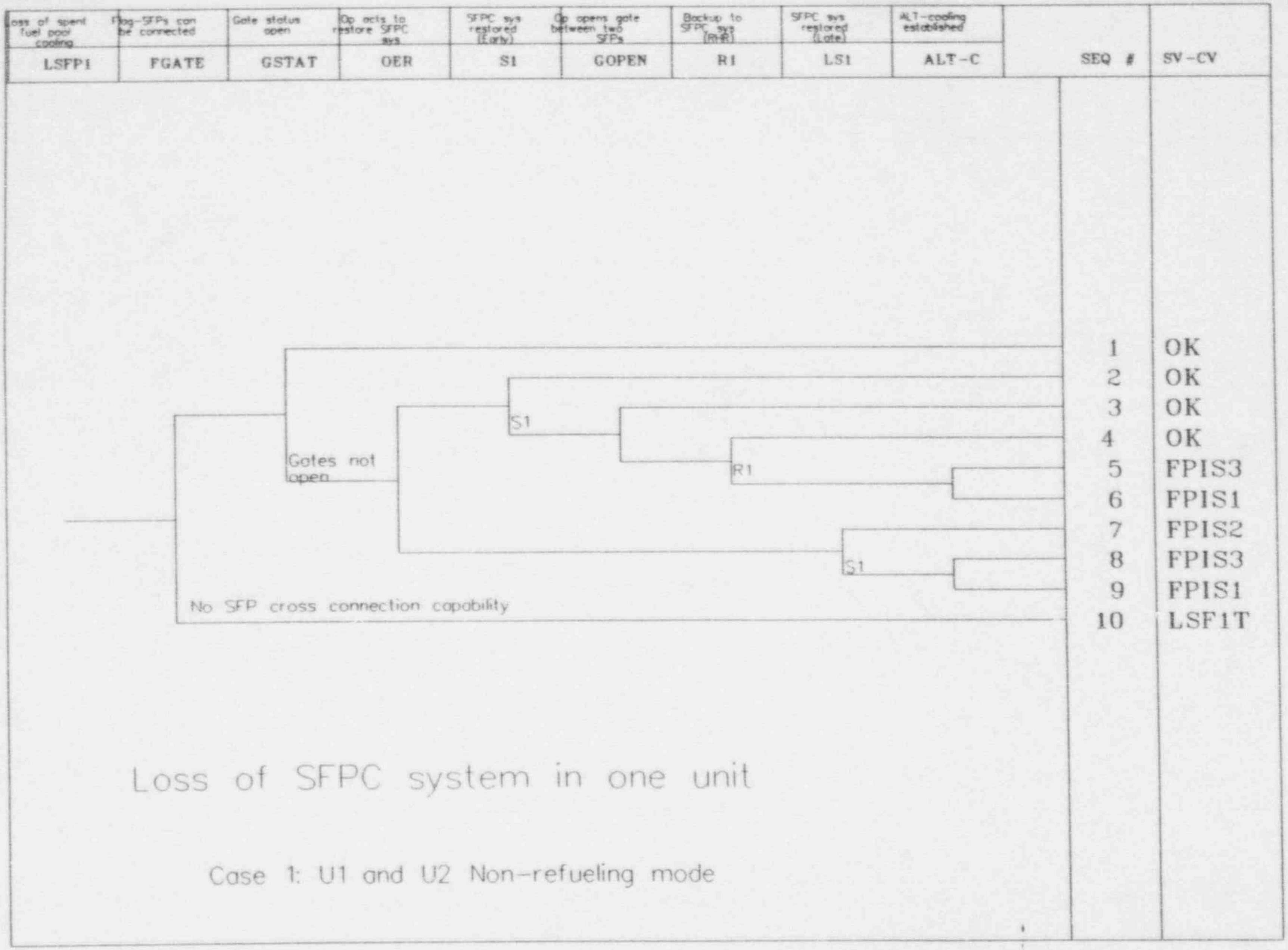
FPSF2 Combination of end states FPIS2 (near boiling) and FPISF (flooding)

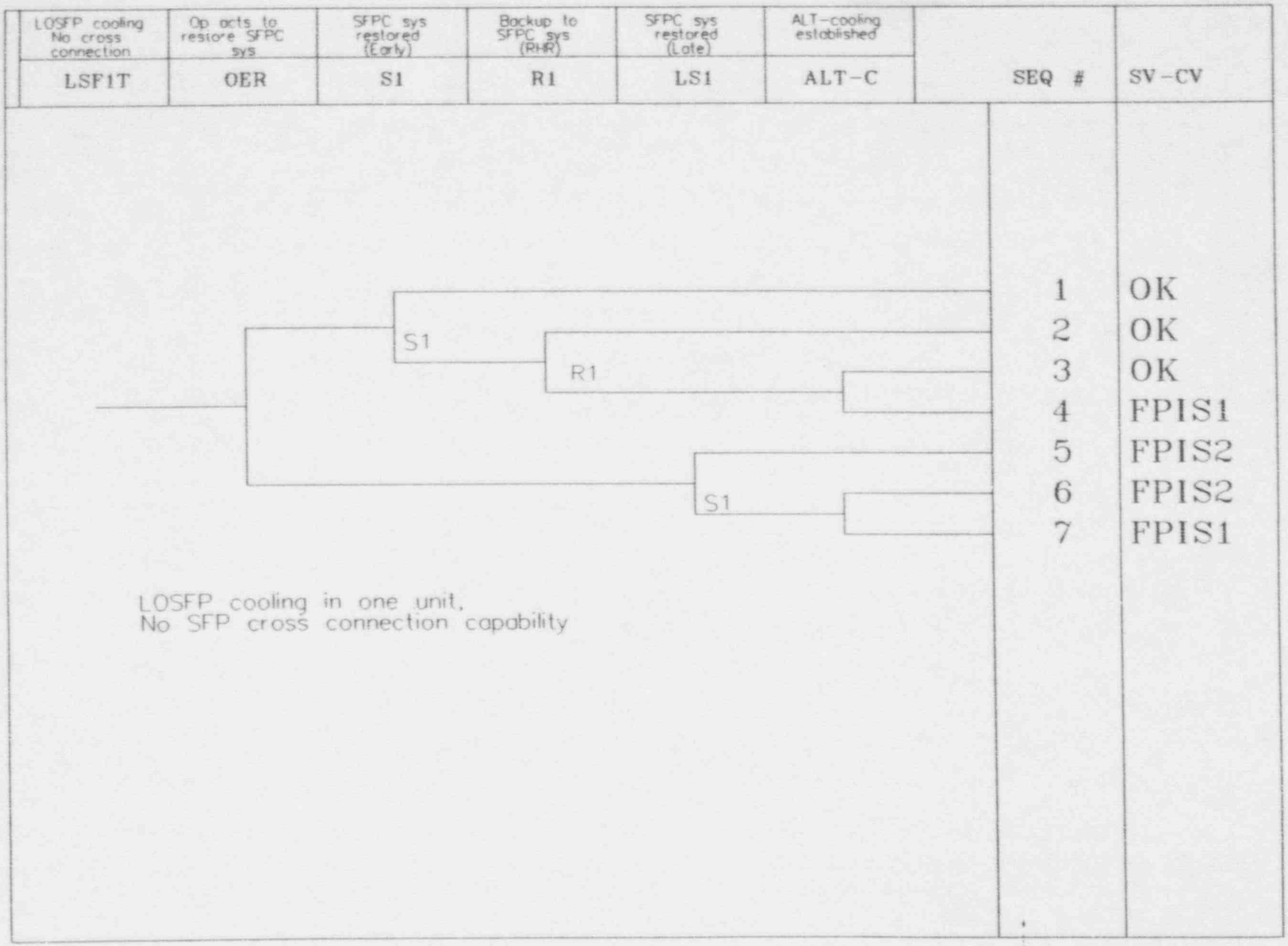
FPSF3 Combination of end states FPIS3 (steaming) and FPISF (flooding)

Note that the direct core damage (CD) endstate is treated only to ensure that scenarios which lead to core damage before pool boiling are excluded from the analysis; the CD endstate is not modeled for some sequences where SFP cooling is assured. The resulting CD endstate frequencies are provided for accounting purposes only, and should not be interpreted as representing the total core damage frequency.

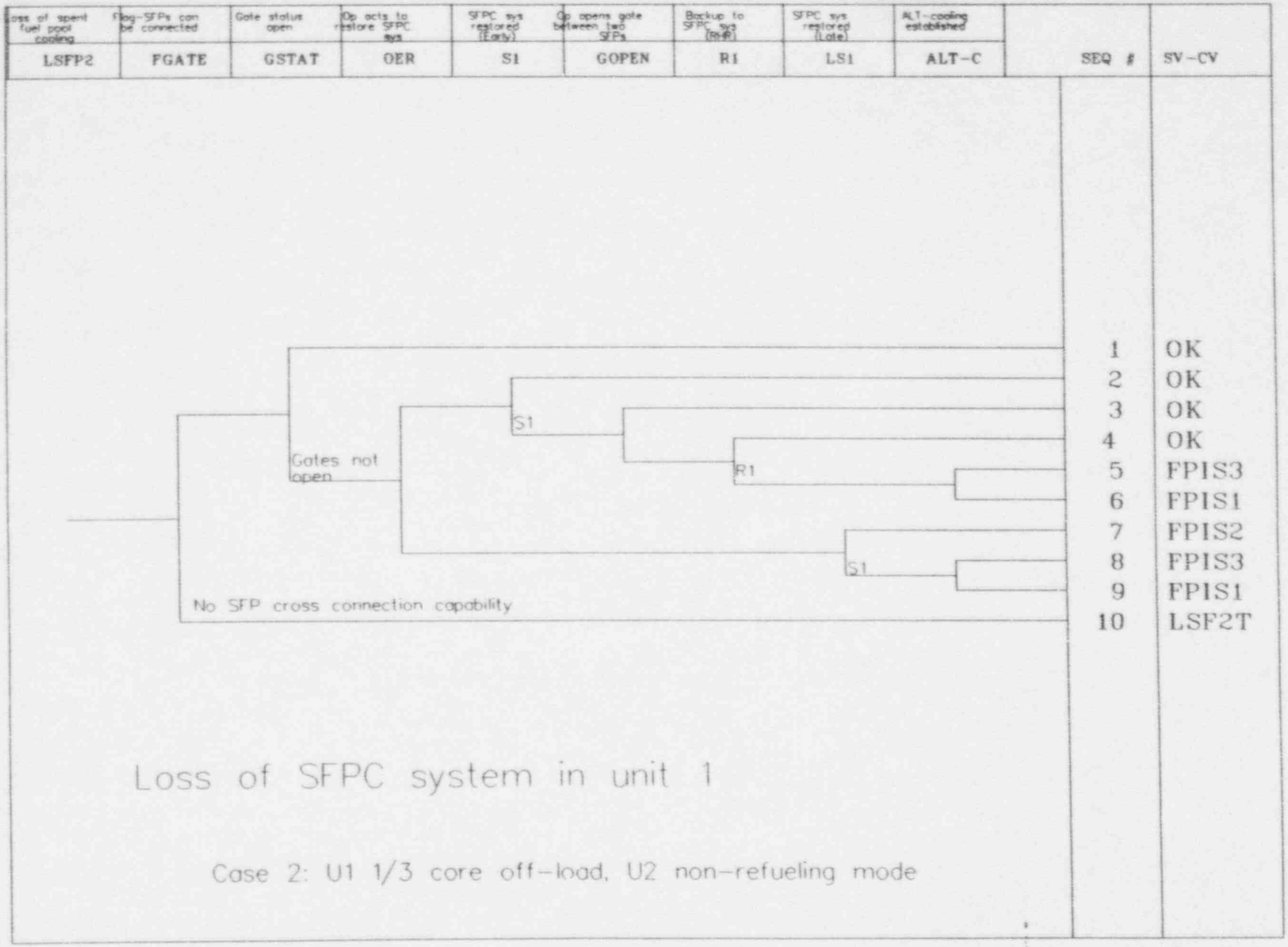
A.4.1 Loss of Spent Fuel Pool Cooling

Three event trees are used to model this class of initiating events. Event tree LSFP1 deals with Case 1, LSFP2 deals with Case 2, and LSFP3 deals with Case 3. The event trees, top event definitions, and success criteria are listed in the following pages. Note that each event tree has one transfer tree.


Loss of spent fuel pool cooling
LSFP1
Flag-SFPs can be connected
FGATE
Gate status open
GSTAT
Op acts to restore SFPC sys
OER
SFPC sys restored (Early)
S1
Op opens gate between two SFPs
GOPEN
Backup to SFPC sys (RHR)
R1
SFPC sys restored (Late)
LS1
ALT-cooling established
ALT-C
SEQ #
SV-CV
Gates not open
S1
R1
S1
No SFP cross connection capability
1 OK
2 OK
3 OK
4 OK
5 FPIS3
6 FPIS1
7 FPIS2
8 FPIS3
9 FPIS1
10 LSF1T
Loss of SFPC system in one unit
Case 1: U1 and U2 Non-refueling mode

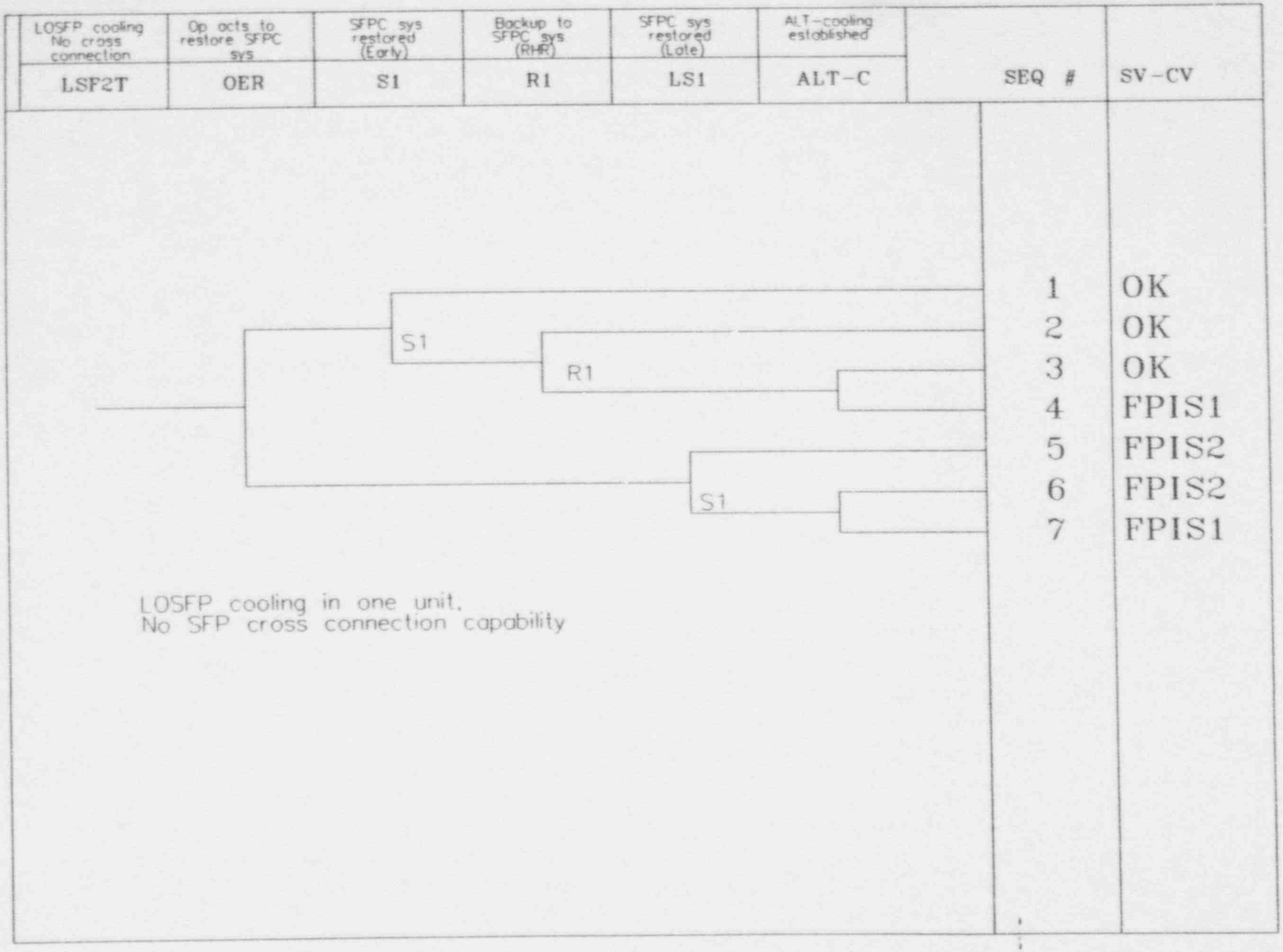


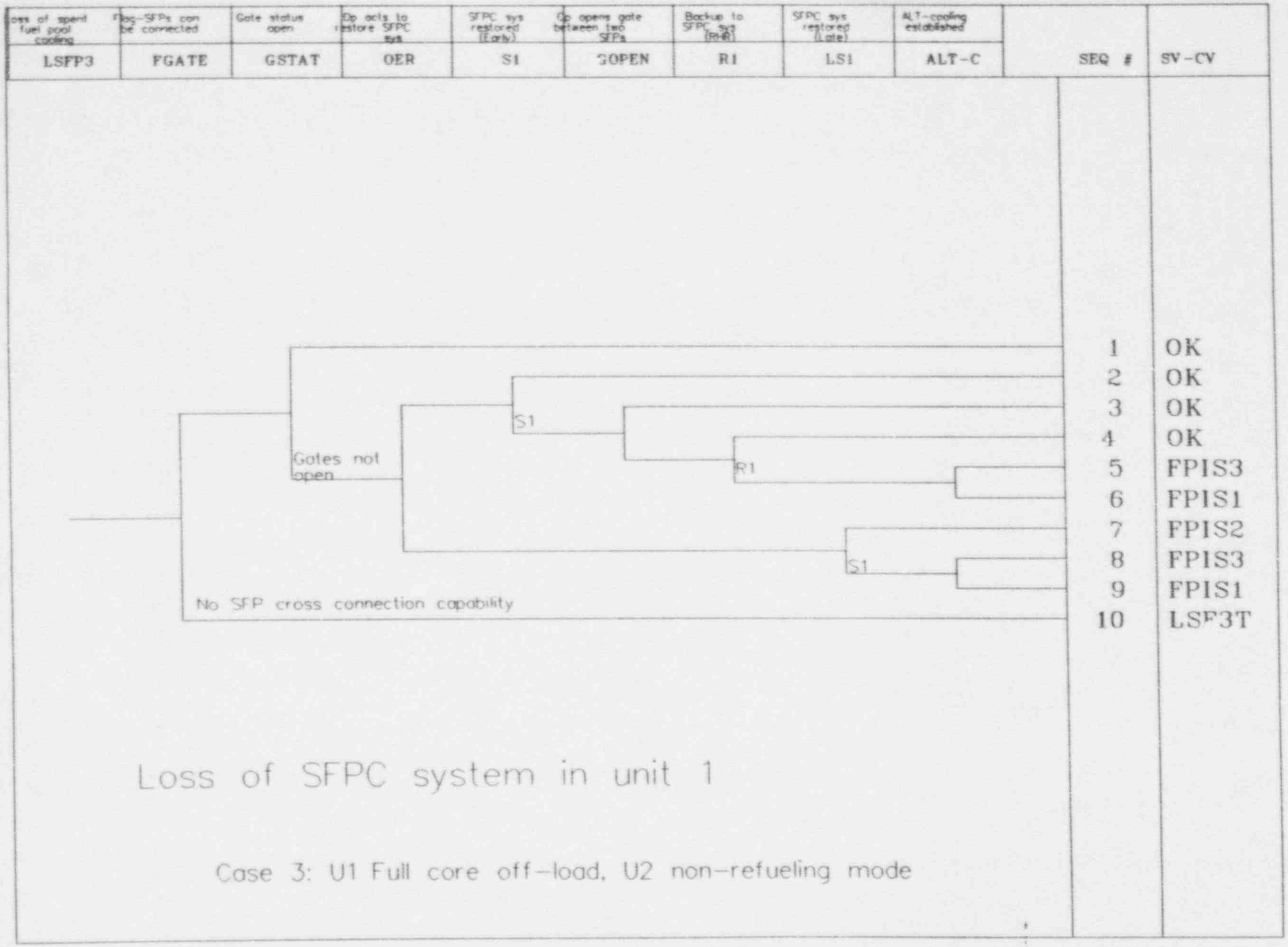
LOSFP cooling No cross connection
LSF1T
Op acts to restore SFPC sys
OER
SFPC sys restored (Early)
S1
Backup to SFPC sys (RHR)
R1
SFPC sys restored (Late)
LS1
ALT-cooling established
ALT-C
SEQ #
SV-CV
S1
R1
S1
1 OK
2 OK
3 OK
4 FPIS1
5 FPIS2
6 FPIS2
7 FPIS1
LOSFP cooling in one unit,
No SFP cross connection capability



Loss of SFPC system in unit 1

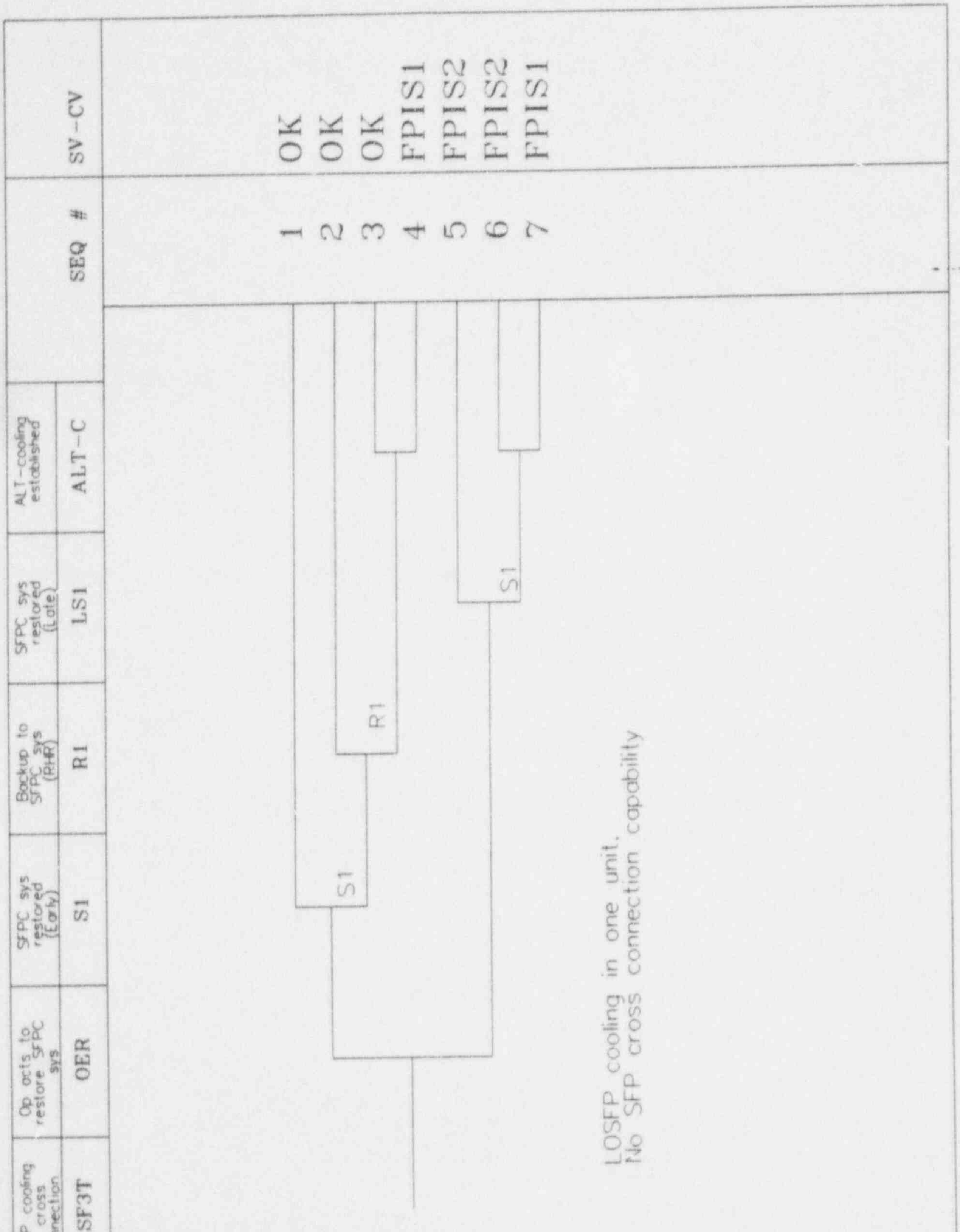
Case 2: U1 1/3 core off-load, U2 non-refueling mode


LOSFP cooling No cross connection
LSF2T
Op acts to restore SFPC sys
OER
SFPC sys restored (Early)
S1
Backup to SFPC sys (RHR)
R1
SFPC sys restored (Late)
LS1
ALT-cooling established
ALT-C
SEQ #
SV-CV
S1
R1
S1
1 OK
2 OK
3 OK
4 FPIS1
5 FPIS2
6 FPIS2
7 FPIS1
LOSFP cooling in one unit.
No SFP cross connection capability



Loss of SFPC system in unit 1

Case 3: U1 Full core off-load, U2 non-refueling mode


LOSFP cooling No cross connection
LSF3T
Op acts to restore SFPC sys
OER
SFPC sys restored (Early)
S1
Backup to SFPC sys (RHR)
R1
SFPC sys restored (Late)
LS1
ALT-cooling established
ALT-C
SEQ #
SV-CV
1 OK
2 OK
3 OK
4 FPIS1
5 FPIS2
6 FPIS2
7 FPIS1
LOSFP cooling in one unit.
No SFP cross connection capability

Top Event Definitions - Loss of Spent Fuel Pool Cooling System Event Trees

LSFP1 Loss of SFPC system at Unit 1 while both units are operating (Case 1). (Initiating events LSFP2 and LSFP3 treat Cases 2 and 3.) This initiating event is analyzed only for cases where the spent fuel pools are not initially cross-connected.

FGATE A flag event: the plant being modeled has the capability to cross-connect the spent fuel pool by opening a gate (or gates). (Note that the upward branches in the event tree, per the usual convention, represent a "yes or success" answer to the top event question.)

GSTAT Status of cross-connect gate(s): the spent fuel pools are cross connected or not at the time of initiating event.

OER Operator response to the loss of SFPC system: operator attempts to restore SFP cooling soon after the initiating event.

S1 Restoration of the SFPC system: operators successfully reestablish cooling.

GOPEN Opening of the gate: operators successfully open the gate(s) and cross-connect the spent fuel pools.

R1 RHR cooling: operators successfully reestablish cooling using the Unit 1 RHR.

LS1 Late restoration of the SFPC system: similar to the top event S1 except all the actions must be taken remotely. (This top event is challenged when the pool has reached near boiling conditions. It is assumed that by this stage, there are a multitude of indications and alarms that will notify the operators of the SFP problems.)

ALT-C Alternate cooling: operators successfully establish evaporative/boiloff cooling by providing water using alternate cooling (e.g., fire water system).

Success Criteria - Loss of Spent Fuel Pool Cooling System Event Trees

Case 1 (LSFP1)

S1	R1	LS1	ALT-C
1 of 3 SFPC pumps	1 train RHR	1 of 3 SFPC pumps	Any available alternate cooling system

Case 2 (LSFP2)

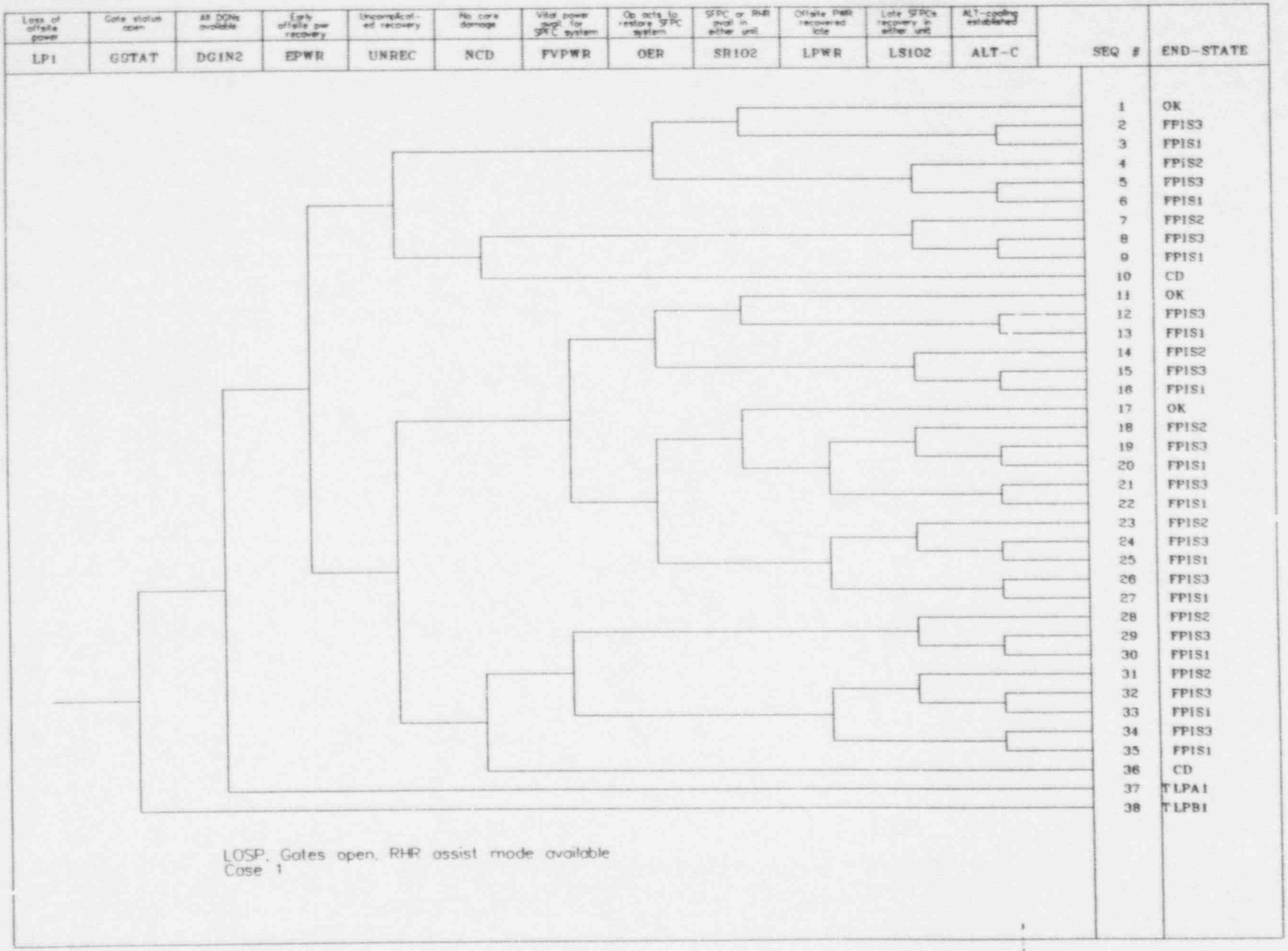
S1	R1	LS1	ALT-C
2 of 3 SFPC pumps	1 train of RHR	2 of 3 SFPC pumps	Any available alternate cooling system

Case 3 (LSFP3)

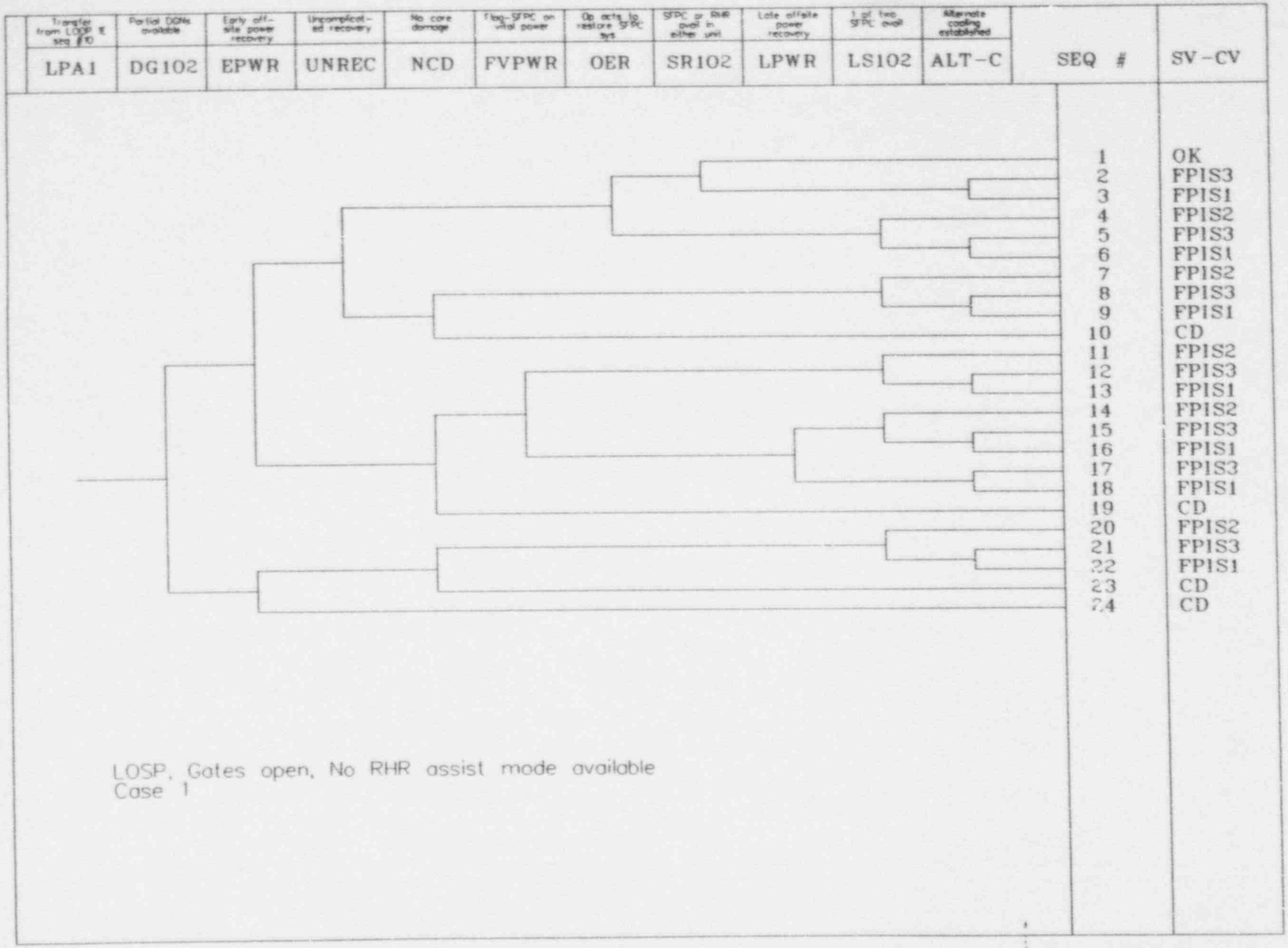
S1	R1	LS1	ALT-C
3 of 3 SFPC pumps	1 train of RHR	3 of 3 SFPC pumps	Any available alternate cooling system

A.4.2 Loss of Offsite Power

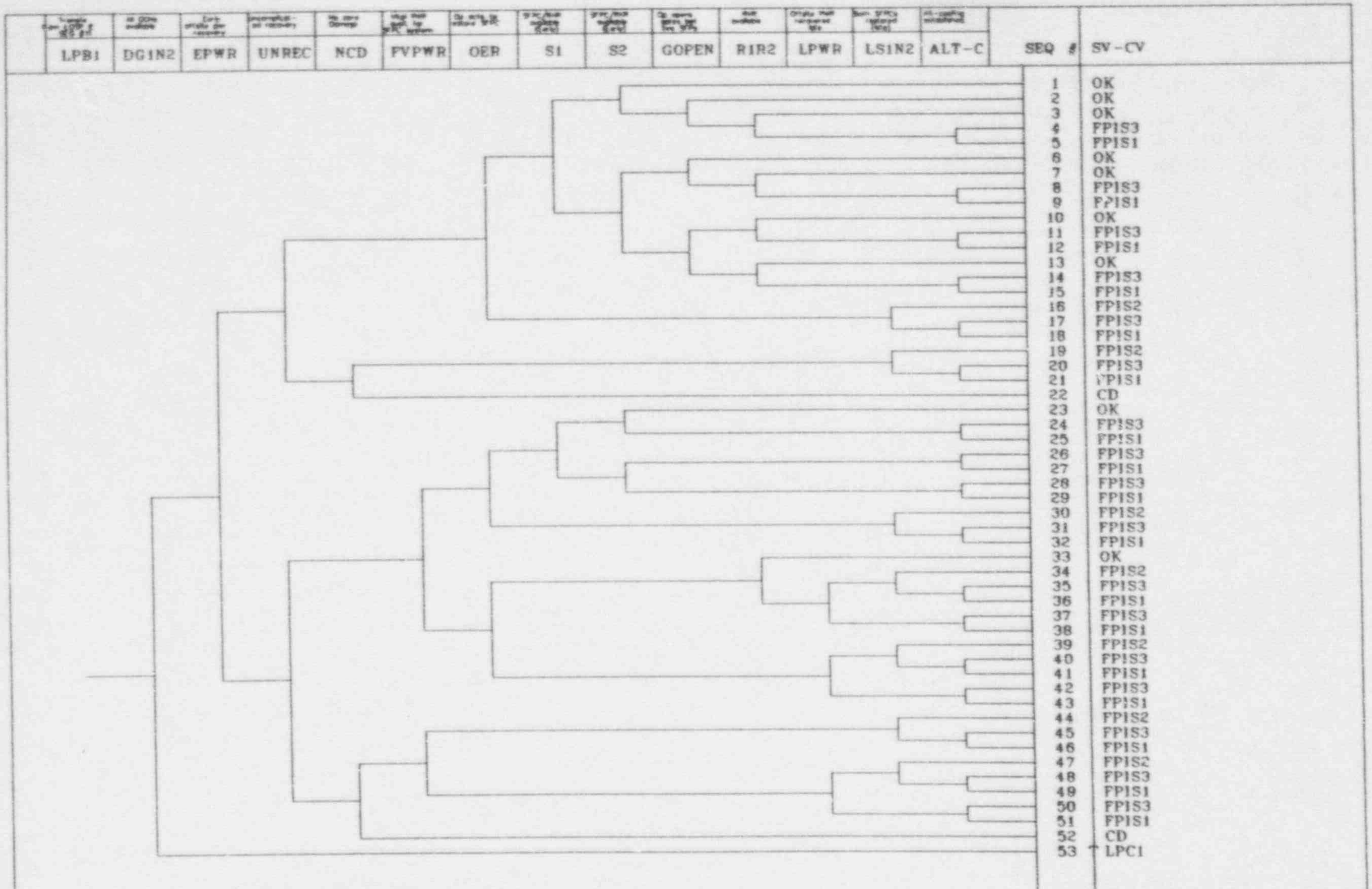
Three event trees are used to model this class of initiating events. Event tree LP1 deals with Case 1, LP2 deals with Case 2, and LP3 deals with Case 3. The event trees, top event definitions, and success criteria are listed in the following pages. Note that each event tree has three transfer trees.



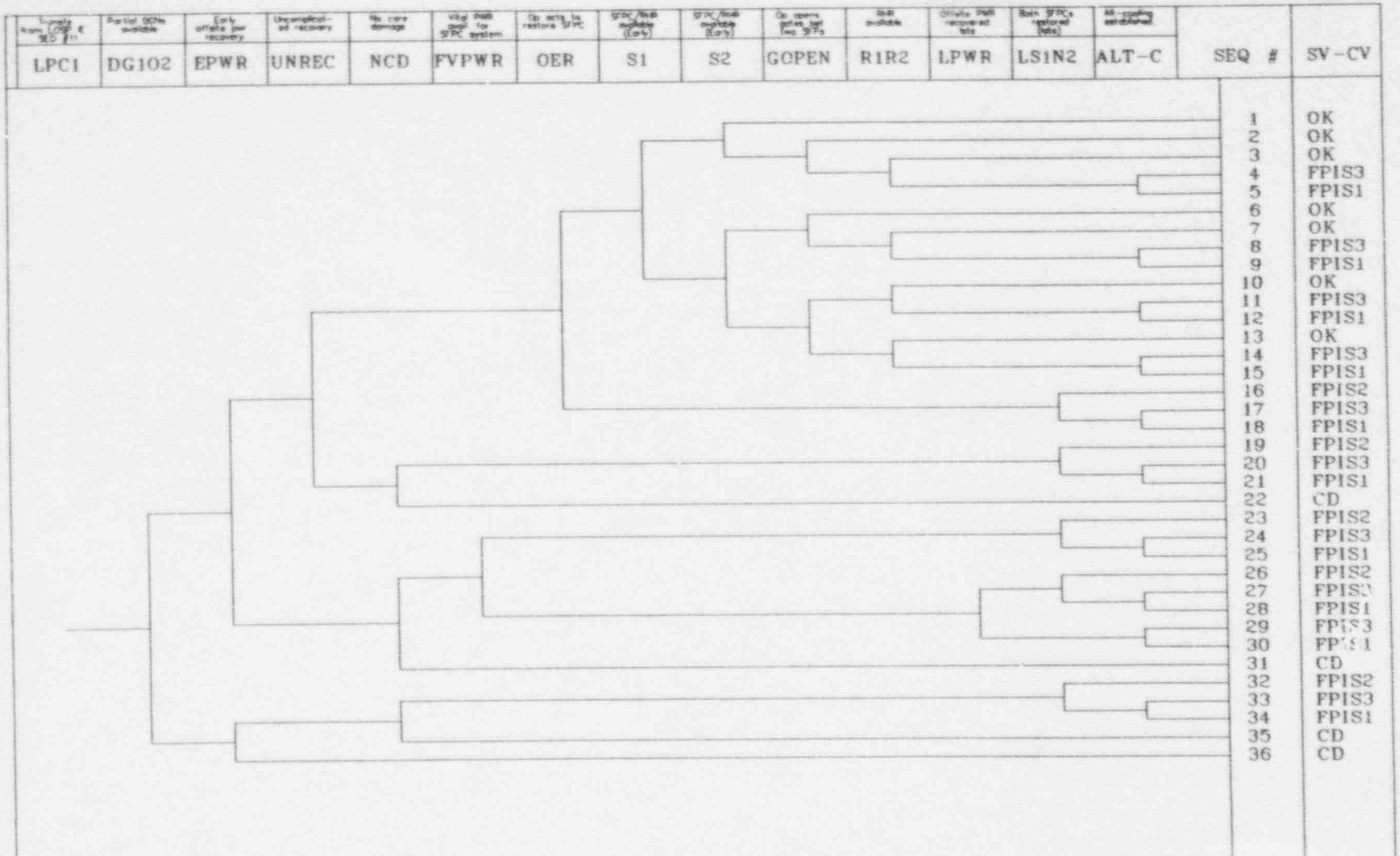
LOSP, Gates open, RHR assist mode available
Case 1



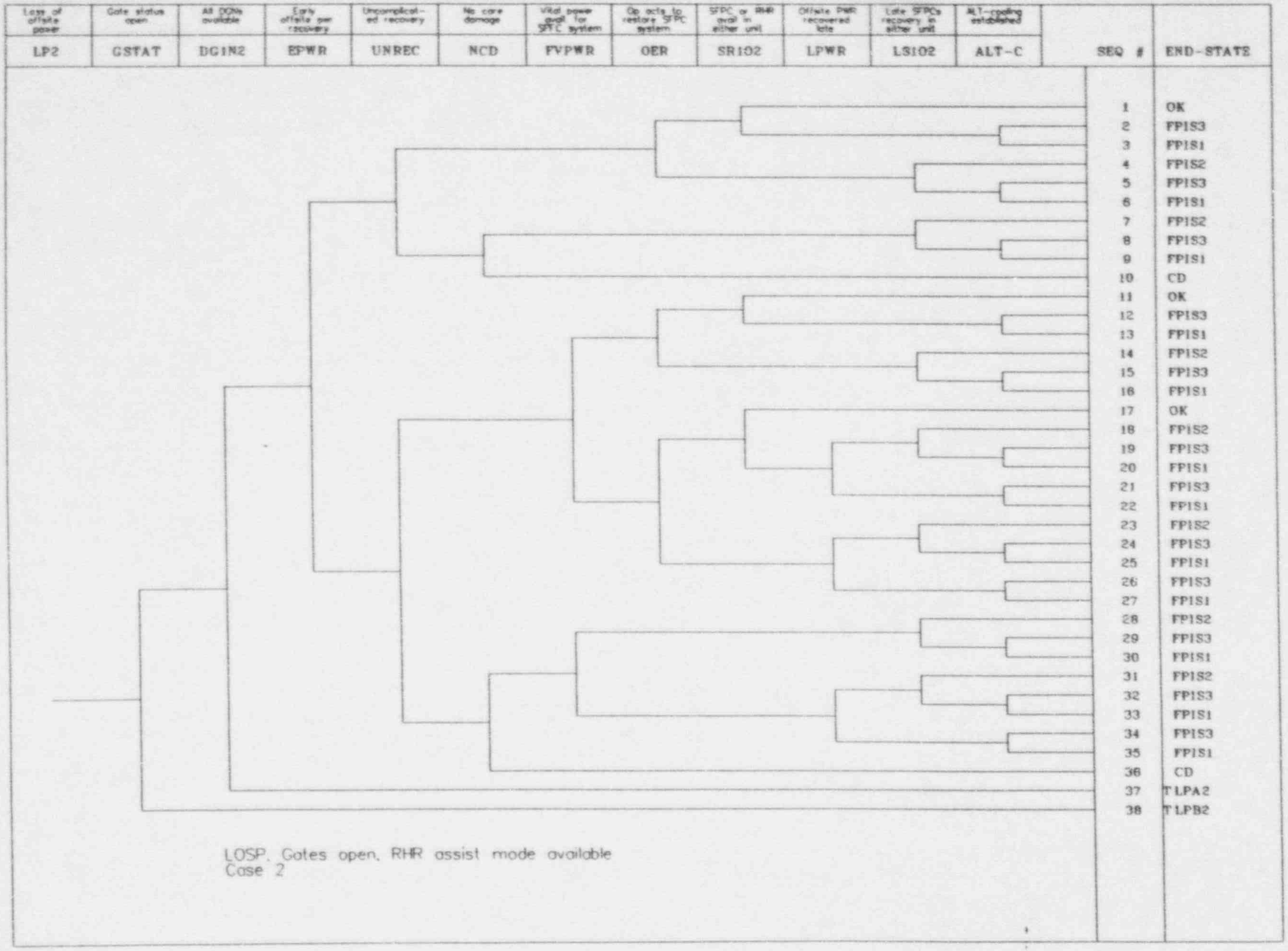
Transfer from LOOP IE seq #10
LPA1
Partial DGNs available
DG102
Early off-site power recovery
EPWR
Uncomplicated recovery
UNREC
No core damage
NCD
Flag-SFPC on vital power
FVPWR
Op acts to restore SFPC sys
OER
SFPC or RHR avail in either unit
SR102
Late offsite power recovery
LPWR
1 of two SFPC avail
LS102
Alternate cooling established
ALT-C
SEQ #
SV-CV
1 OK
2 FPIS3
3 FPIS1
4 FPIS2
5 FPIS3
6 FPIS1
7 FPIS2
8 FPIS3
9 FPIS1
10 CD
11 FPIS2
12 FPIS3
13 FPIS1
14 FPIS2
15 FPIS3
16 FPIS1
17 FPIS3
18 FPIS1
19 CD
20 FPIS2
21 FPIS3
22 FPIS1
23 CD
24 CD
LOSP, Gates open, No RHR assist mode available
Case 1



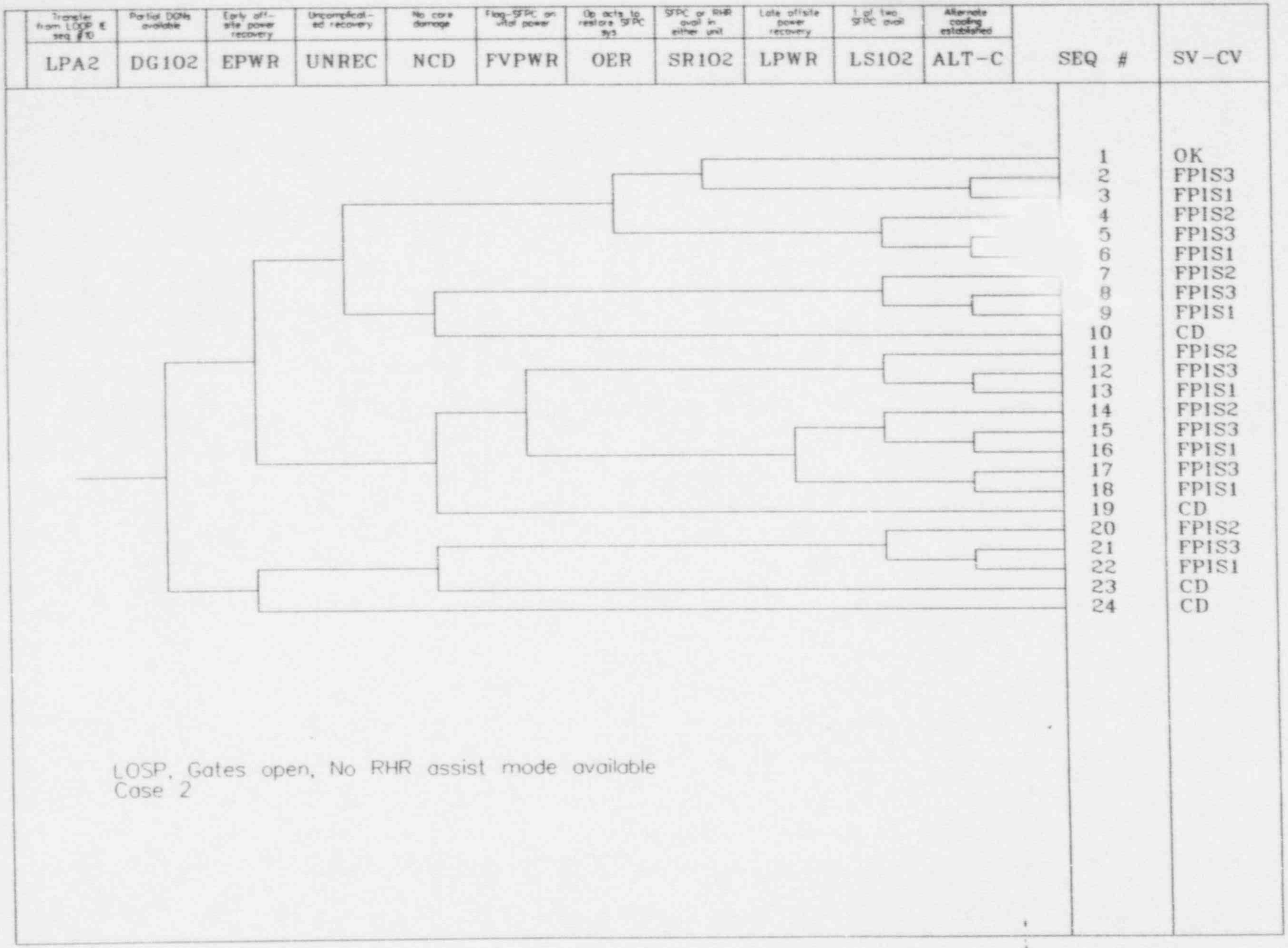
LOSP, Gates are not open, RHR assist mode available
Case 1

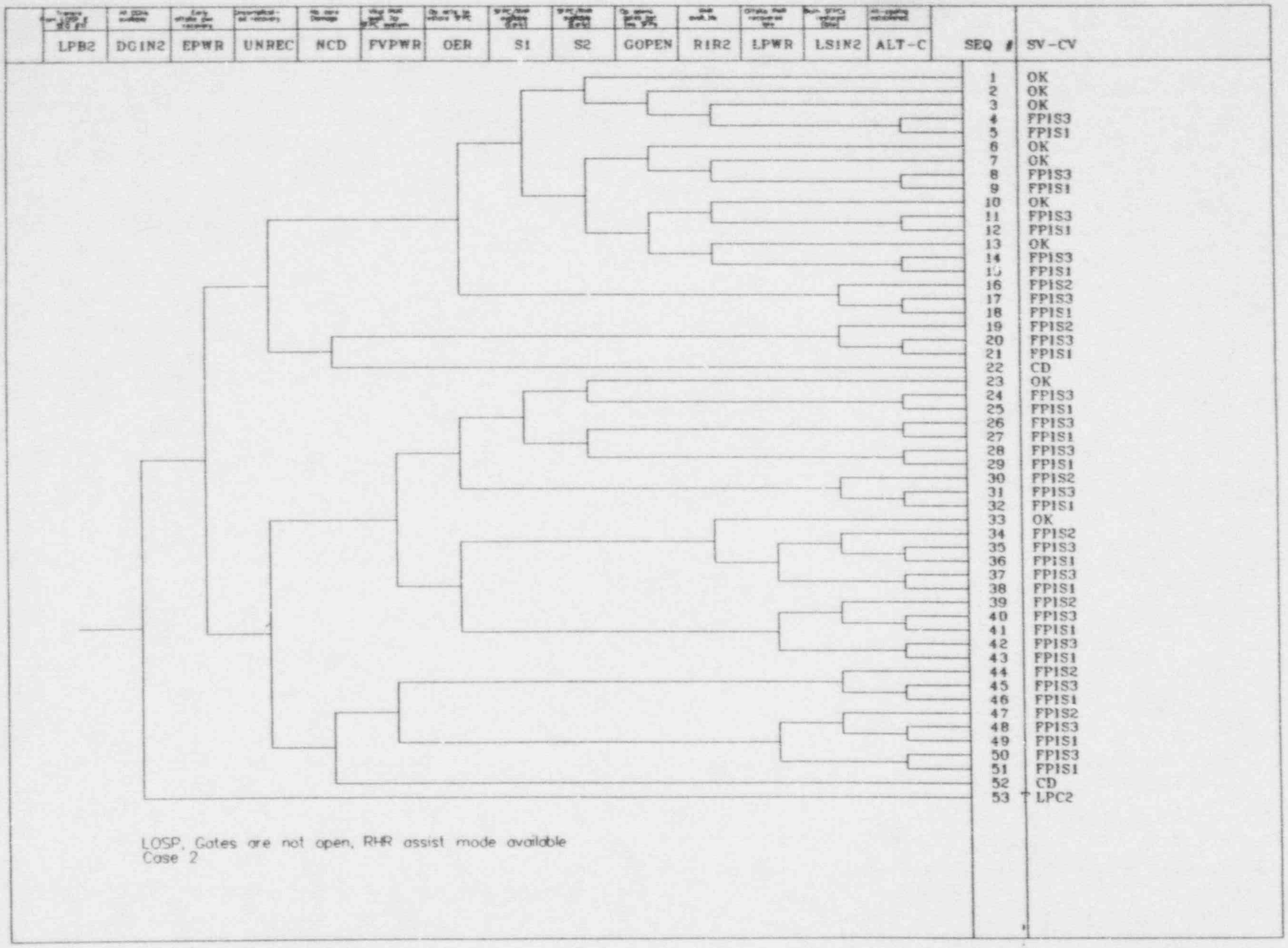


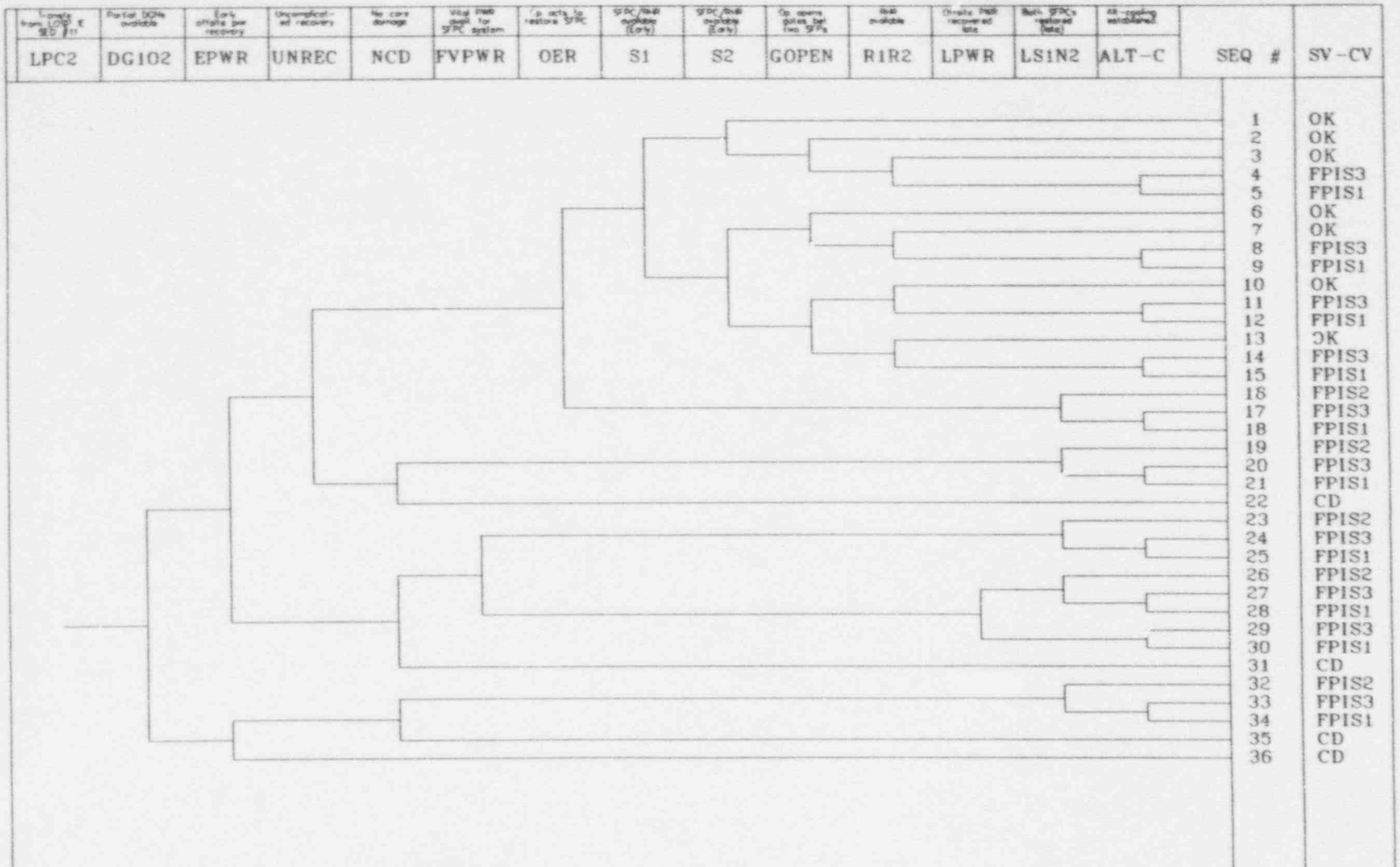
LOSP, Gates are not open, RHR assist mode available
Case 1



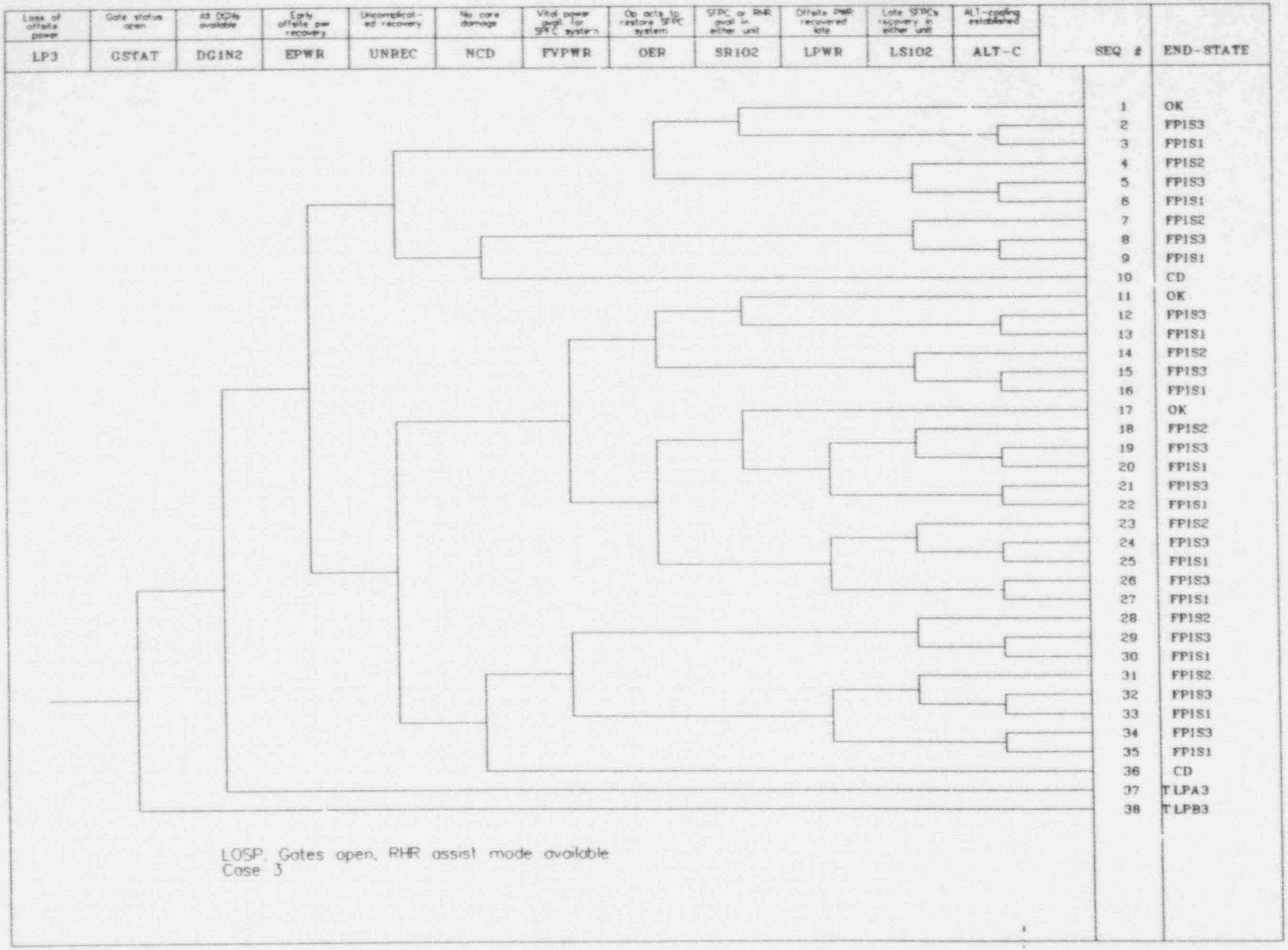
LOSP, Gates open, RHR assist mode available
Case 2


Transfer from LOOP & seq #10
LPA2
Partial DGNs available
DG102
Early off-site power recovery
EPWR
Uncomplicated recovery
UNREC
No core damage
NCD
Flag-SFPC on vital power
FVPWR
Op acts to restore SFPC sys
OER
SFPC or RHR avail in either unit
SR102
Late offsite power recovery
LPWR
1 of two SFPC avail
LS102
Alternate cooling established
ALT-C
SEQ #
SV-CV
1 OK
2 FPIS3
3 FPIS1
4 FPIS2
5 FPIS3
6 FPIS1
7 FPIS2
8 FPIS3
9 FPIS1
10 CD
11 FPIS2
12 FPIS3
13 FPIS1
14 FPIS2
15 FPIS3
16 FPIS1
17 FPIS3
18 FPIS1
19 CD
20 FPIS2
21 FPIS3
22 FPIS1
23 CD
24 CD
LOSP, Gates open, No RHR assist mode available
Case 2

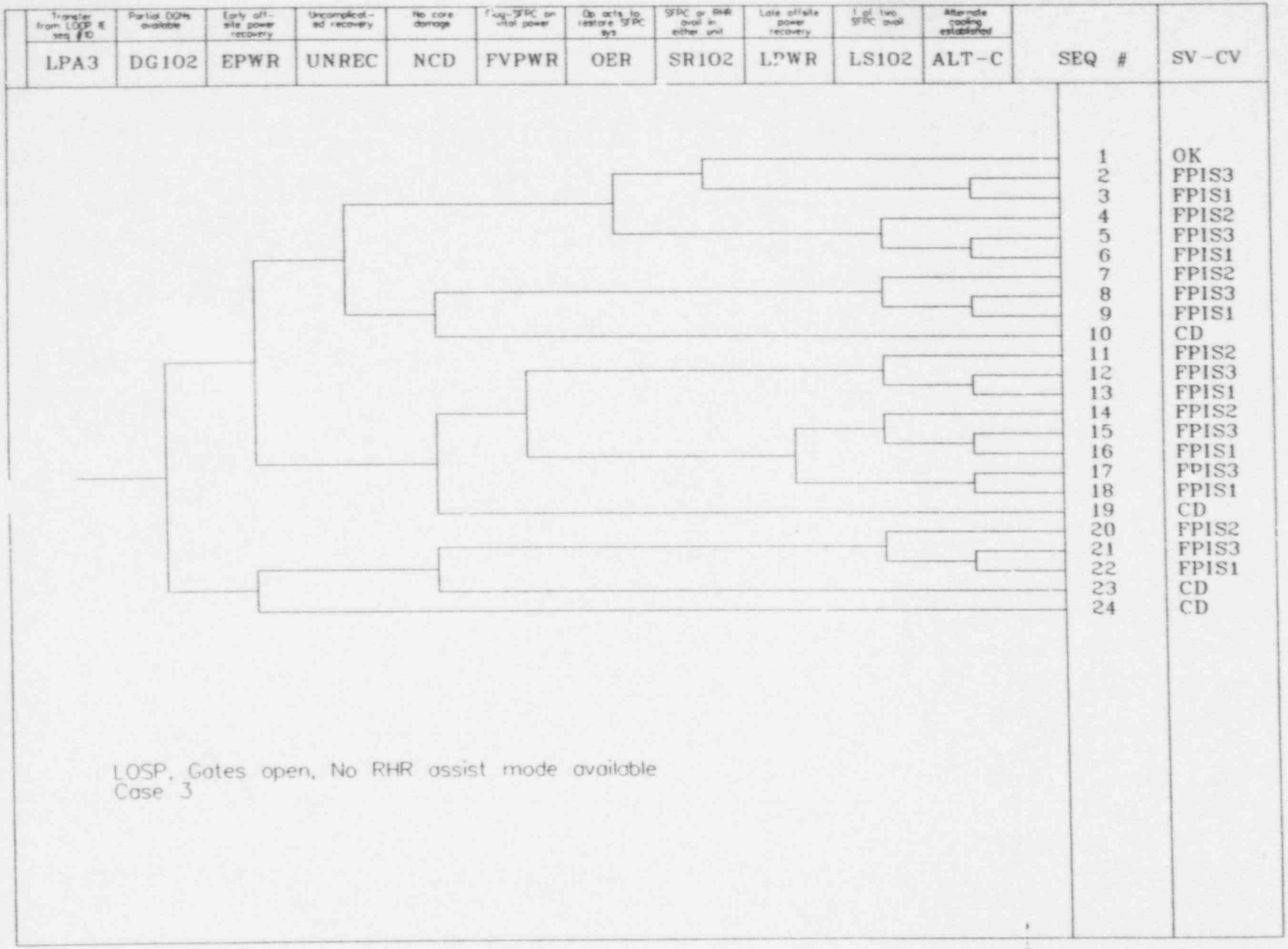

LPB2
DGIN2
EPWR
UNREC
NCD
FVPWR
OER
S1
S2
GOPEN
RIR2
LPWR
LSIN2
ALT-C
SEQ #
SV-CV
1 OK
2 OK
3 OK
4 FPIS3
5 FPIS1
6 OK
7 OK
8 FPIS3
9 FPIS1
10 OK
11 FPIS3
12 FPIS1
13 OK
14 FPIS3
15 FPIS1
16 FPIS2
17 FPIS3
18 FPIS1
19 FPIS2
20 FPIS3
21 FPIS1
22 CD
23 OK
24 FPIS3
25 FPIS1
26 FPIS3
27 FPIS1
28 FPIS3
29 FPIS1
30 FPIS2
31 FPIS3
32 FPIS1
33 OK
34 FPIS2
35 FPIS3
36 FPIS1
37 FPIS3
38 FPIS1
39 FPIS2
40 FPIS3
41 FPIS1
42 FPIS3
43 FPIS1
44 FPIS2
45 FPIS3
46 FPIS1
47 FPIS2
48 FPIS3
49 FPIS1
50 FPIS3
51 FPIS1
52 CD
53 LPC2
LOSP, Gates are not open, RHR assist mode available
Case 2

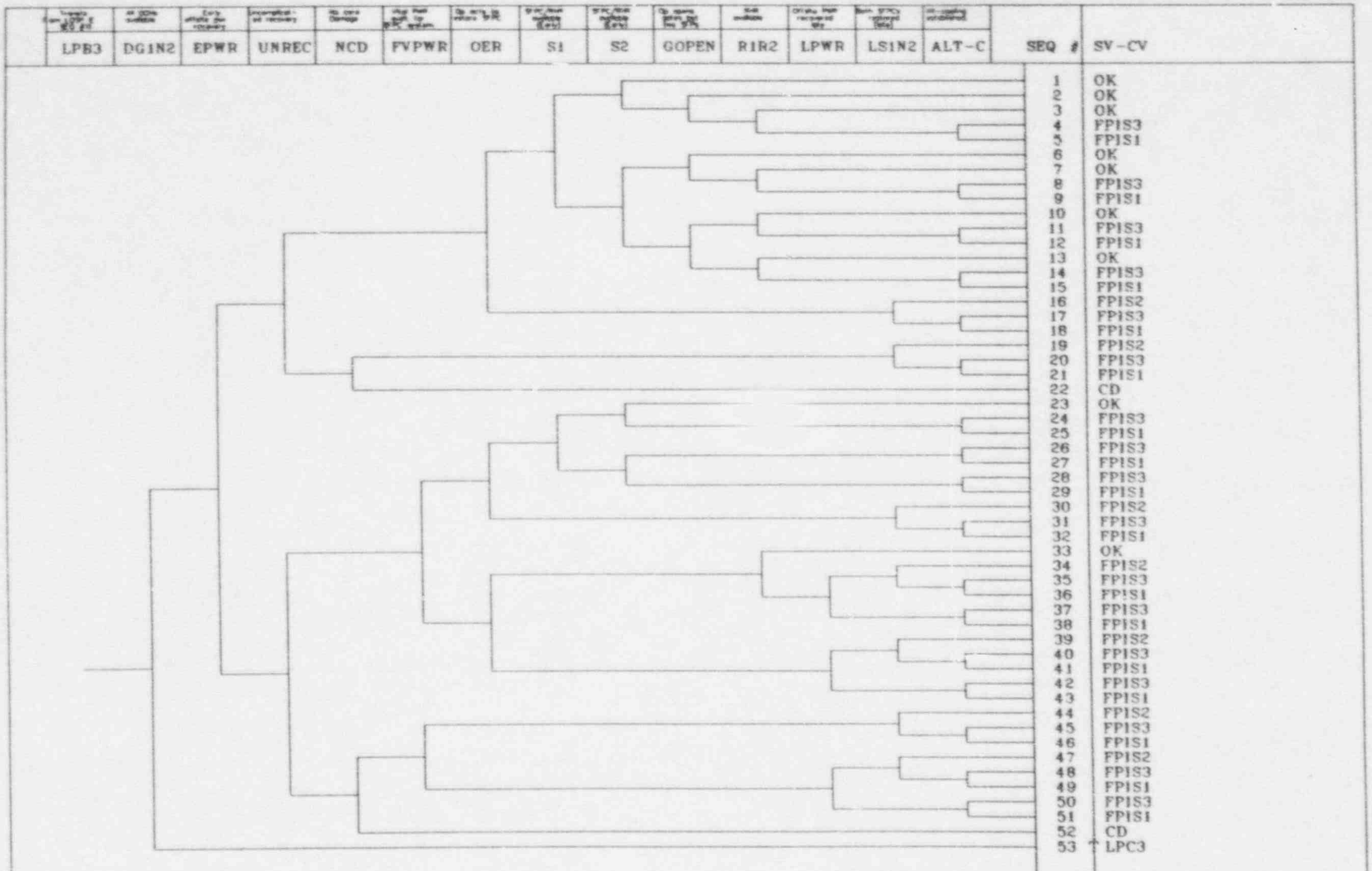


LOSP. Gates are not open, RHR assist mode available
Case 2

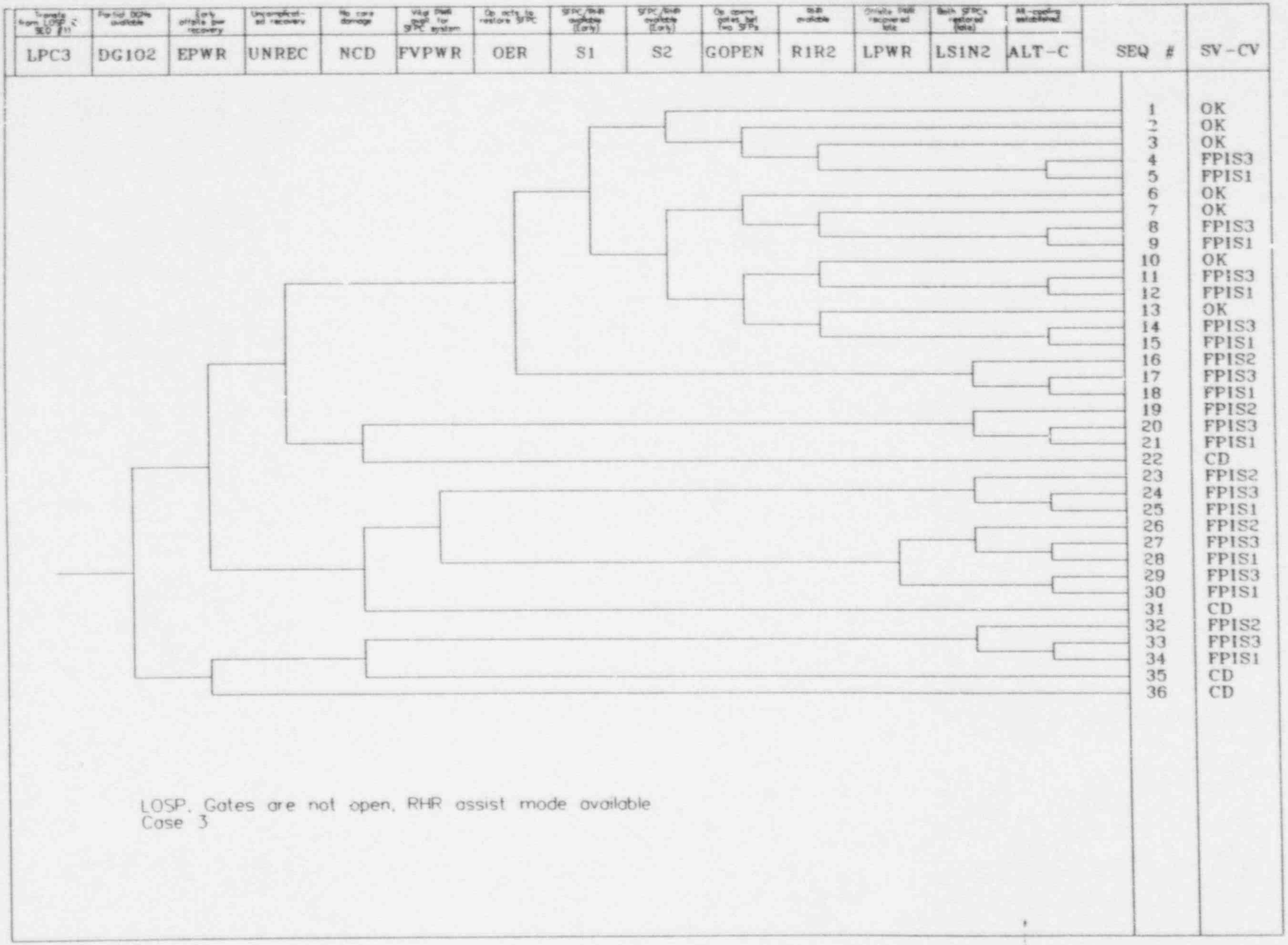


LOSP, Gates open, RHR assist mode available
Case 3


Transfer from LOOP IE seq #10
Early off-site power recovery
Uncomplicat-ed recovery
No core damage
Op acts to restore SFPC sys
SFPC or RHR avail in either unit
Late offsite power recovery
1 of two SFPC avail
Alternate cooling established
LPA3
DG102
EPWR
UNREC
NCD
FVPWR
OER
SR102
L?WR
LS102
ALT-C
SEQ #
SV-CV
1 OK
2 FPIS3
3 FPIS1
4 FPIS2
5 FPIS3
6 FPIS1
7 FPIS2
8 FPIS3
9 FPIS1
10 CD
11 FPIS2
12 FPIS3
13 FPIS1
14 FPIS2
15 FPIS3
16 FPIS1
17 FPIS3
18 FPIS1
19 CD
20 FPIS2
21 FPIS3
22 FPIS1
23 CD
24 CD
LOSP, Gates open, No RHR assist mode available
Case 3



LOSP, Gates are not open, RHR assist mode available
Case 3



LOSP, Gates are not open, RHR assist mode available
Case 3

Top Event Definitions - Loss of Offsite Power Event Trees

LP1 Site-wide loss of offsite power while both units are in operating mode (Case 1). (Initiating events LP2 and LP3 treat Cases 2 and 3 refueling unit; i.e., unit 1, for 1/3 offload and full offload, respectively.)

GSTAT Status of cross-connect gate(s): the spent fuel pools are cross connected or not at the time of initiating event.

DG1N2 Availability of all (four) emergency diesel generators (EDGs).

EPWR Early offsite power recovery: offsite power is recovered in 4 hours. (If all EDGs fail, it is assumed that the core cannot be cooled past 4 hours since DC power will last only for 4 hours.)

UNREC Uncomplicated recovery on primary side: operators are not distracted from restoring spent fuel pool cooling prior to boiling.

NCD No core damage. This top event is questioned only during scenarios involving complicated recovery.

FVPWR A flag event: the plant being modeled has the capability to load SFPC pumps on EDGs.

OER Operator response to the loss of SFPC system: operator attempts to restore SFPC soon after the initiating event.

SR1O2 Restoration of the spent fuel pool cooling: operators successfully reestablish cooling using SFPC or RHR from either unit.

LPWR Late offsite power recovery: offsite power is recovered after 16 hours. (After 16 hours it is assumed that RHR cannot be used.)

LS1O2 Late restoration of the SFPC system: operators successfully reestablish cooling using SFPC from either unit.

ALT-C Alternate cooling: operators successfully establish evaporative/boiloff cooling by providing water using the alternate cooling system (e.g., fire water system).

DG1O2 No station blackout : between 1 and 3 EDGs are available.

S1 Restoration of the SFPC system: operators successfully reestablish cooling to Unit 1 SFP.

S2 Restoration of the SFPC system: operators successfully reestablish cooling to Unit 2 SFP.

GOPEN Opening of the gate: operators successfully open the gate(s) and cross connect the spent fuel pools if the SFPC in one of the unit fails.

R1R2 RHR cooling: operators successfully reestablish cooling in both SFPs using RHR for the respective units.

LS1N2 Late restoration of the SFPC system: operators successfully reestablish cooling in both SFPs using SFPC for the respective units.

Success Criteria - Loss of Offsite Power Event Tree

Case 1, Gates Open

DGs Available	Offsite Power	SR1O2	LS1O2	ALT-C
All	Early recovery	2 of 6 SFPC pumps or 1 train RHR in any unit	2 of 6 SFPC pumps	Any available alternate cooling system
All	Late recovery	1 train RHR in any unit	2 of 6 SFPC pumps	Any available alternate cooling system
All	None	1 train RHR in any unit	Not modeled	Any available alternate cooling system
Some	Early recovery	2 of 6 SFPC pumps or 1 train RHR in any unit	2 of 6 SFPC pumps	Any available alternate cooling system
Some	Late recovery	Not modeled	2 of 6 SFPC pumps	Any available alternate cooling system
Some	None	Not modeled	Not modeled	Any available alternate cooling system
None	Early recovery	Not modeled	2 of 6 SFPC pumps	Any available alternate cooling system

Case 1, Gates Not Open

DG power	Offsite Power	S1	S2*	R1R2	LS1N2	ALT-C
All	Early recovery	1 of 3 SFPC pumps in Unit 1	2 of 3 SFPC pumps in Unit 2	1 train of RHR in the unit where no SFPC pump is available	1 of 3 SFPC pumps in each unit	Any available alternate cooling system
All	Late recovery			1 train of RHR in each unit	1 of 3 SFPC pumps in each unit	Any available alternate cooling system
All	None			1 train RHR in each unit	Not modeled	Any available alternate cooling system
Some	Early recovery	1 of 3 SFPC pumps in Unit 1	2 of 3 SFPC pumps in Unit 2	1 train RHR in the unit where no SFPC pump is available	1 of 3 SFPC pumps in each unit	Any available alternate cooling system
Some	Late recovery	Not modeled	Not modeled	Not modeled	1 of 3 SFPC pumps in each unit	Any available alternate cooling system
Some	None	Not modeled	Not modeled	Not modeled	Not modeled	Any available alternate cooling system
None	Early recovery	Not modeled	Not modeled	Not modeled	1 of 3 SFPC pumps in each unit	Any available alternate cooling system

* Given SFPC system in Unit 1 fails

Case 2, Gates Open

DC power	Offsite Power	SR1O2	LS1O2	ALT-C
All	Early recovery	3 of 6 SFPC pumps or 1 train RHR in any unit	3 of 6 SFPC pumps	Any available alternate cooling system
All	Late recovery	1 train RHR in any unit	3 of 6 SFPC pumps	Any available alternate cooling system
All	None	1 train RHR in any unit	Not modeled	Any available alternate cooling system
Some	Early recovery	3 of 6 SFPC pumps or 1 train RHR in any unit	3 of 6 SFPC pumps	Any available alternate cooling system
Some	Late recovery	Not modeled	3 of 6 SFPC pumps	Any available alternate cooling system
Some	None	Not modeled	Not modeled	Any available alternate cooling system
None	Early recovery	Not modeled	3 of 6 SFPC pumps	Any available alternate cooling system

Case 2, Gates Not Open

DG power	Offsite Power	S1	S2*	R1R2	LS1N2	ALT-C
All	Early recovery	2 of 3 SFPC pumps in Unit 1	2 of 3 SFPC pumps in Unit 2	1 train of RHR in the unit where no SFPC pump is available	2 of 3 SFPC pumps in each unit	Any available alternate cooling system
All	Late recovery			1 train of RHR in each unit	2 of 3 SFPC pumps in each unit	Any available alternate cooling system
All	None			1 train of RHR in each unit	Not modeled	Any available alternate cooling system
Some	Early recovery	2 of 3 SFPC pumps Unit 1	2 of 3 SFPC pumps in Unit 2	1 train of RHR in the unit where no SFPC pump is available	2 of 3 SFPC pumps in each unit	Any available alternate cooling system
Some	Late recovery	Not modeled	Not modeled	Not modeled	2 of 3 SFPC pumps in each unit	Any available alternate cooling system
Some	None	Not modeled	Not modeled	Not modeled	Not modeled	Any available alternate cooling system
None	Early recovery	Not modeled	Not modeled	Not modeled	2 of 3 SFPC pumps in each unit	Any available alternate cooling system

* Given SFPC system in Unit 1 fails

Case 3, Gates Open

DG power	Offsite Power	SR1O2	LS1O2	ALT-C
All	Early recovery	4 of 6 SFPC pumps or 1 train RHR in any unit	4 of 6 SFPC pumps	Any available alternate cooling system
All	Late recovery	1 train RHR in any unit	4 of 6 SFPC pumps	Any available alternate cooling system
All	None	1 train RHR in any unit	Not modeled	Any available alternate cooling system
Some	Early recovery	4 of 6 SFPC pumps or 1 train RHR in any unit	4 of 6 SFPC pumps	Any available alternate cooling system
Some	Late recovery	Not modeled	4 of 6 SFPC pumps	Any available alternate cooling system
Some	None	Not modeled	Not modeled	Any available alternate cooling system
None	Early recovery	Not modeled	4 of 6 SFPC pumps	Any available alternate cooling system

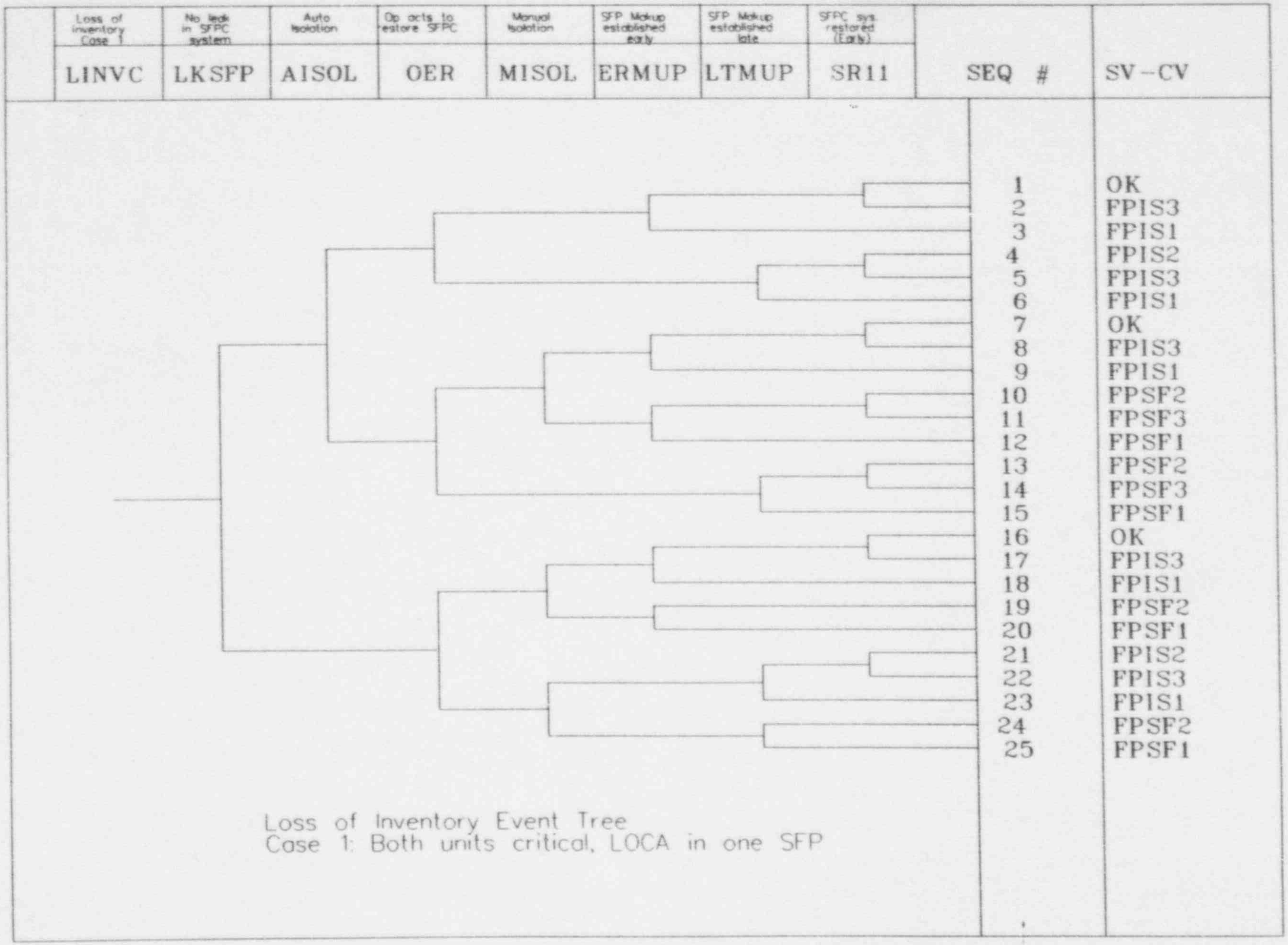
Case 3, Gates Not Open

DG power	Offsite Power	S1	S2*	R1R2	LS1N2	ALT-C
All	Early recovery	3 of 3 SFPC pumps in Unit 1	3 of 3 SFPC pumps in Unit 2	1 train of RHR in the unit where no SFPC pump is available	3 of 3 SFPC pumps in Unit 1, 1 of 3 in Unit 2	Any available alternate cooling system
All	Late recovery			1 train of RHR in each unit	3 of 3 SFPC pumps in Unit 1, 1 of 3 in Unit 2	Any available alternate cooling system
All	None			1 train of RHR in each unit	Not modeled	Any available alternate cooling system
Some	Early recovery	3 of 3 SFPC pumps Unit 1	3 of 3 SFPC pumps in Unit 2	1 train of RHR in the unit where no SFPC pump is available	3 of 3 SFPC pumps in Unit 1, 1 of 3 in Unit 2	Any available alternate cooling system
Some	Late recovery	Not modeled	Not modeled	Not modeled	3 of 3 SFPC pumps in Unit 1, 1 of 3 in Unit 2	Any available alternate cooling system
Some	None	Not modeled	Not modeled	Not modeled	Not modeled	Any available alternate cooling system
None	Early recovery	Not modeled	Not modeled	Not modeled	3 of 3 SFPC pumps in Unit 1, 1 of 3 in Unit 2	Any available alternate cooling system

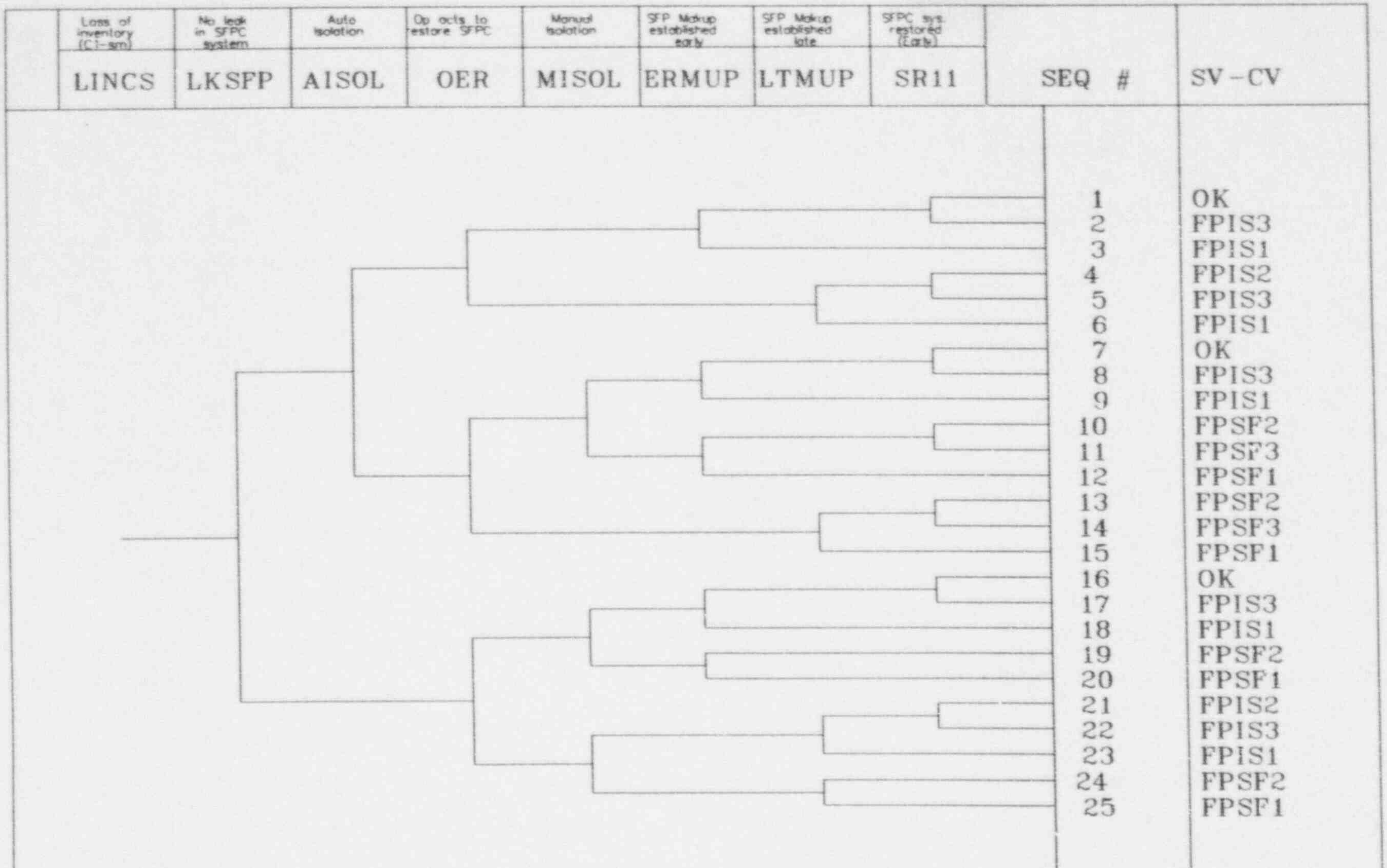
* Given SFPC system in Unit 1 fails

A.4.3 Loss of Inventory

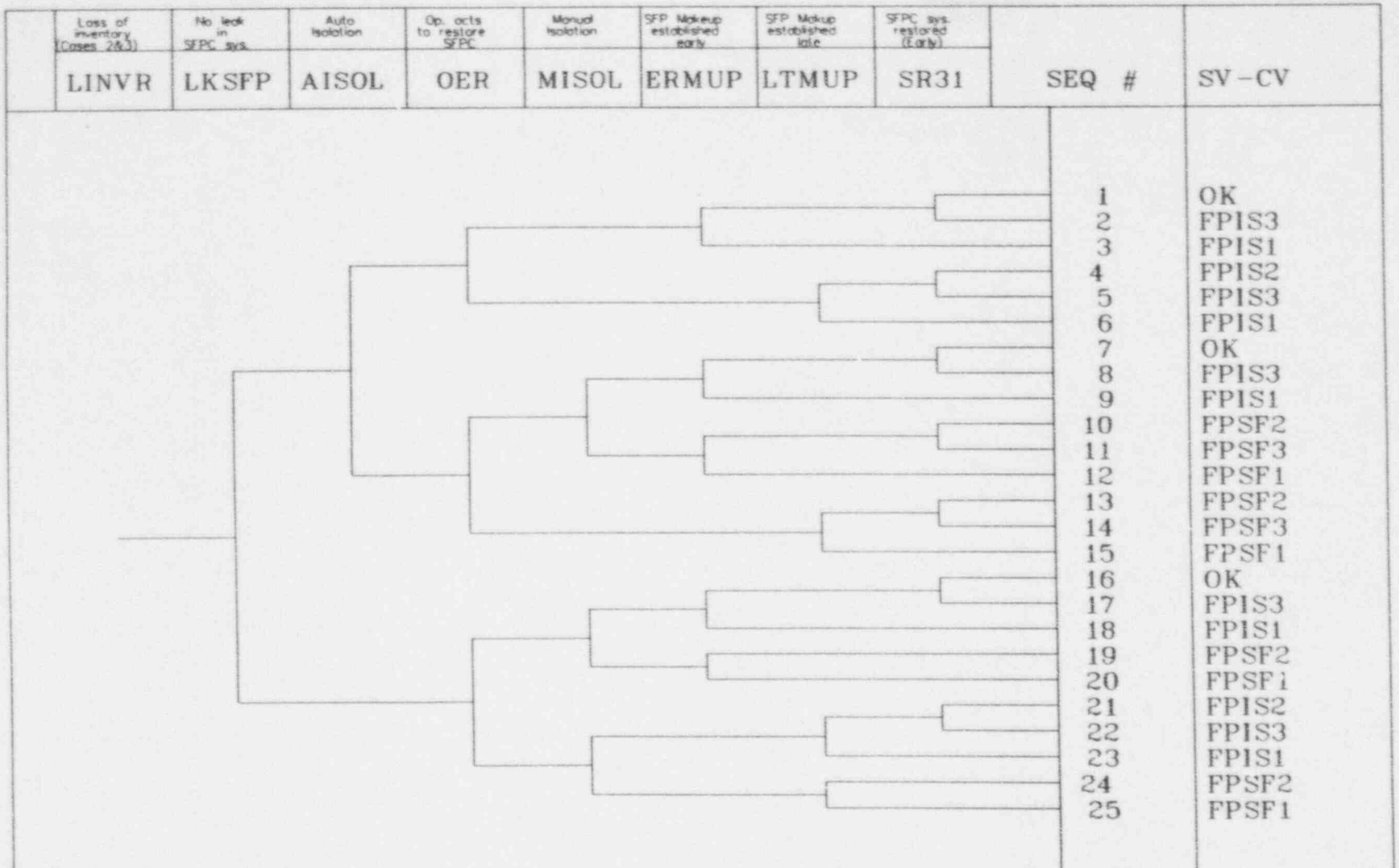
Four event trees are used to model this class of initiating events. Event tree LINVC deals with large losses of inventory during operation (Case 1), tree LINCS deals with small losses during operation, tree LINVR deals with large losses during refueling (Cases 2 and 3), and tree LINRS deals with small losses during refueling. The event trees, top event definitions, and success criteria are listed in the following pages.



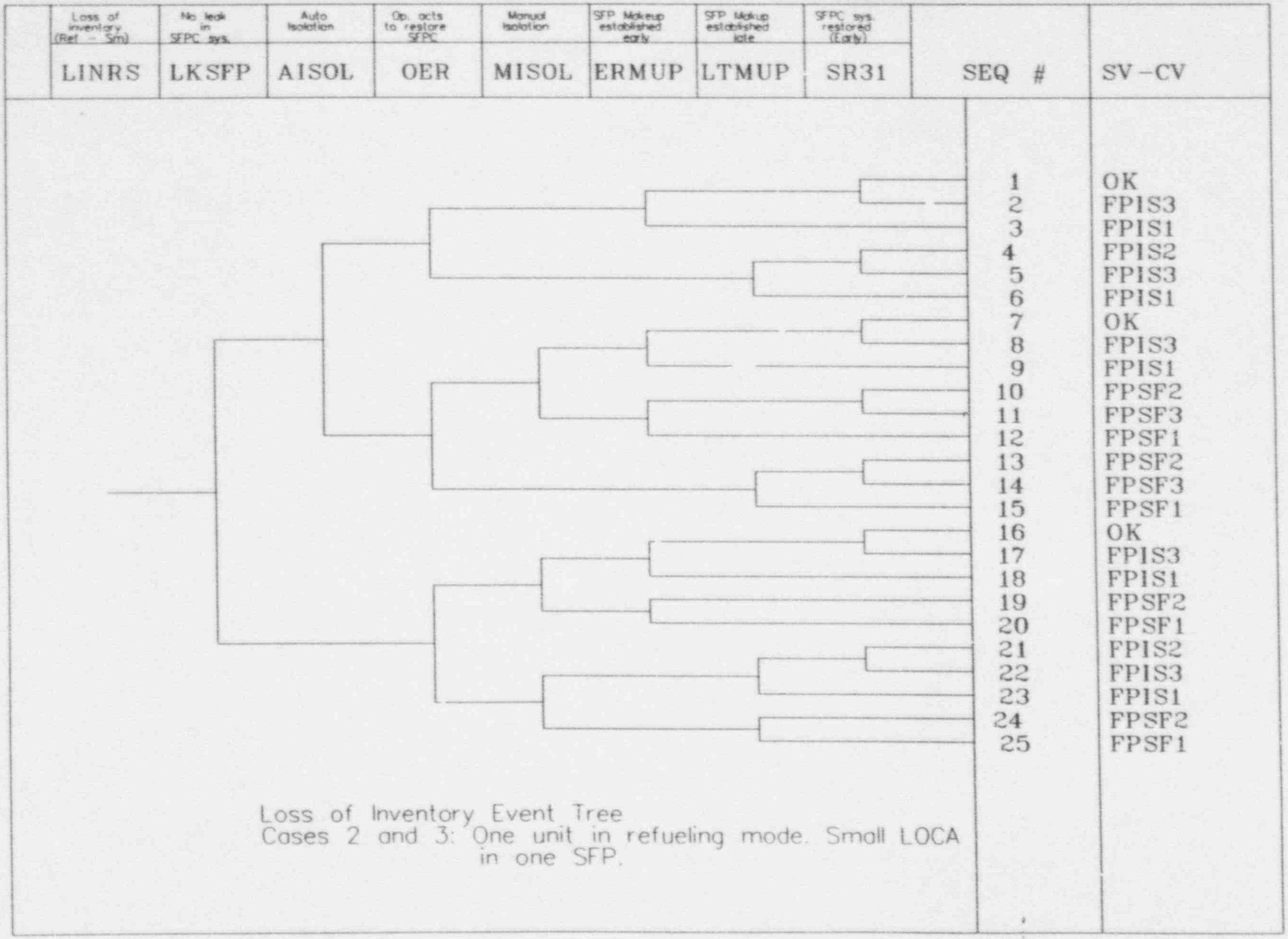
Loss of Inventory Event Tree
Case 1: Both units critical, LOCA in one SFP



Loss of Inventory Event Tree
Case 1: Both units critical, Small LOCA in one SFP



Loss of Inventory Event Tree
Cases 2 and 3: One unit in refueling mode.



Loss of Inventory Event Tree
Cases 2 and 3: One unit in refueling mode. Small LOCA in one SFP.

Top Event Definitions - Loss of Inventory Event Trees

LINVC Large loss of inventory from Unit 1 spent fuel pool while both units are operating (Case 1). (Initiating event LINCS represents a small loss of inventory while both units are operating, LINVR represents a large loss of inventory while Unit 1 is refueling and Unit 2 is operating, and LINRS represents a small loss of inventory while Unit 1 is refueling and Unit 2 is operating.)

LKSFP Leak is in SFPC system. (Lower branch indicates a leak resulting from failure of the spent fuel pool boundary.)

AISOL Auto isolation of leak due to siphon breaker. (Applicable only if the leak is in the SFPC system.)

OER Operator response to the loss of spent fuel pool cooling system: operator attempts to restore SFP cooling soon after the initiating event.

MISOL Manual isolation of leak: operator isolates the leak.

ERMUP Early spent fuel pool makeup: operator uses normal or alternate makeup systems. (In refueling mode, the ECCS can be used to provide makeup.)

LTMUP Late spent fuel pool makeup: operator uses normal or alternate makeup systems. (Due to radiation hazards, the operator actions required, e.g., to provide makeup using an alternate cooling system, may be difficult. All the actions must be taken remotely. In refueling mode, the ECCS can be used to provide makeup.)

SR11 Restoration of the SFPC system: operators successfully reestablish cooling using either SFPC.

Success Criteria - Loss of Inventory Event Trees

Case 1

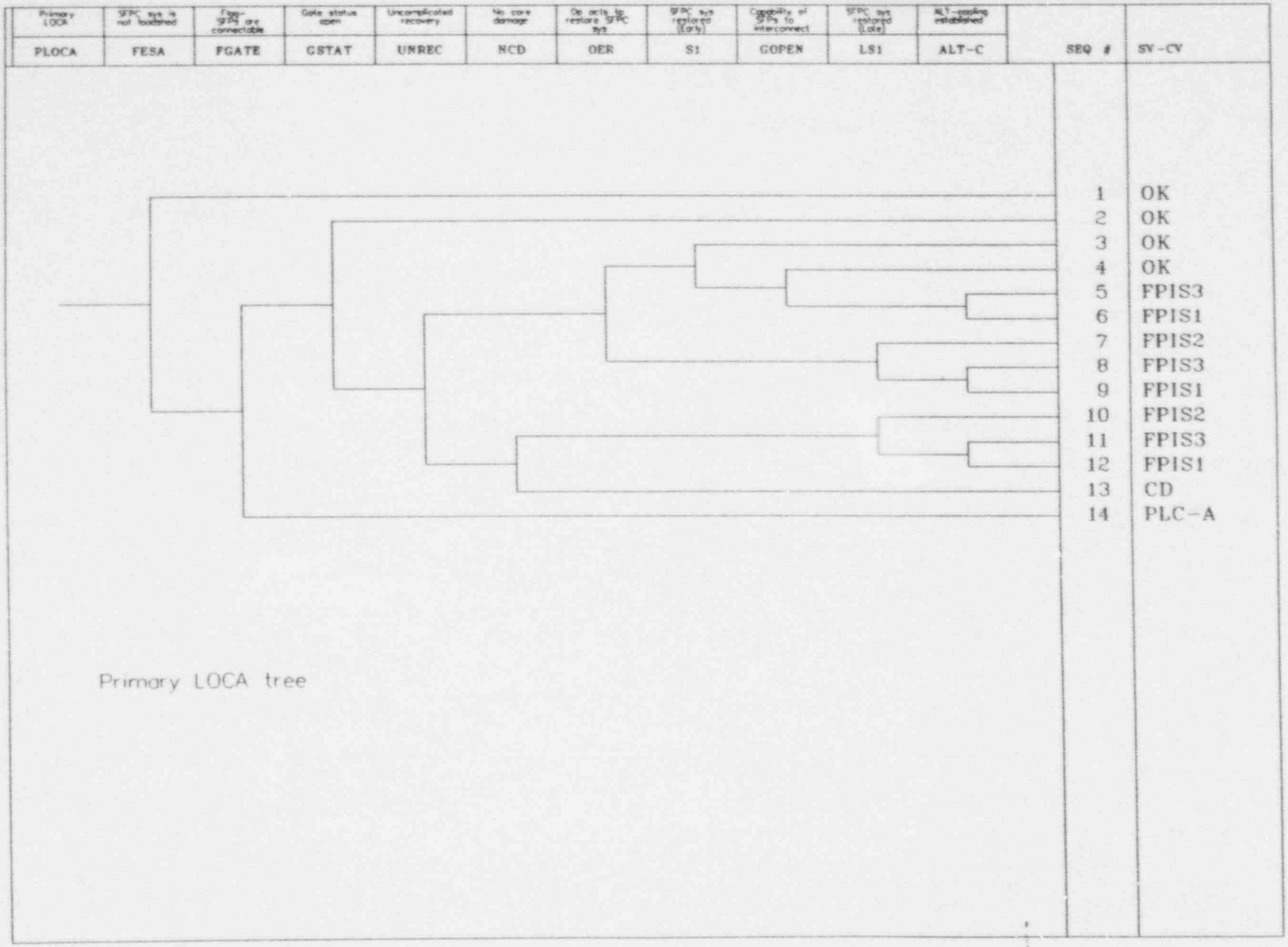
ERMUP	LTMUP	SR11
Normal makeup or any alternate cooling system	Normal makeup or any alternate cooling system which can be operated remotely	1 of 3 SFPC pumps or 1 RHR train

Cases 2 and 3

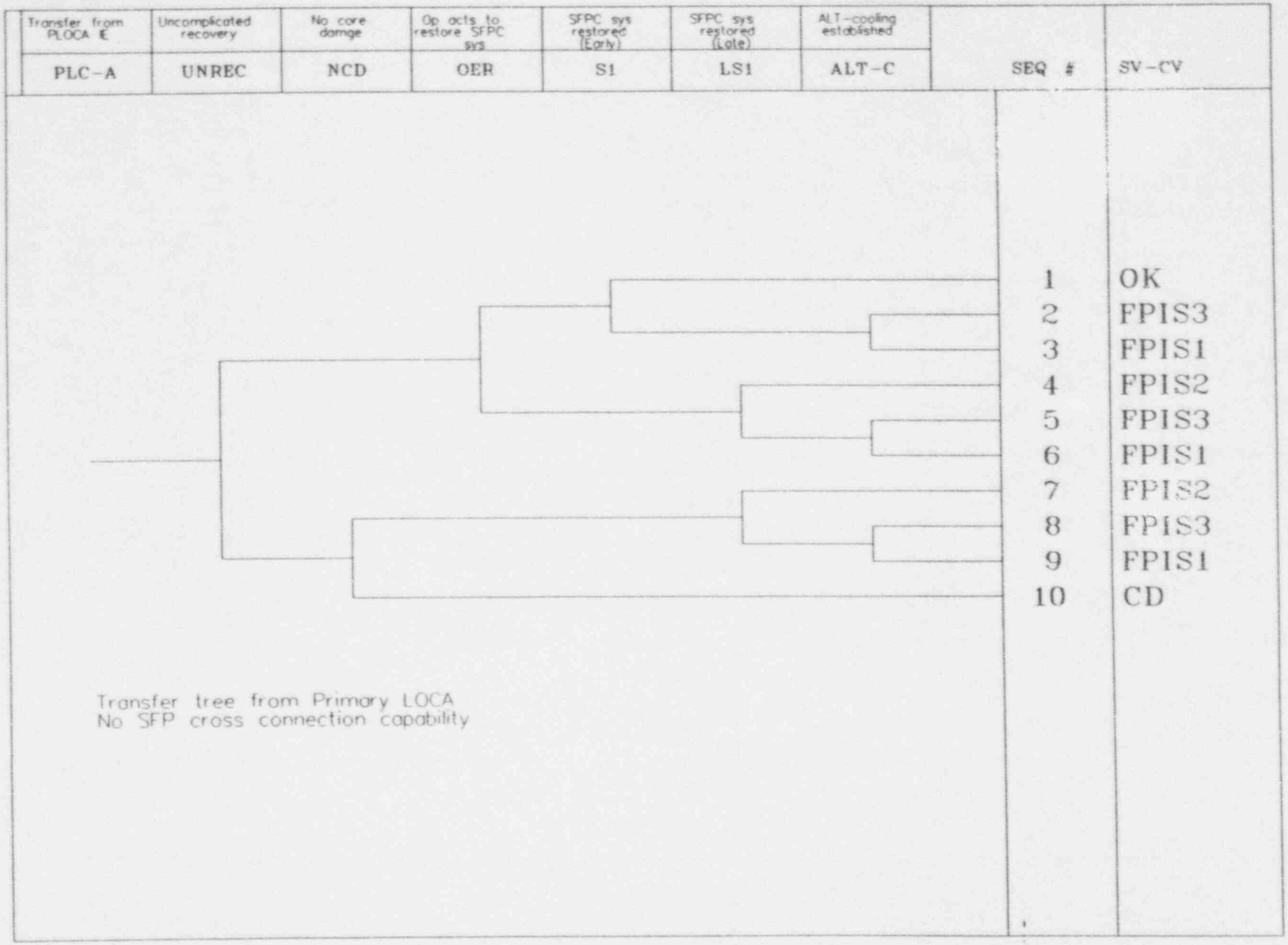
ERMUP	LTMUP	SR11
ECCS injection, Normal makeup or any alternate cooling system	ECCS injection, Normal makeup or Any available alternate cooling system	3 of 3 SFPC pumps

A.4.4 Loss of Primary Coolant

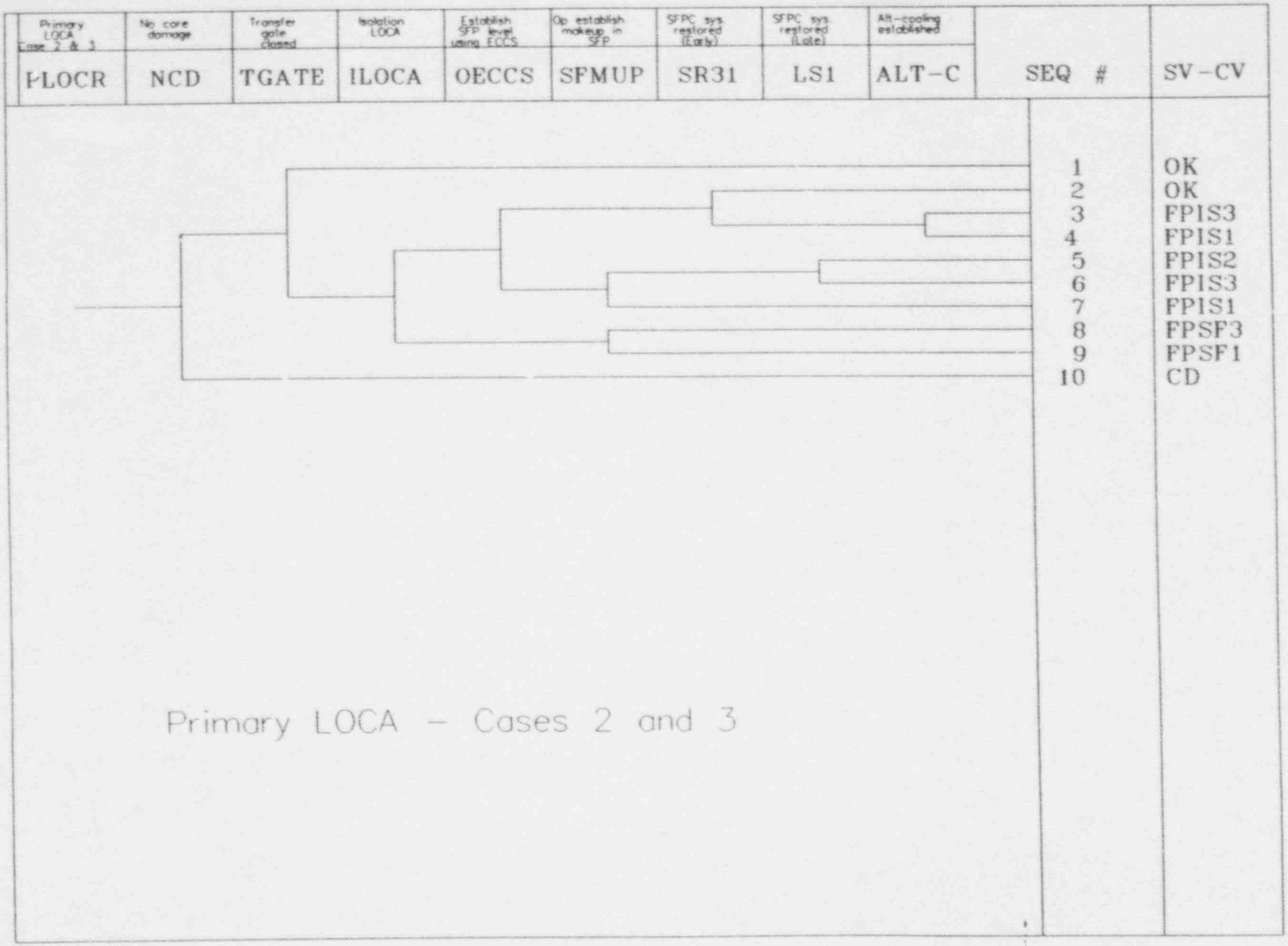
Two event trees are used to model this class of initiating events. Event tree PLOCA deals with a LOCA when both units are operating (Case 1) and PLOCR deals with a LOCA in Unit 1 when Unit 1 is refueling and Unit 2 is operating (Cases 2 and 3). The event trees, top event definitions, and success criteria are listed in the following pages. Note that the PLOCA event tree has one transfer tree.



Primary LOCA tree



Transfer tree from Primary LOCA
No SFP cross connection capability



Primary LOCA - Cases 2 and 3

Top Event Definitions - Primary LOCA Event Trees

PLOCA	Loss of coolant accident in primary system of Unit 1 while both units are operating (Case 1). (Initiating event PLOCR represents a LOCA in the primary system of Unit 1 during refueling, i.e., Cases 2 and 3.)
FESA	A flag event: the SFPC system does not trip on ESF actuation in the plant being modeled (relevant for Case 1).
FGATE	A flag event: the plant being modeled has the capability to cross-connect the spent fuel pool by opening a gate (or gates) (relevant for Case 1).
GSTAT	Status of cross-connect gate(s): the spent fuel pools are cross connected or not at the time of initiating event (only for Case 1).
UNREC	Uncomplicated recovery on primary side: operators are not distracted from restoring spent fuel pool cooling prior to boiling. (Relevant for Case 1.)
NCD	No core damage. This top event is questioned only during scenarios involving complicated recovery. (Relevant for Case 1.)
OER	Operator response to the loss of SFPC system: operator attempts to restore SFP cooling soon after the initiating event.
S1	Restoration of the SFPC system: operators successfully reestablish cooling using either SFPC.
GOPEN	Opening of the gate: operators successfully open the gate(s) and cross connect the spent fuel pools.
SR31	SFPC and RHR cooling: operators successfully reestablish cooling using Unit 1 SFPC or RHR.
LS1	Late restoration of the SFPC system: similar to the top event S1 except all the actions must be taken remotely.
ALT-C	Alternate cooling: operators successfully establish evaporative/boiloff cooling by providing water using the alternate cooling system (e.g., fire water system).
TGATE	Status of a transfer gate: the refueling cavity and the spent fuel pool are cross-connected at the time of initiating event (relevant for Case 2 and 3).
ILOCA	Isolation of leak (relevant for Cases 2 and 3).
OECCS	Operators restore the level in the spent fuel pool using ECCS (relevant for Cases 2 and 3).
SFMUP	Operators restore the level in the spent fuel pool using SFP makeup or alternate cooling (relevant for Cases 2 and 3).

Success Criteria - Primary LOCA Event Trees

Case 1

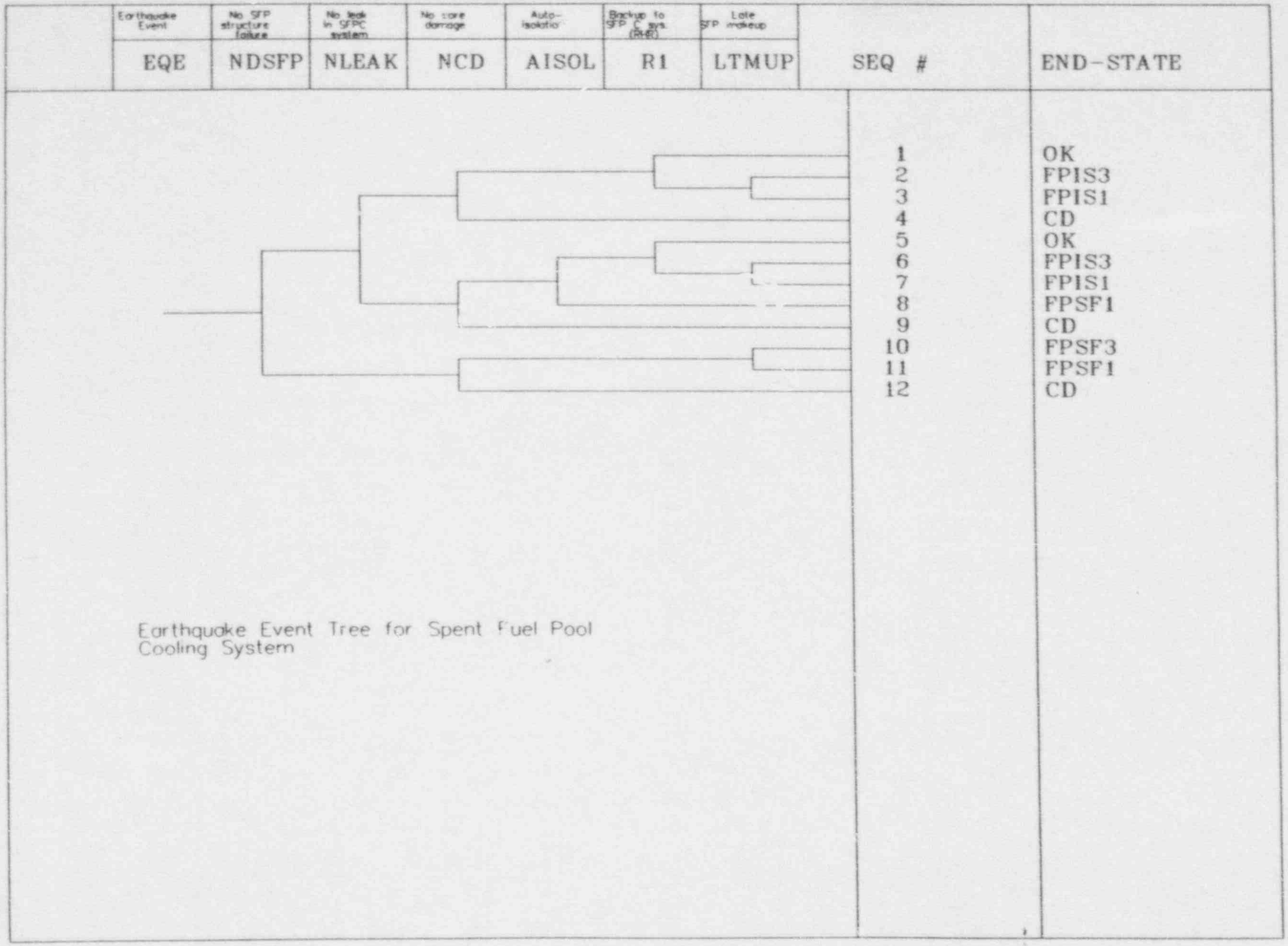
S1	LS1	ALT-C
1 of 3 SFPC pumps	1 of 3 SFPC pumps	Any available alternate cooling system

Cases 2 and 3

OECCS	SFMUP	SR31	LS1	ALT-C
ECCS Injection	Main SFP makeup or alternate cooling	3 of 3 SFPC pumps or 1 RHR train	3 of 3 SFPC pumps	Any available alternate cooling system

A.4.5 Earthquake

One event tree is used to model this class of initiating events. Note that earthquakes with peak ground acceleration (PGA) below 0.2g are assumed to have negligible risk impact, and that earthquakes with PGA greater than 0.6g are assumed to lead directly to core melt (for the purposes of this analysis.) The event tree, top event definitions, and success criteria are listed in the following pages.



Earthquake Event Tree for Spent Fuel Pool Cooling System

Top Event Definitions - Seismic Event Tree

EQE Seismic initiating event.

NDSFP No damage to the spent fuel pool structure from the seismic event.

NLEAK No leak through the SFPC system (caused by the seismic event).

NCD No direct core damage from the seismic event.

AISOL Auto isolation of leak due to siphon breaker. (Applicable only if the leak is in the SFPC system.)

R1 Restoration of spent fuel pool cooling using RHR.

LTMUP Late spent fuel pool makeup using alternate makeup systems. (Operator actions required would be difficult; all actions must be taken remotely.)

Success Criteria - Seismic Event Tree

All Cases

R1	LTMUP
No SFPC system or RHR makeup	Any available alternate cooling system

A.5 Post-Heatup Event Trees

The post-heatup event trees (PHETs) treat the progression of selected accident scenarios past pool heatup; one or more separate trees are developed for each non-successful endstate of the NBF trees. (Multiple trees are required for endstates where steaming and flooding effects are of potential concern.) They address the following issues: the spatial isolation of the spent fuel pool from other safety equipment, the vulnerability of exposed safety equipment to the hazards associated with the scenario (i.e., heat and humidity from pool boiling, water from losses of pool inventory), the ability of operators to divert steam/water away from the safety equipment, and the recoverability of safety equipment affected by the steam/water.

Four PHETs are used in this study. The first three treat the effects of pool heatup on the rest of the plant; the last treats the effect of flooding. (Note that since flooding and pool heatup are not mutually exclusive, a quantitative analysis will need to employ multiple PHETs for a number of NBF event tree endstates.) The PHETs and their entry conditions are as follows:

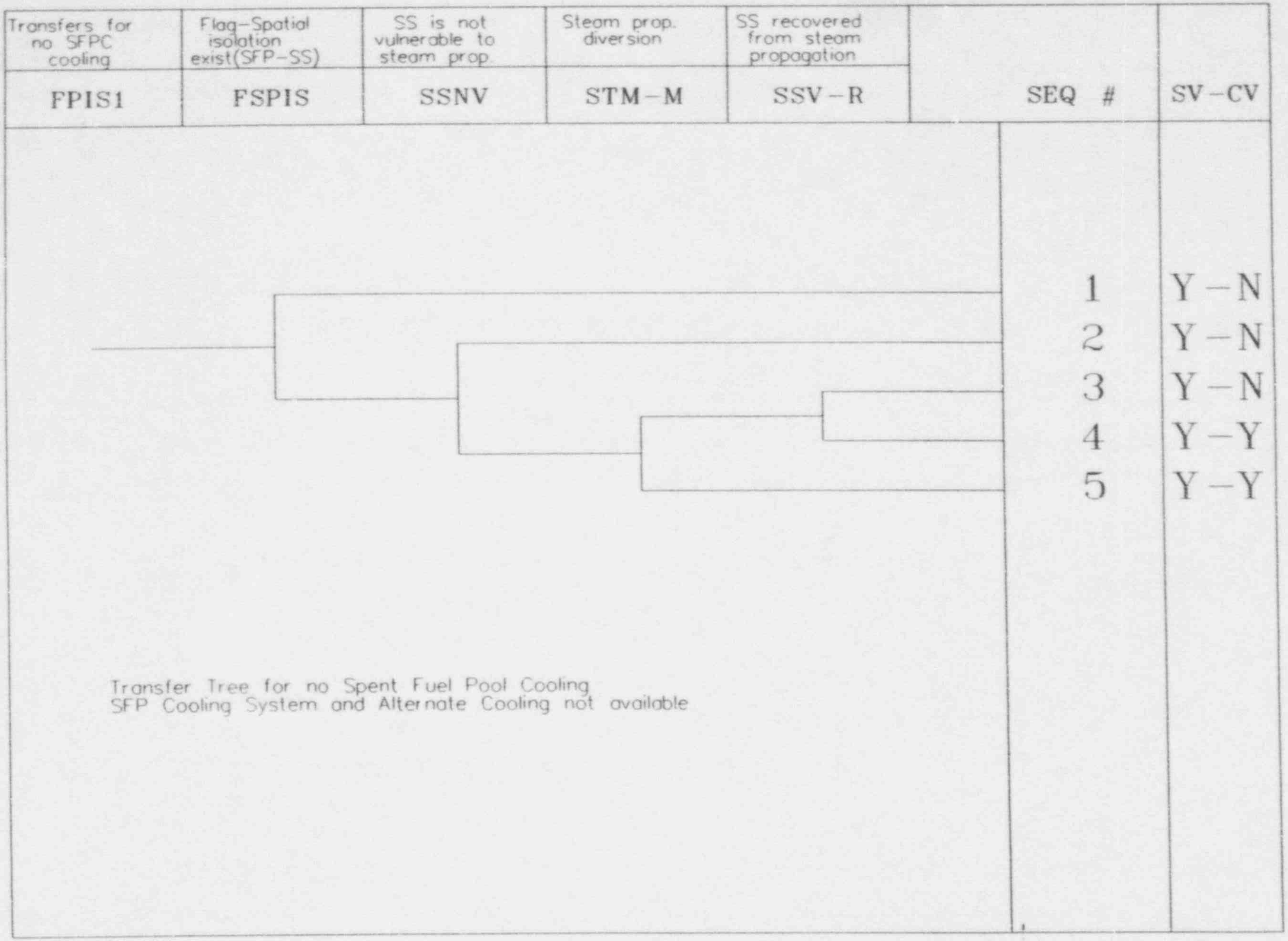
FPIS1 SFP boiling; SFPC has been lost, spent fuel pool (SFP) level is not maintained.

FPIS2 SFP heatup; SFPC has been restored late.

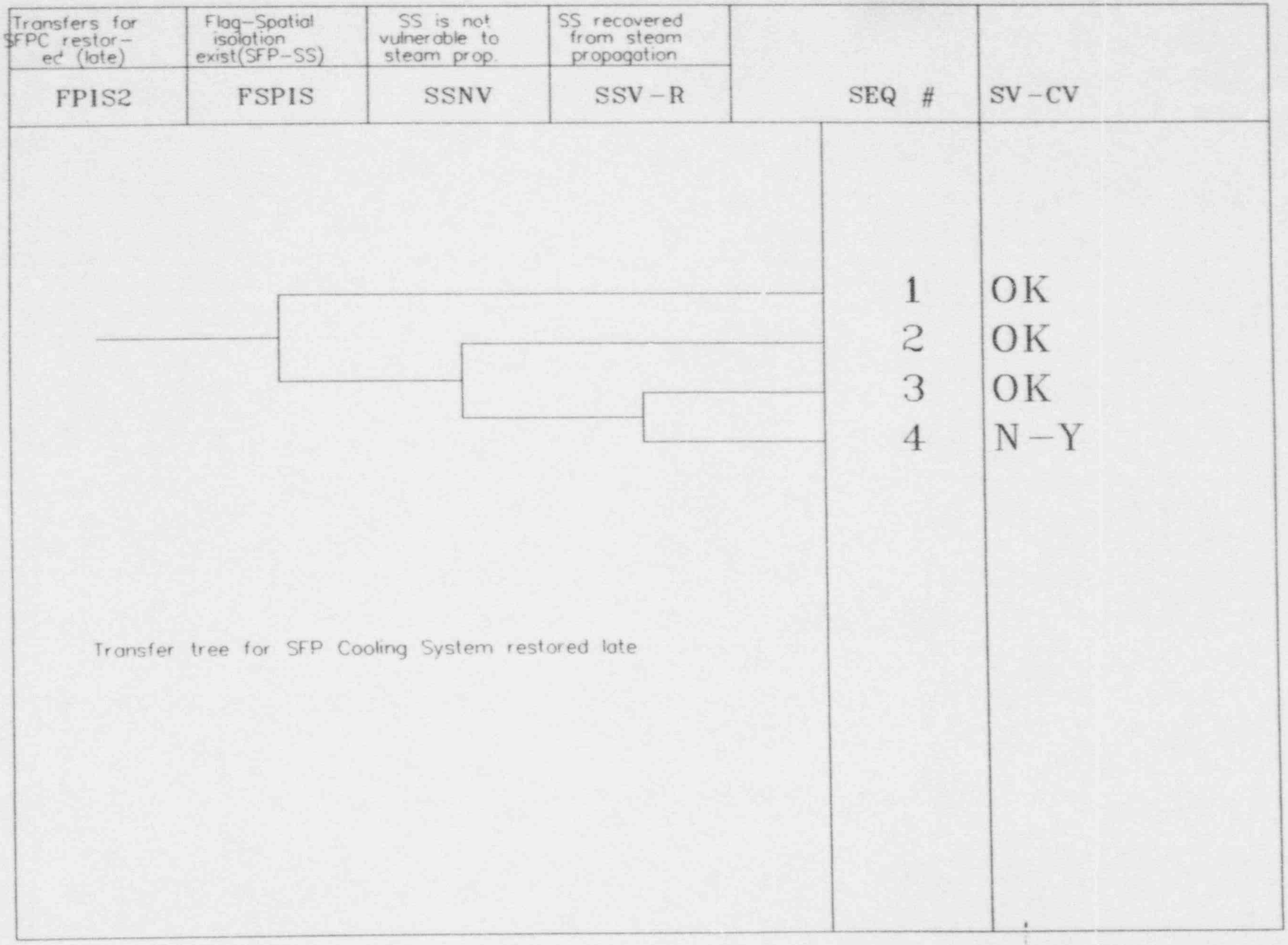
FPIS3 SFP steaming; alternate cooling is being used and SFP level is maintained.

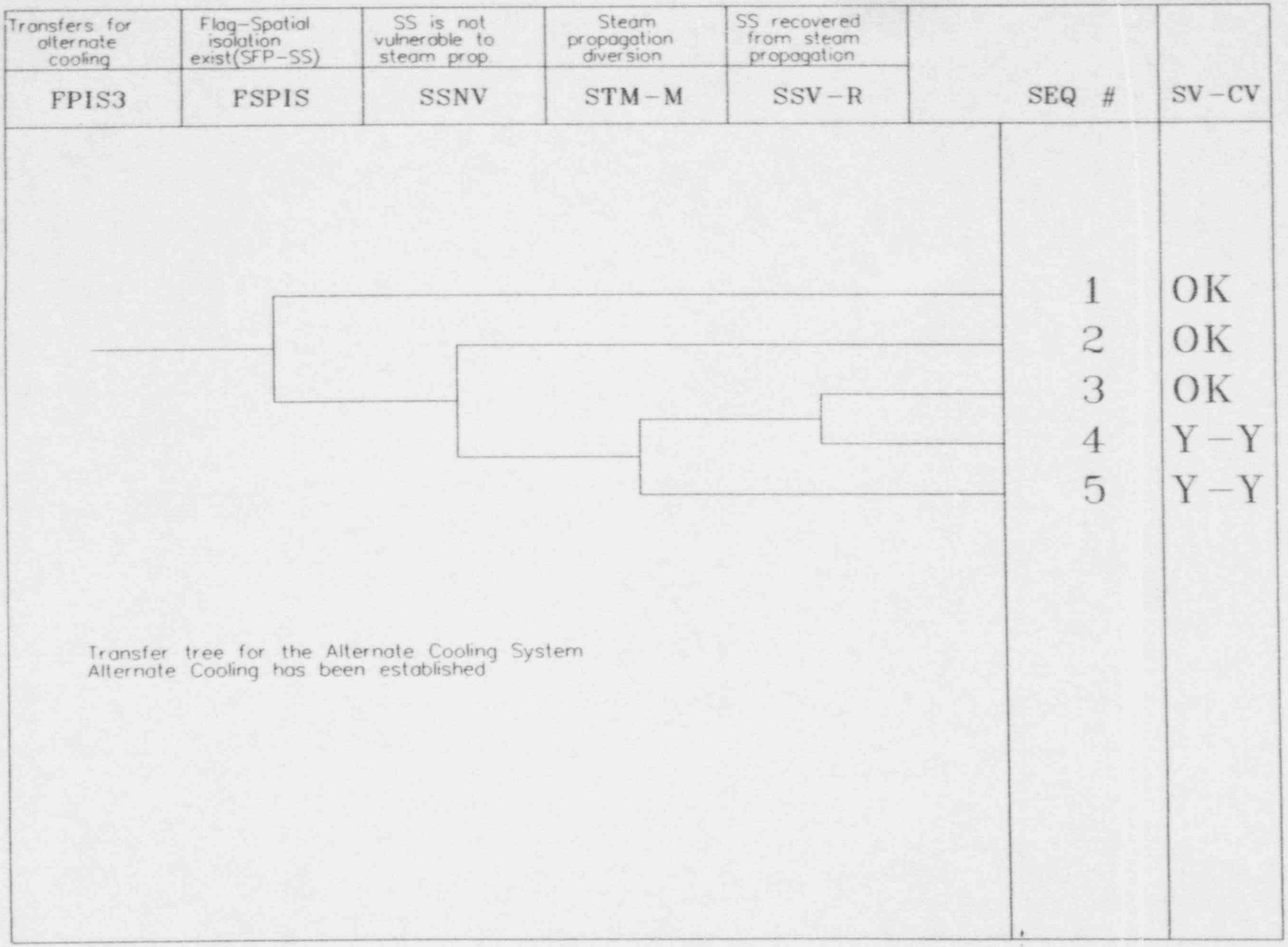
FPISF Flooding has occurred.

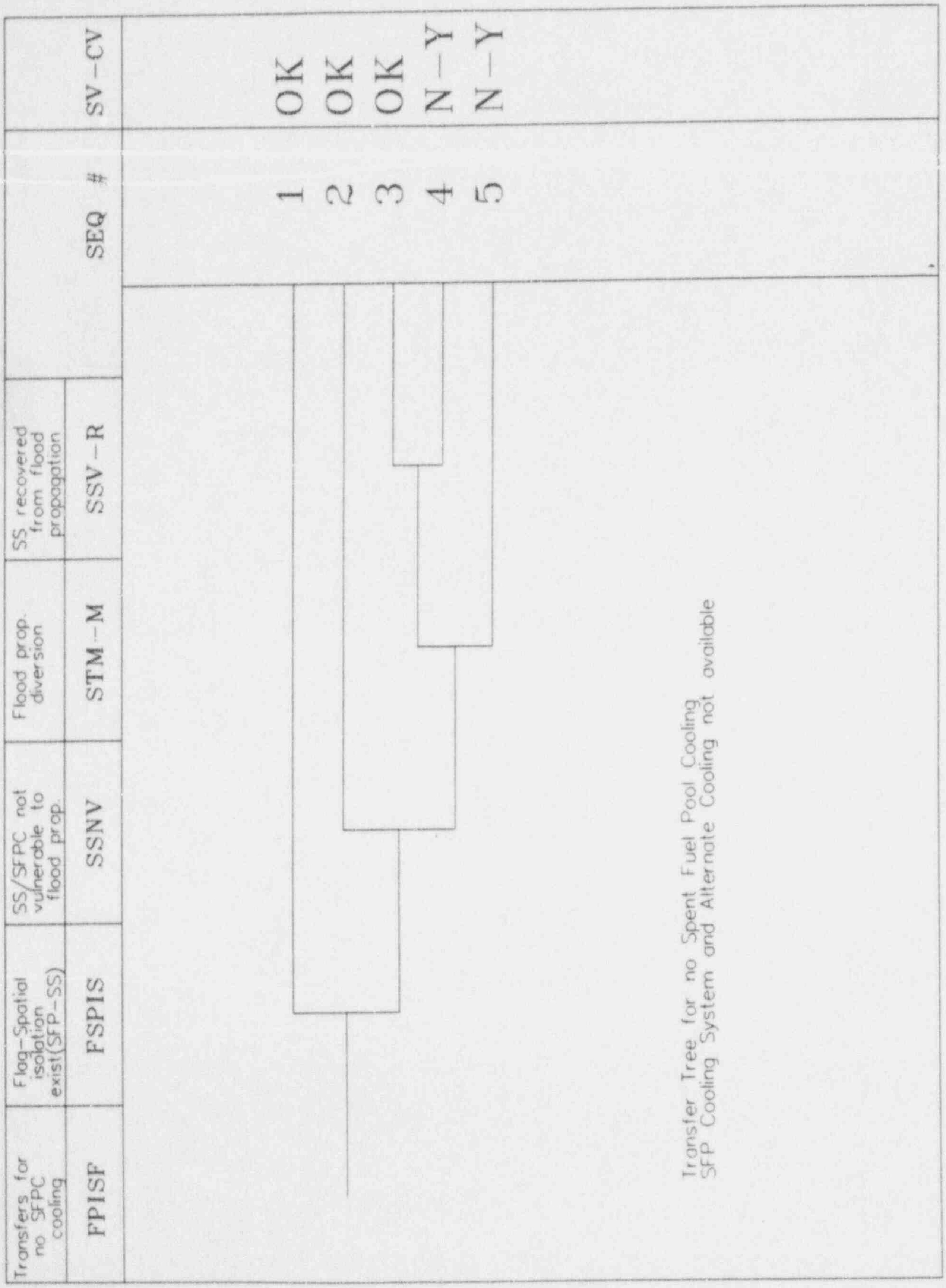
These trees are presented in the following pages.



Transfer Tree for no Spent Fuel Pool Cooling
SFP Cooling System and Alternate Cooling not available


Transfers for SFPC restor-ed (late)
Flag-Spatial isolation exist(SFP-SS)
SS is not vulnerable to steam prop.
SS recovered from steam propogation
FPIS2
FSPIS
SSNV
SSV-R
SEQ #
SV-CV
1
OK
2
OK
3
OK
4
N-Y
Transfer tree for SFP Cooling System restored late

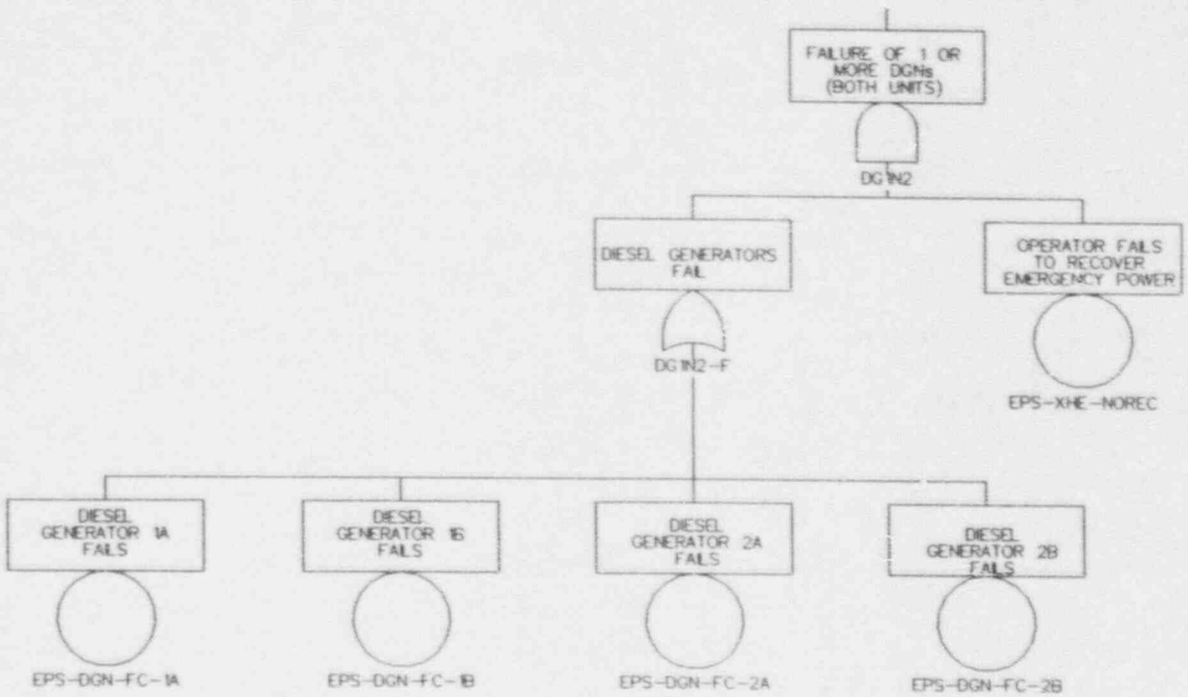

Transfers for alternate cooling
FPIS3
Flag-Spatial isolation exist(SFP-SS)
FSPIS
SS is not vulnerable to steam prop.
SSNV
Steam propagation diversion
STM-M
SS recovered from steam propagation
SSV-R
SEQ #
SV-CV
1 OK
2 OK
3 OK
4 Y-Y
5 Y-Y
Transfer tree for the Alternate Cooling System
Alternate Cooling has been established



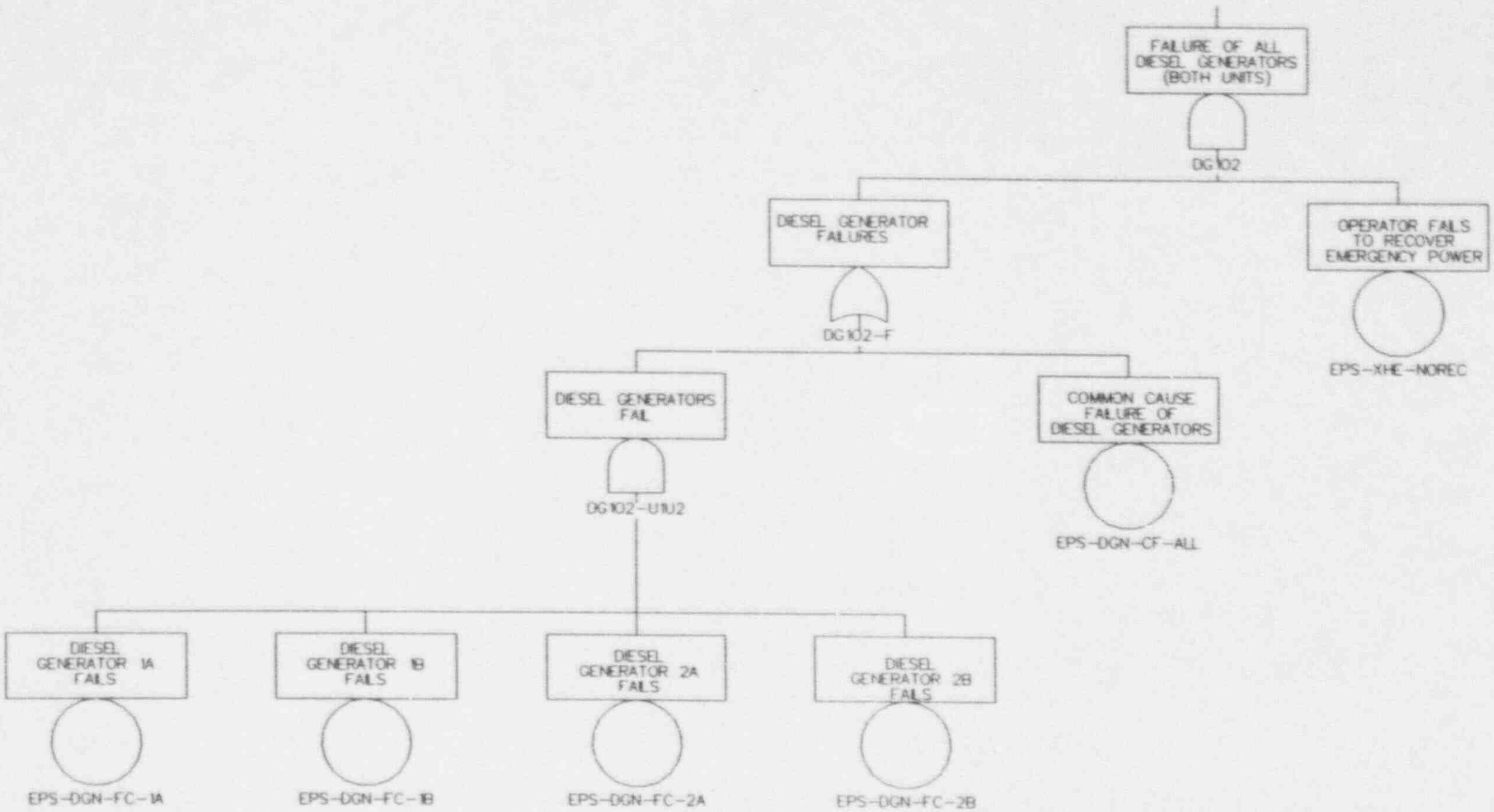
Transfer Tree for no Spent Fuel Pool Cooling
SFP Cooling System and Alternate Cooling not available

A.6 Fault Trees

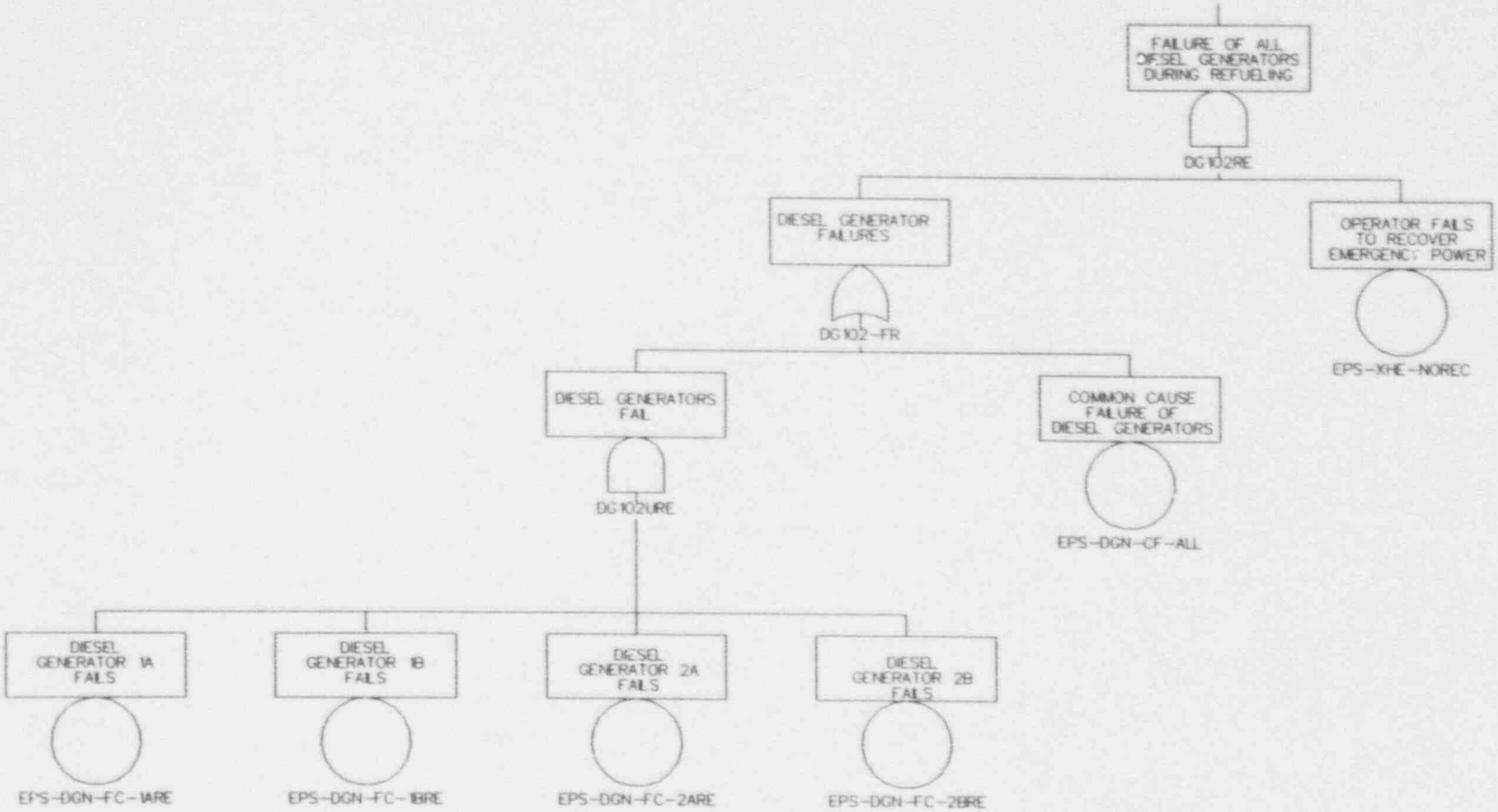
This section presents the non-trivial (i.e., more than one basic event) fault trees. For many of these trees, e.g., for treating the unavailability of the SFPC system and the RHR system(s), the models supporting Ref. A.2 have been used as a starting point. These trees have been modified using a modeling approach similar in spirit to that used in developing Accident Sequence Precursor (ASP) models (see for example Ref. A.5). Using this approach, components on a single pipe segment are generally grouped into super-components. In the case of makeup and alternate cooling top events, entire trains or systems of equipment are treated with a single super-component. Also, a number of low probability failure modes (e.g., normally closed manual valves transferring open during the scenario) are omitted. This simplified approach is judged to be adequate for treating spent fuel pool scenarios whose risk, as shown in Ref. A.2, tends to be dominated by human error contributions.



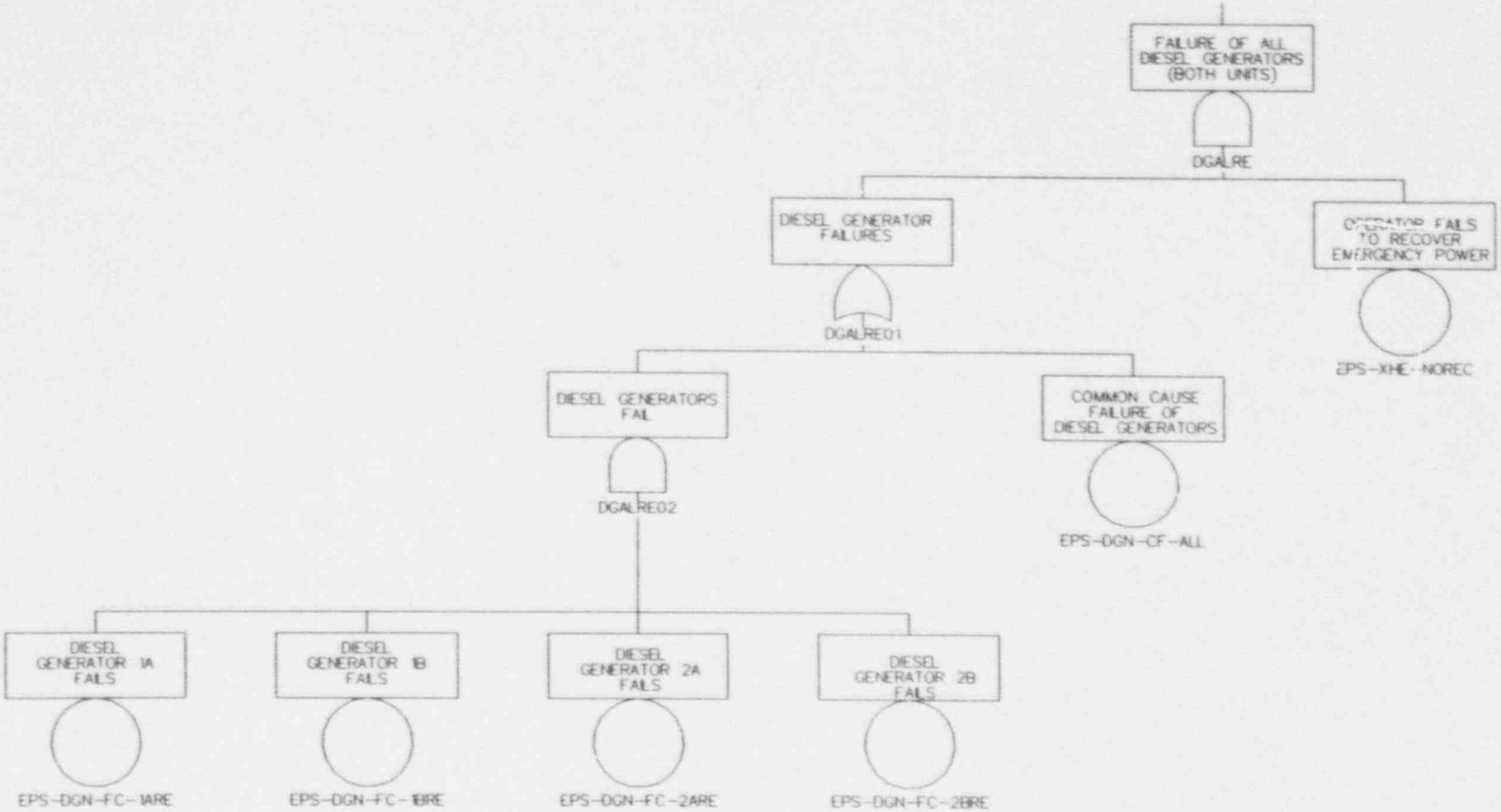
FAILURE OF UNIT 1 AND 2 DIESEL GENERATORS
ALL DIESEL GENERATORS AVAILABLE FOR SUCCESS



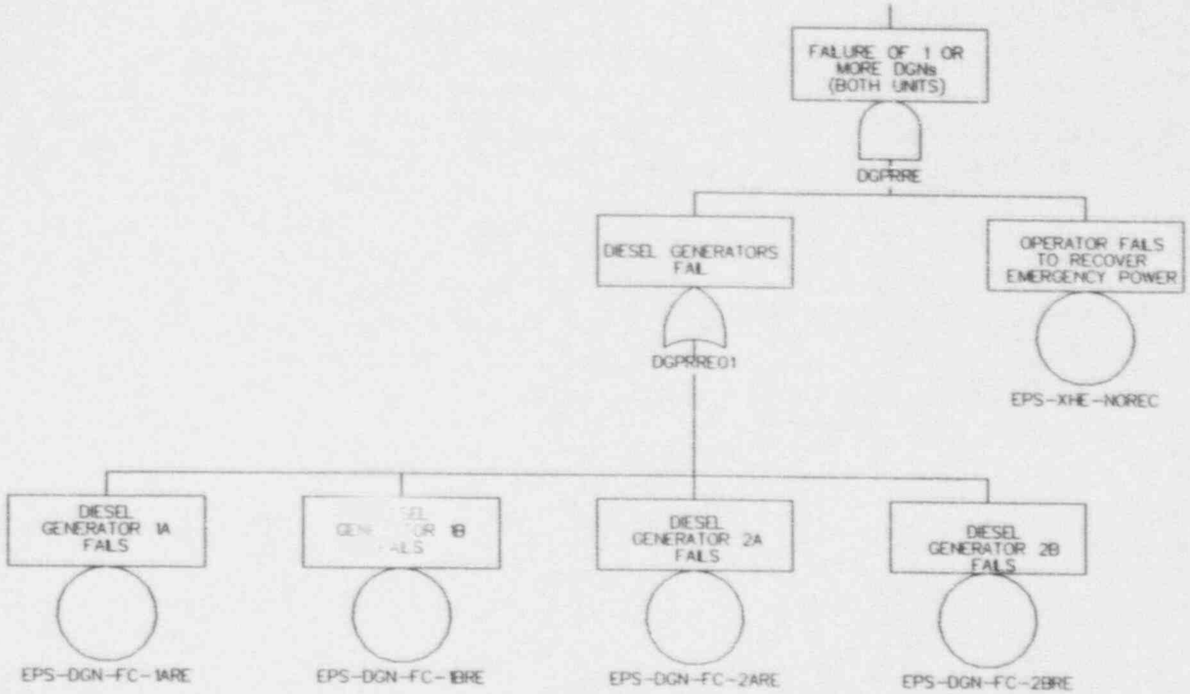
FAILURE OF UNIT 1 AND 2 DIESEL GENERATORS
PARTIAL DIESEL GENERATORS AVAILABLE FOR SUCCESS



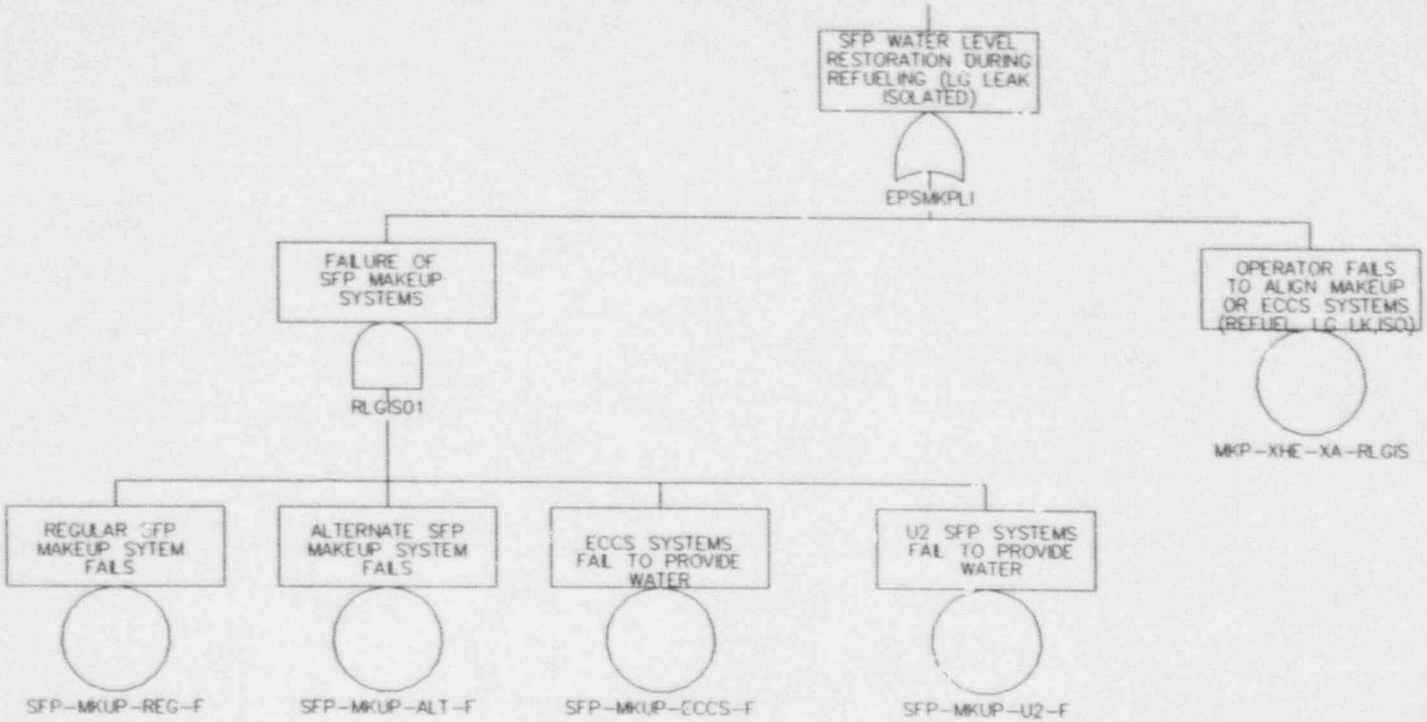
FAILURE OF UNIT 1 AND 2 DIESEL GENERATORS
PARTIAL DIESEL GENERATORS AVAILABLE FOR SUCCESS
ONE UNIT IN REFUELING



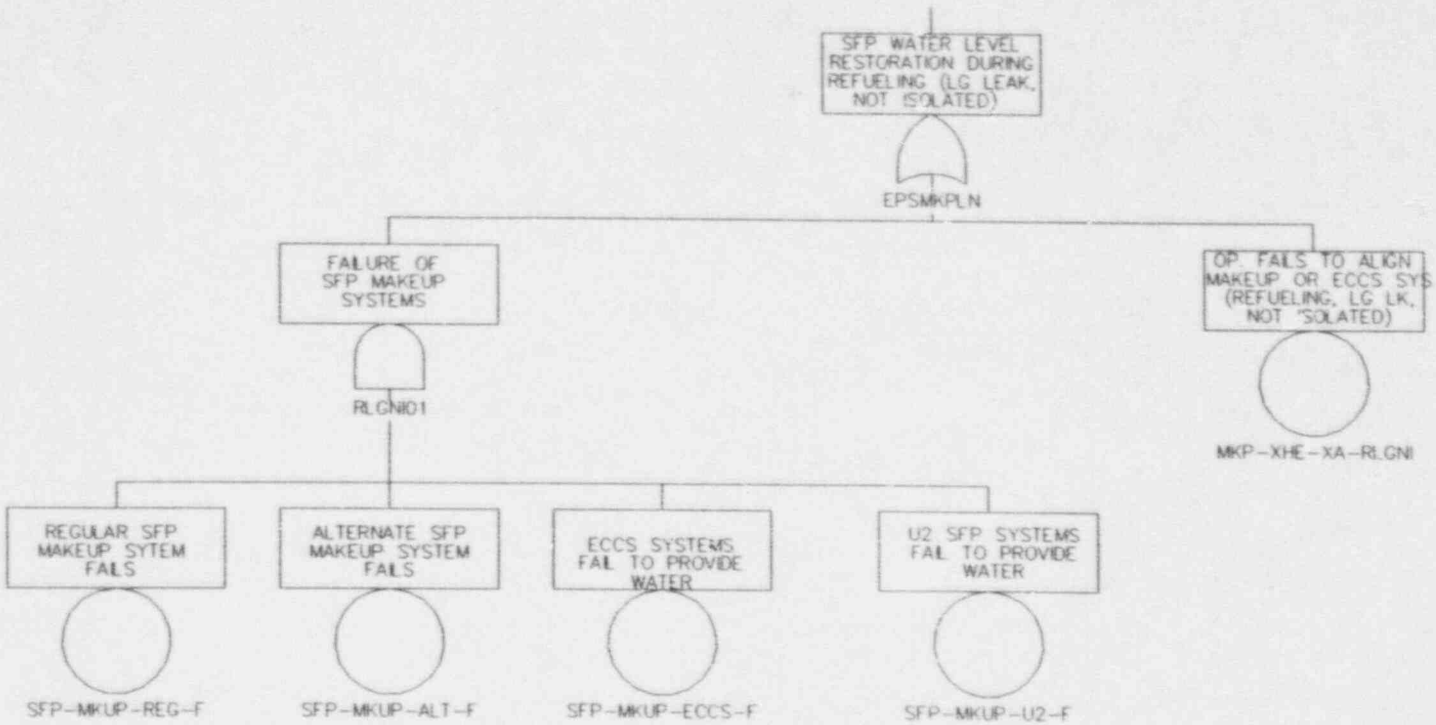
FAILURE OF UNIT 1 AND 2 DIESEL GENERATORS
PARTIAL DIESEL GENERATORS AVAILABLE FOR SUCCESS
ONE UNIT IN REFUELING



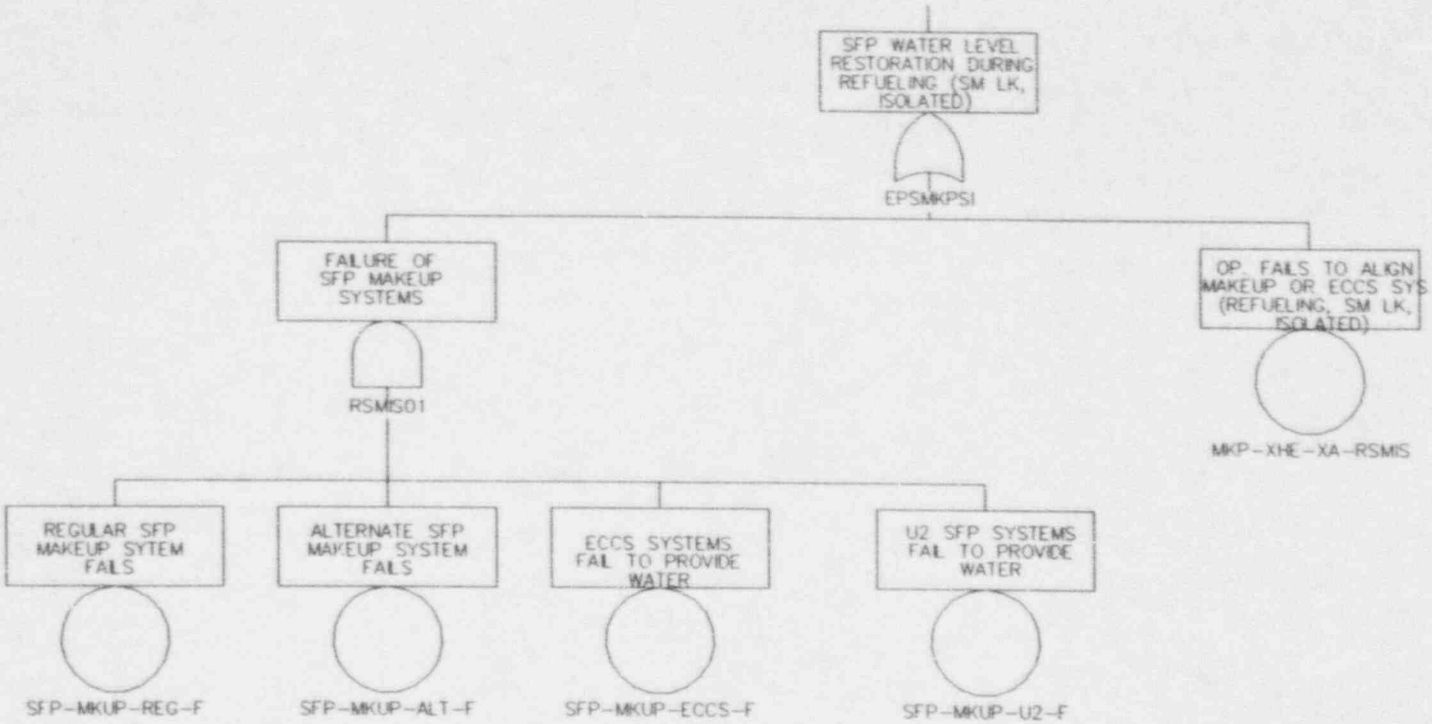
FAILURE OF UNIT 1 AND 2 DIESEL GENERATORS
ALL DIESEL GENERATORS AVAILABLE FOR SUCCESS
ONE UNIT IN REFUELING



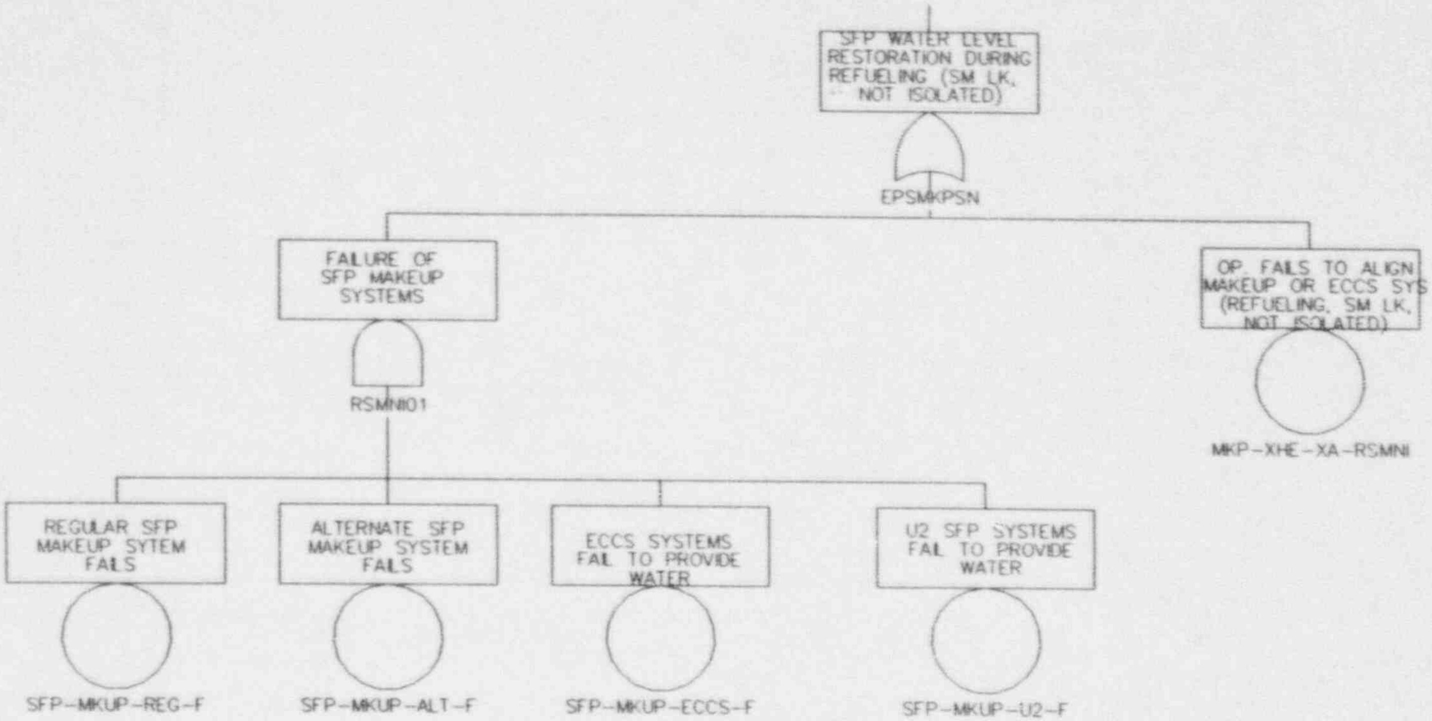
SPENT FUEL POOL COOLING
WATER LEVEL RESTORATION
USING ECCS OR ESFP MAKEUP
ONE UNIT IS REFUELING
LARGE LEAK, ISOLATED



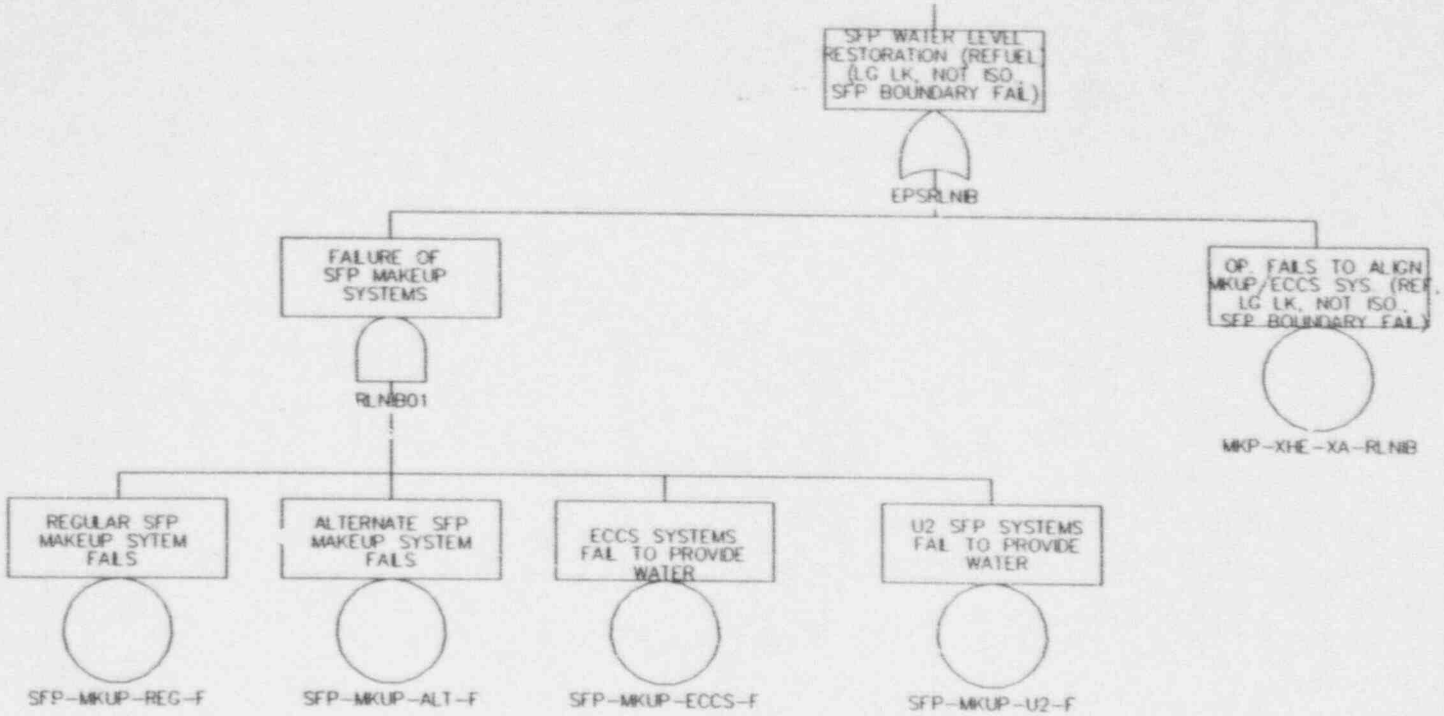
SPENT FUEL POOL COOLING
WATER LEVEL RESTORATION
USING ECCS OR ESFP MAKEUP
ONE UNIT IS REFUELING
LARGE LEAK, NOT ISOLATED



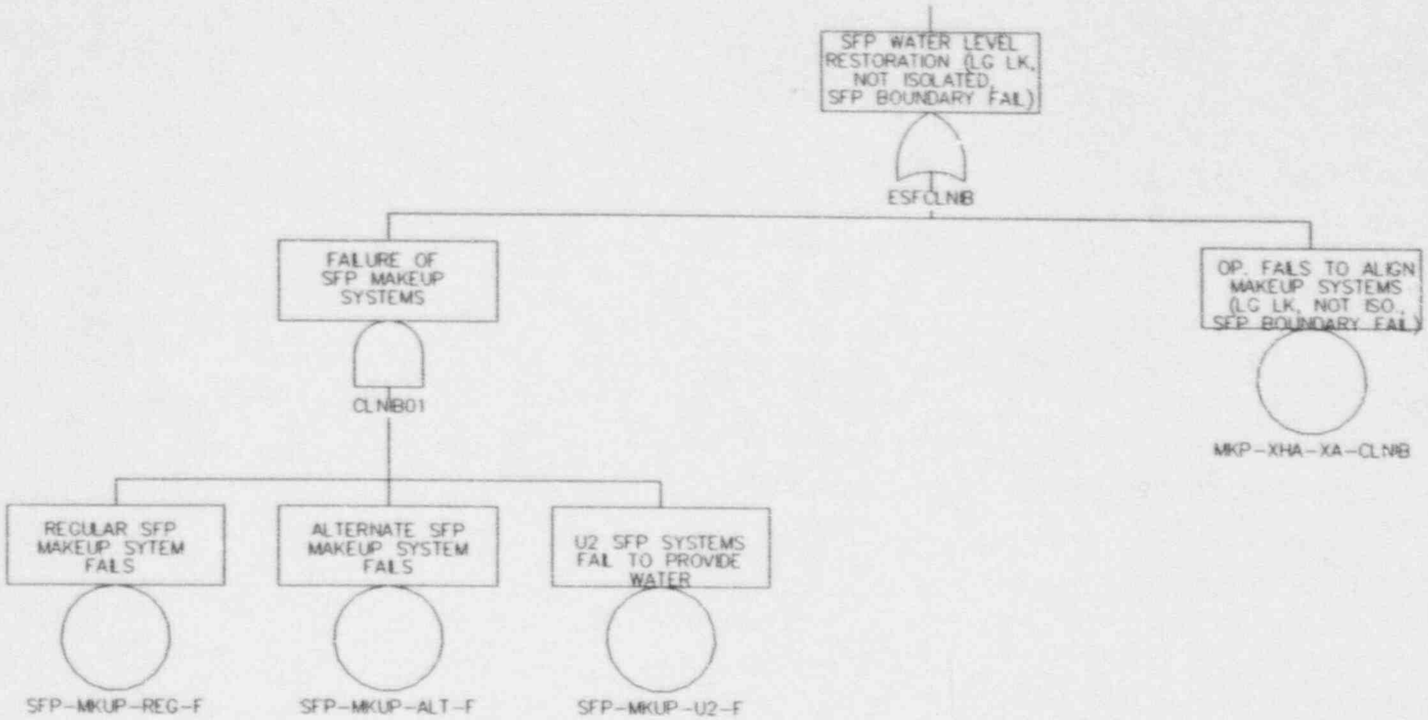
SPENT FUEL POOL COOLING
WATER LEVEL RESTORATION
USING ECCS OR ESFP MAKEUP
ONE UNIT IS REFUELING
SMALL LEAK, ISOLATED



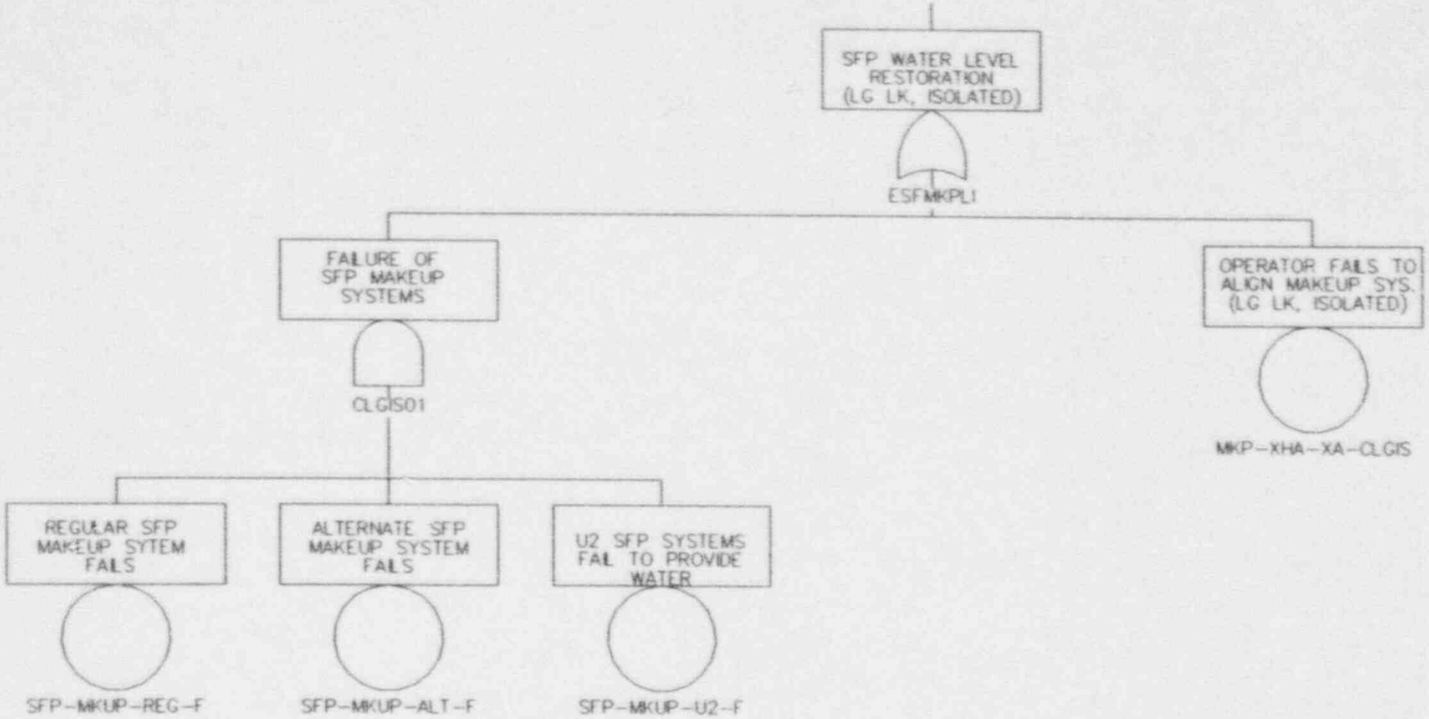
SPENT FUEL POOL COOLING
WATER LEVEL RESTORATION
USING ECCS OR ESFP MAKEUP
ONE UNIT IS REFUELING
SMALL LEAK, NOT ISOLATED



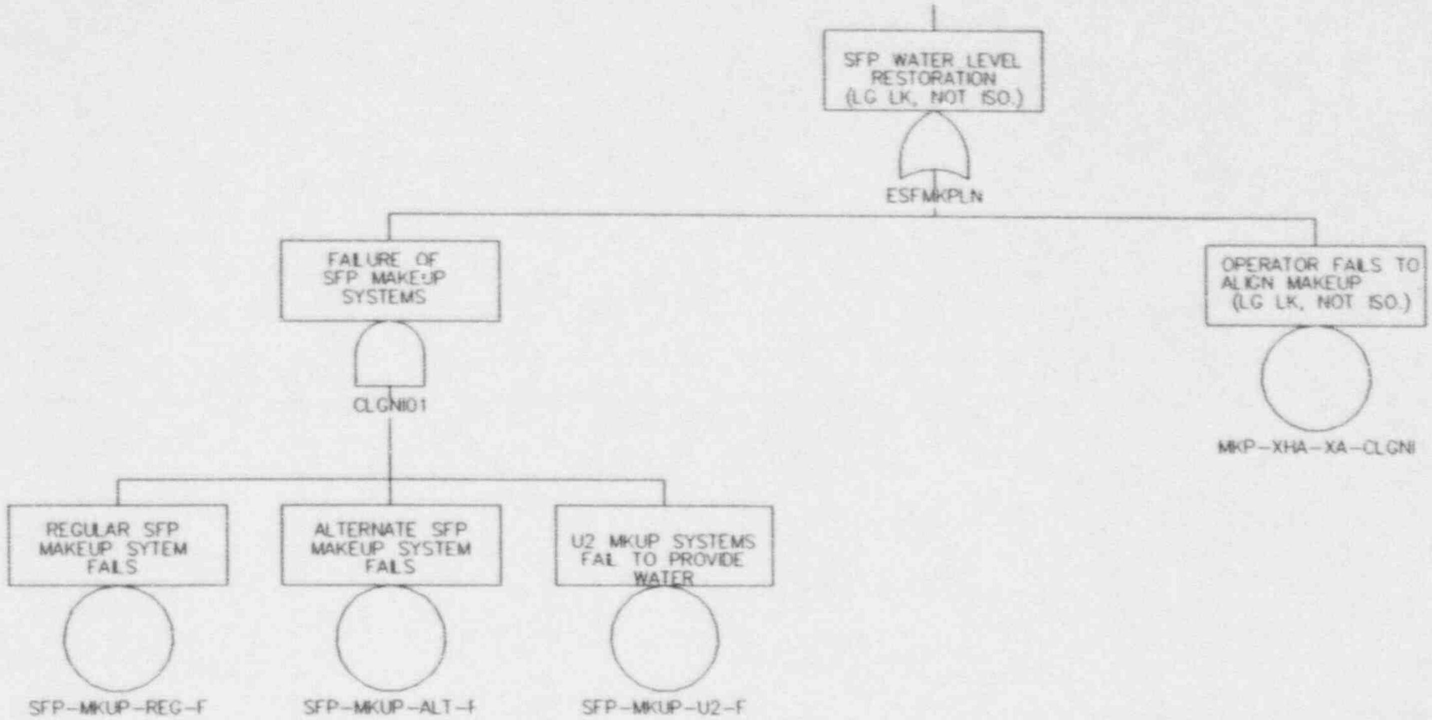
SPENT FUEL POOL COOLING
WATER LEVEL RESTORATION
USING ECCS OR ESFP MAKEUP
ONE UNIT IS REFUELING
SFP BOUNDARY FAILURE
LARGE LEAK, NOT ISOLATED



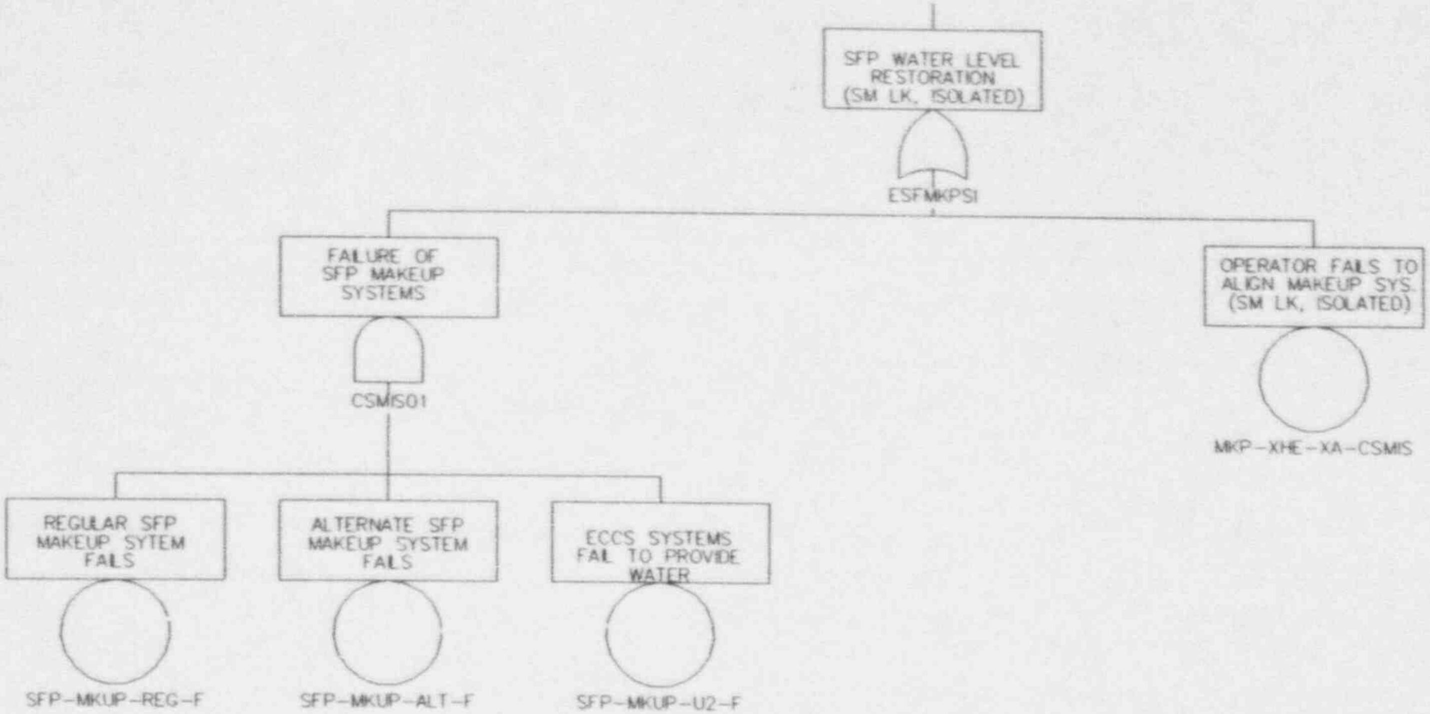
SPENT FUEL POOL COOLING
WATER LEVEL RESTORATION
ESFP MAKEUP
LARGE LEAK, NOT ISOLATED
SFP BOUNDARY FAILURE



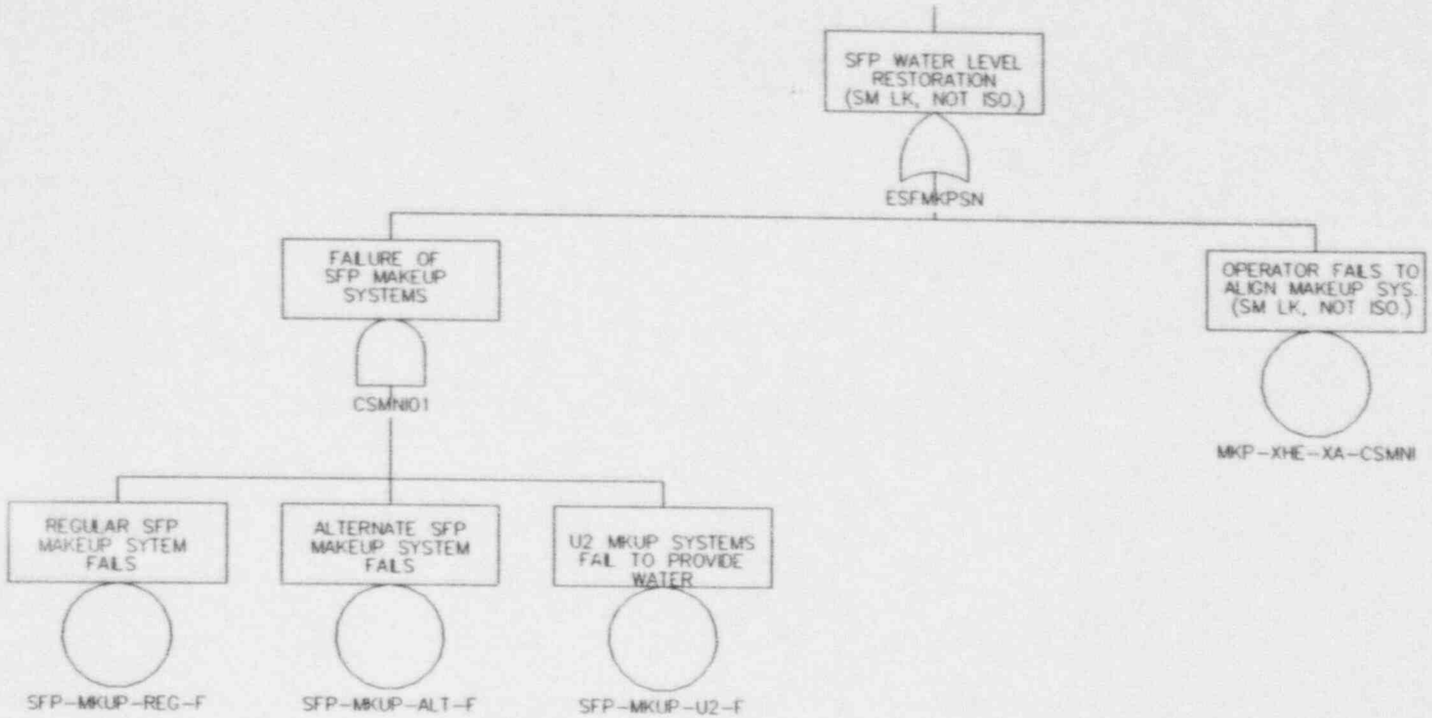
SPENT FUEL POOL COOLING
WATER LEVEL RESTORATION
USING ESFP MAKEUP
LARGE LEAK, ISOLATED



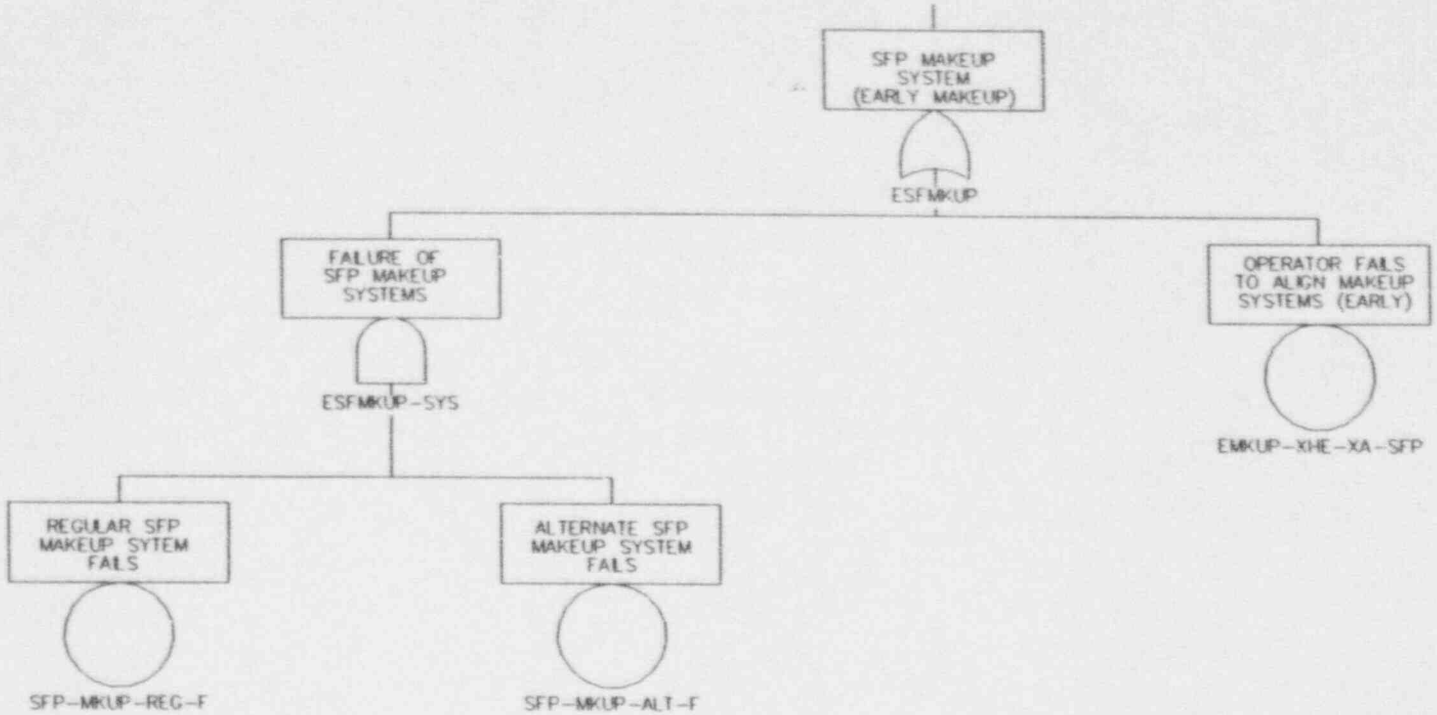
SPENT FUEL POOL COOLING
WATER LEVEL RESTORATION
USING ESFP MAKEUP
LARGE LEAK, NOT ISOLATED



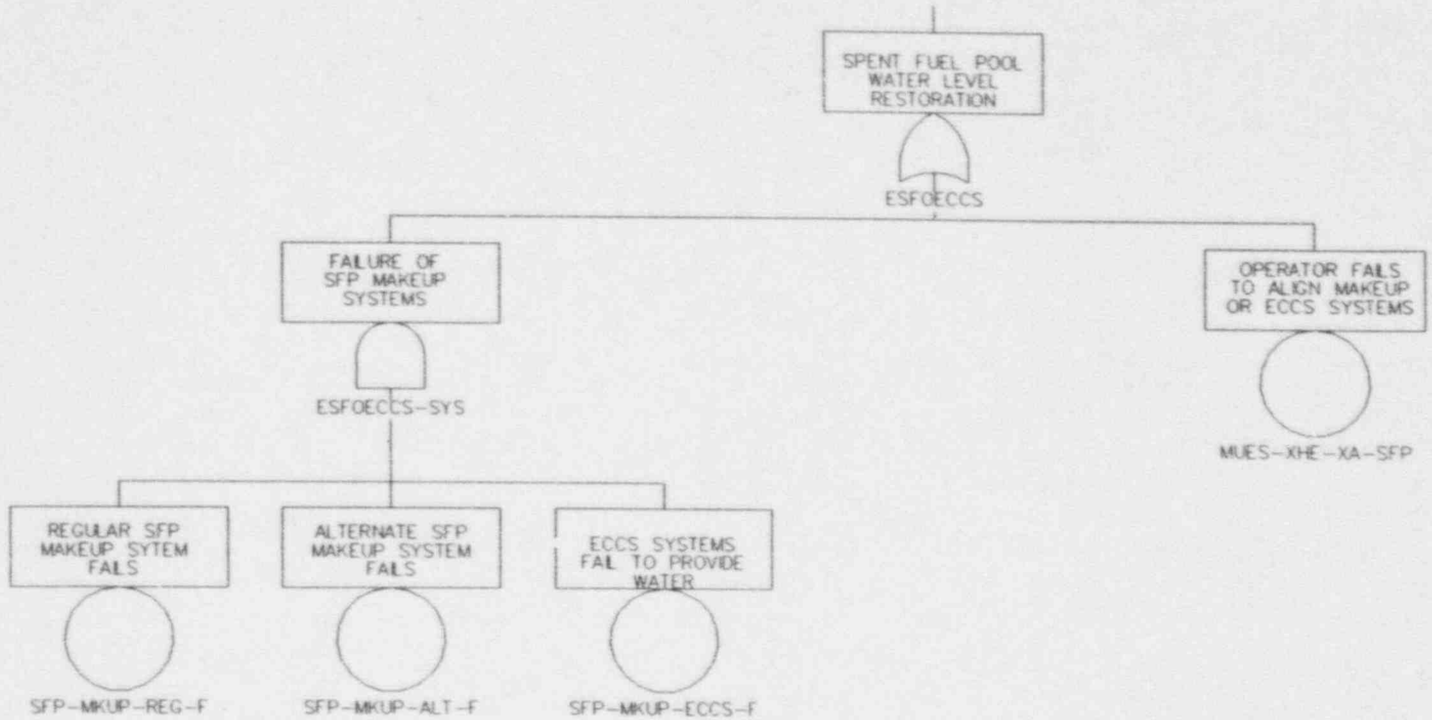
SPENT FUEL POOL COOLING
WATER LEVEL RESTORATION
USING ESFP MAKEUP
SMALL LEAK, ISOLATED



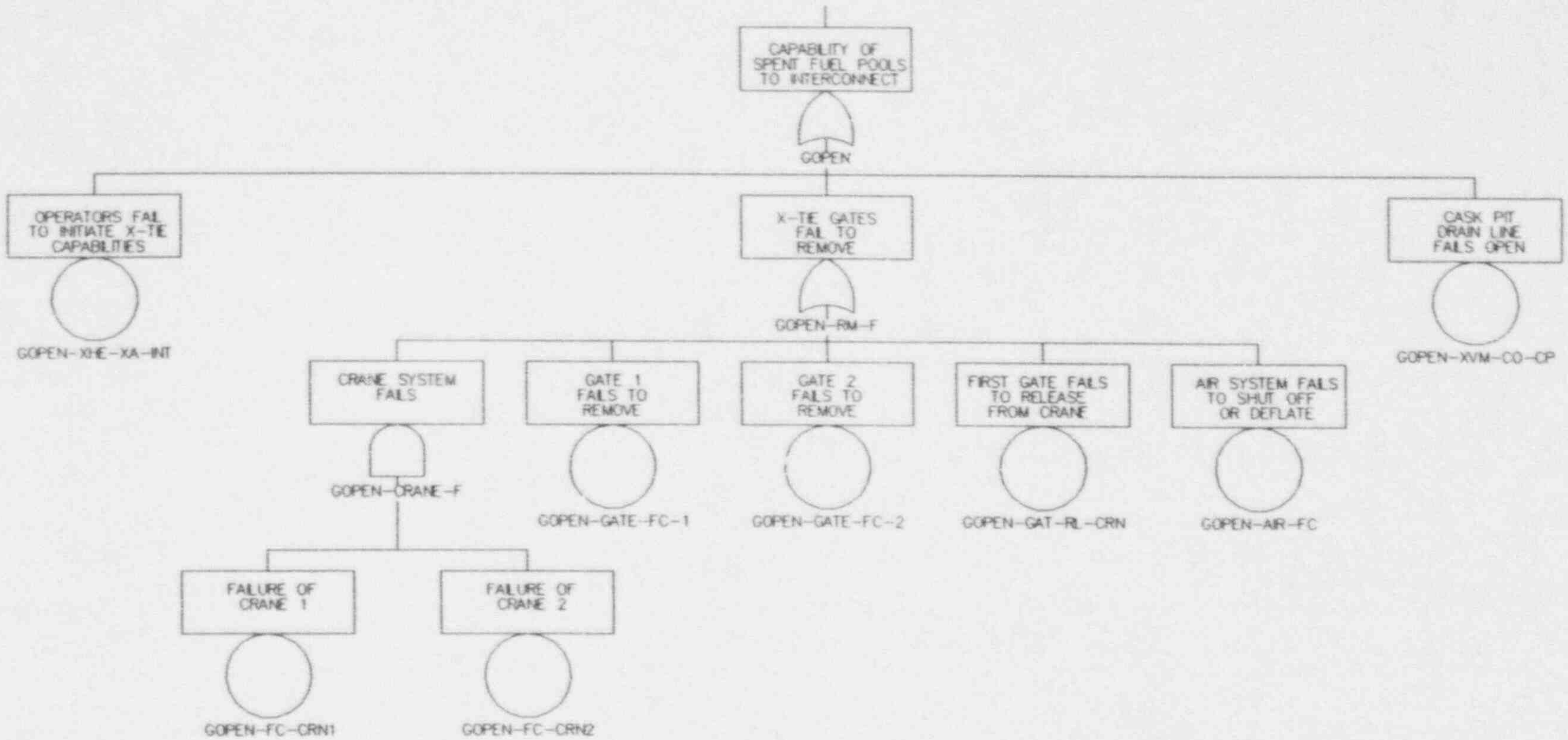
SPENT FUEL POOL COOLING
WATER LEVEL RESTORATION
USING ESFP MAKEUP
SMALL LEAK, NOT ISOLATED



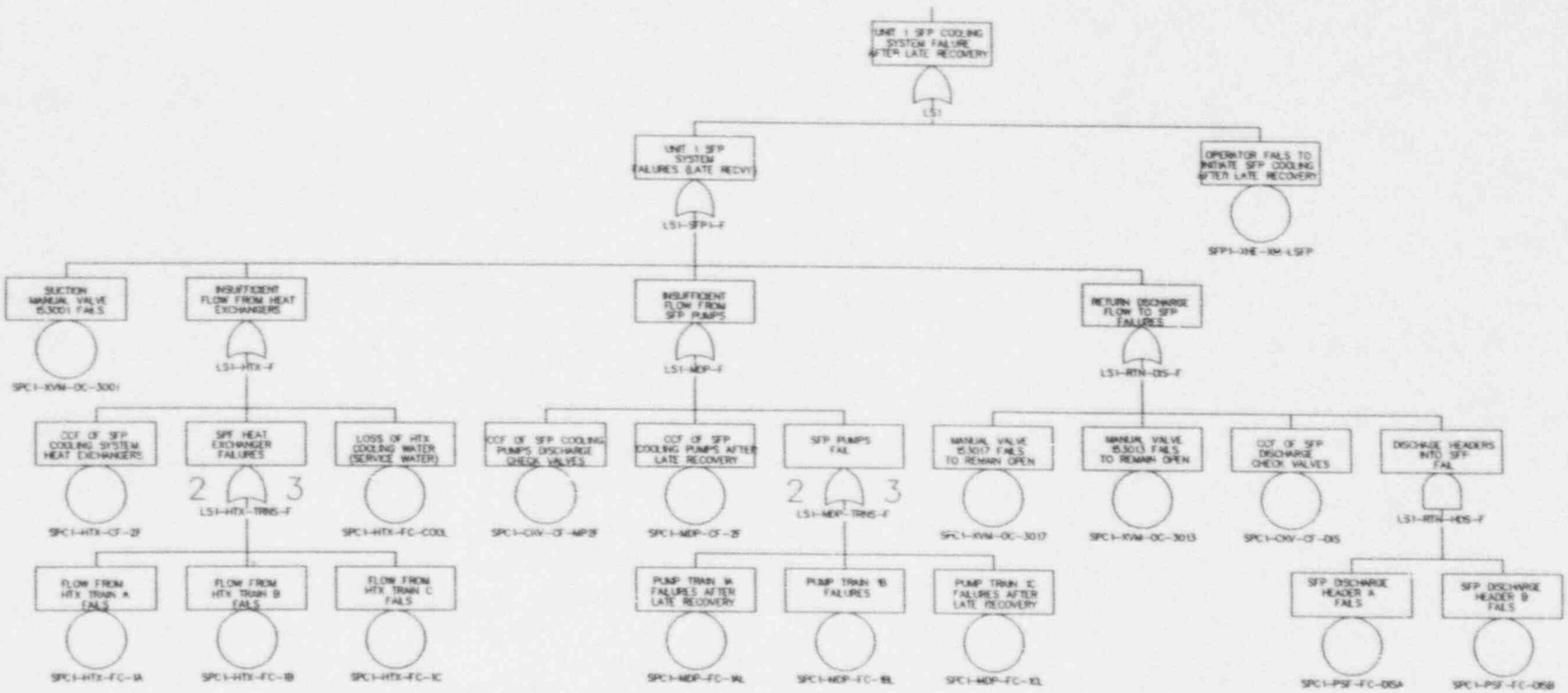
SPENT FUEL POOL COOLING PROVIDED
BY REGULAR OR ALTERNATE MAKEUP SYSTEMS
(EARLY MAKEUP)



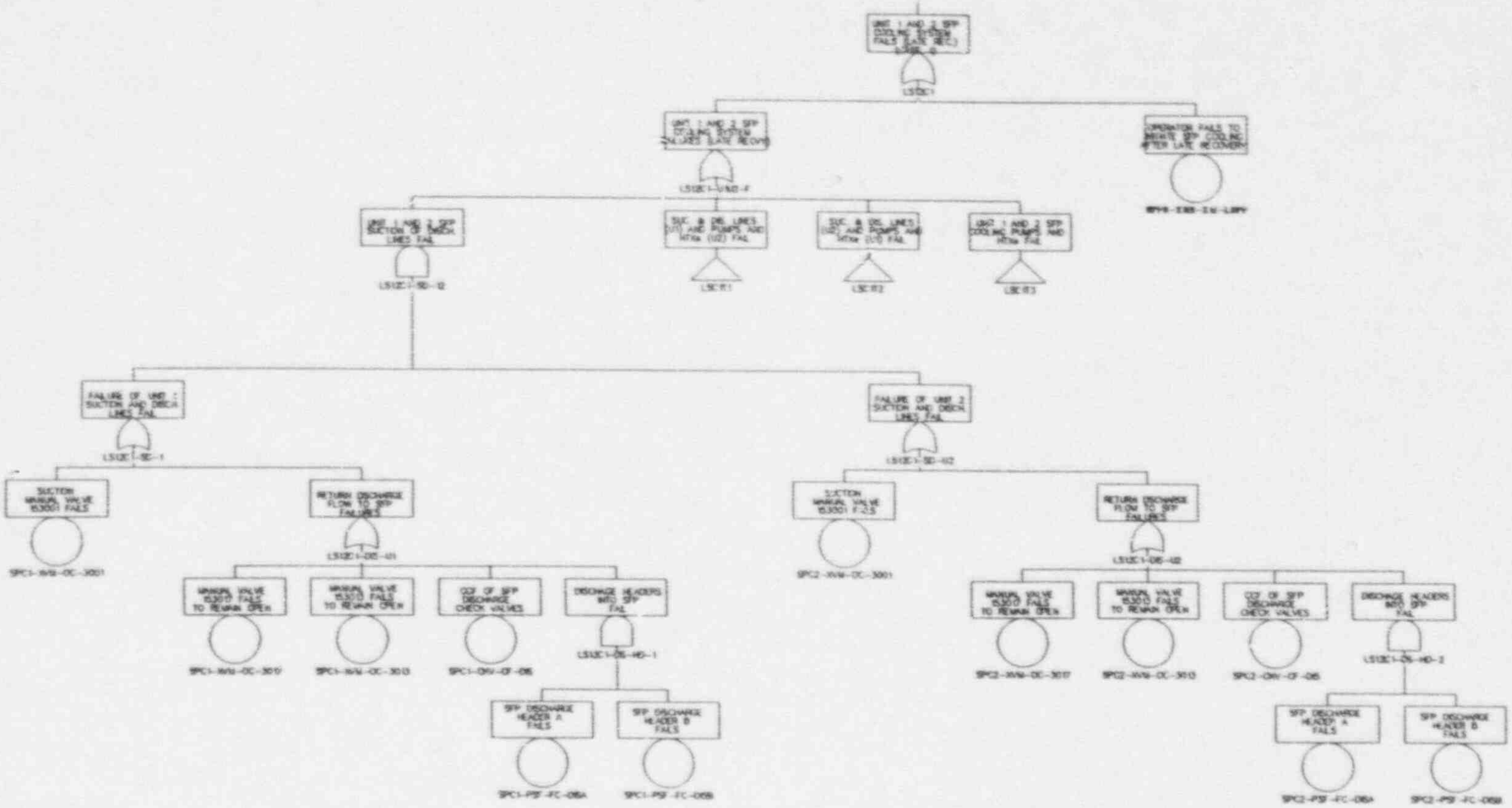
SPENT FUEL POOL COOLING
WATER LEVEL RESTORATION
USING ECCS OR ESFP MAKEUP



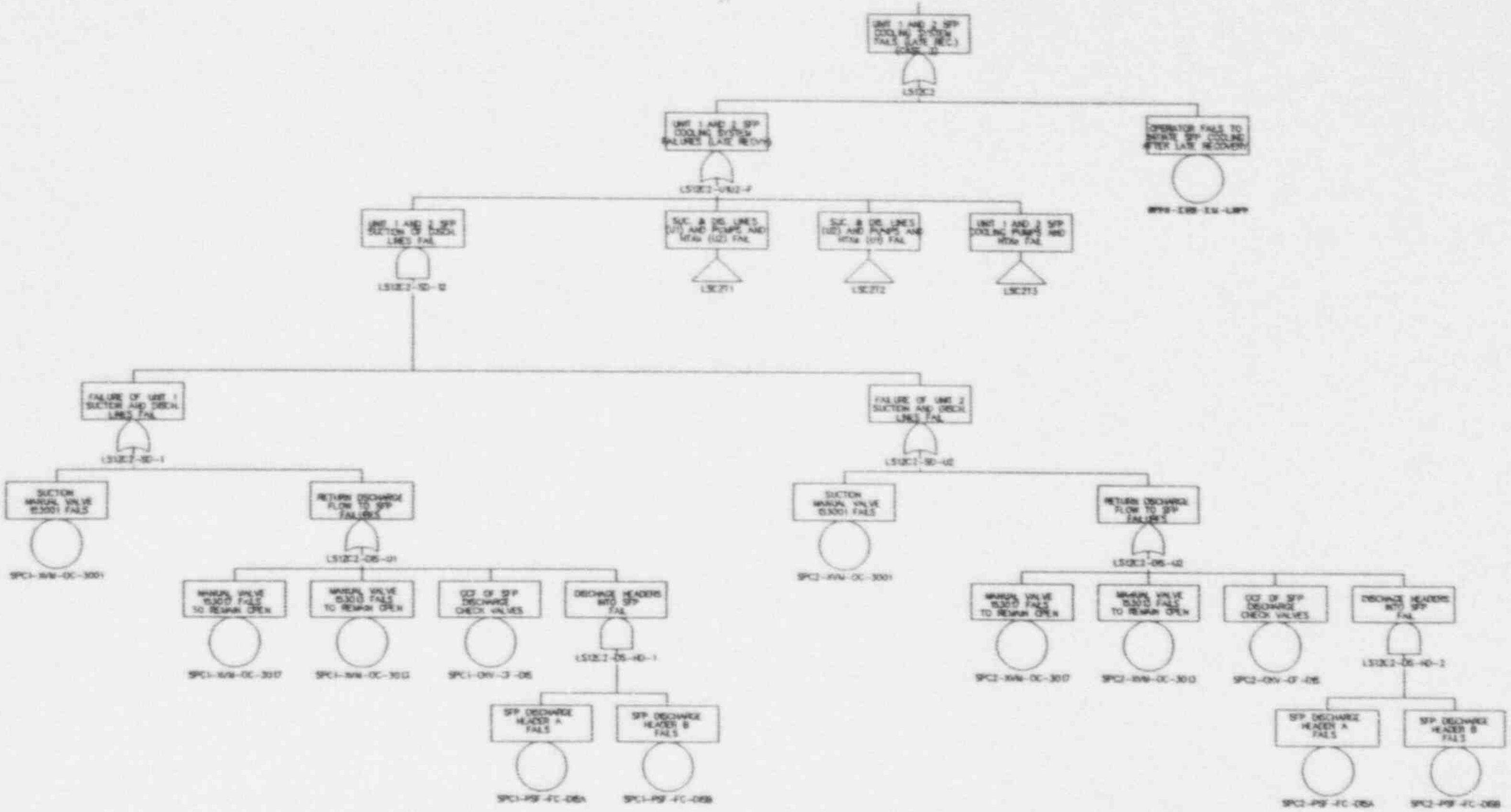
CAPABILITY OF SPENT FUEL POOLS
TO INTERCONNECT



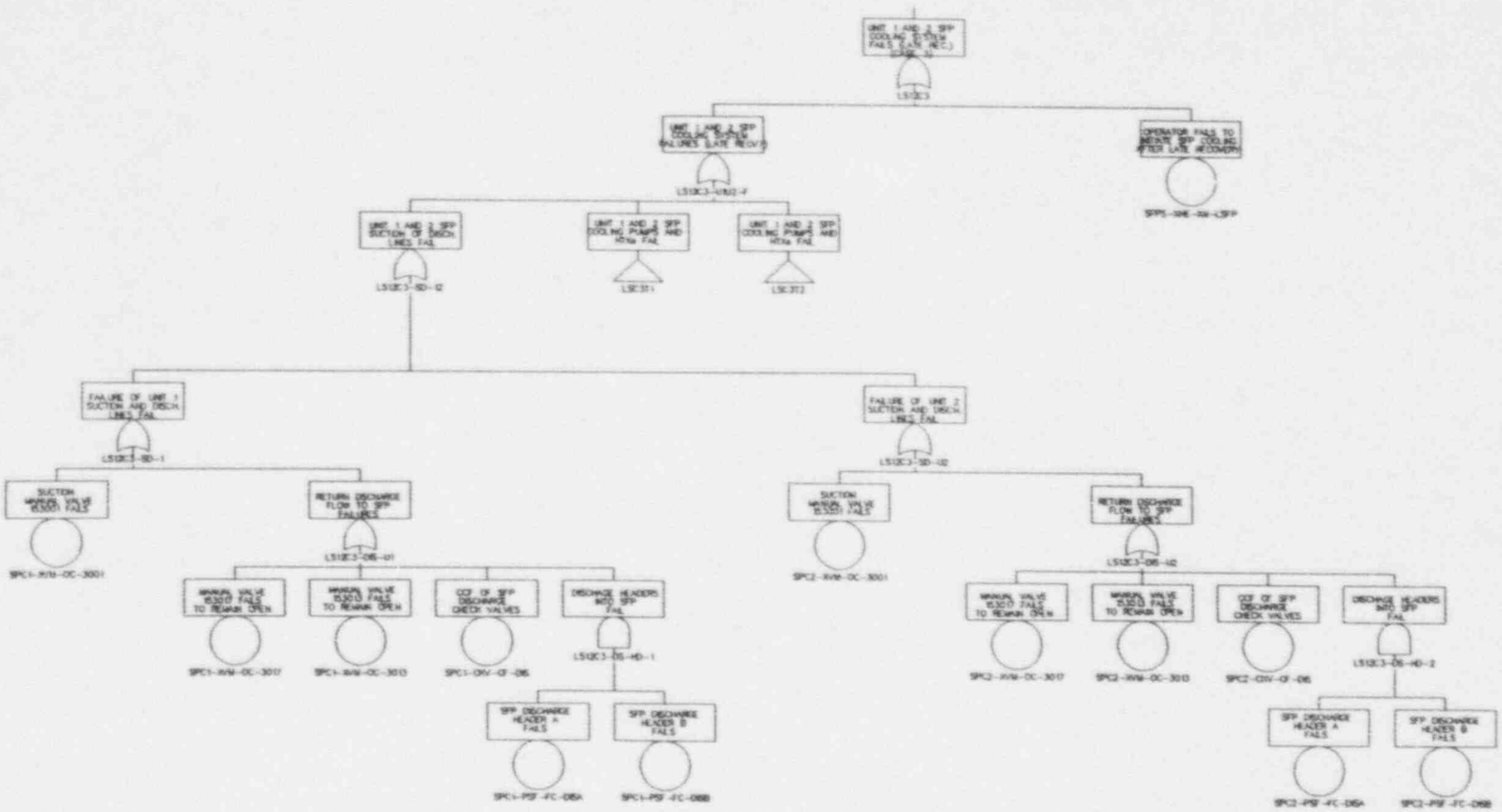
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 1)
LATE RECOVERY
2-OUT-OF-3 COOLING PUMPS AND
2-OUT-OF-3 HEAT EXCHANGERS FOR SUCCESS



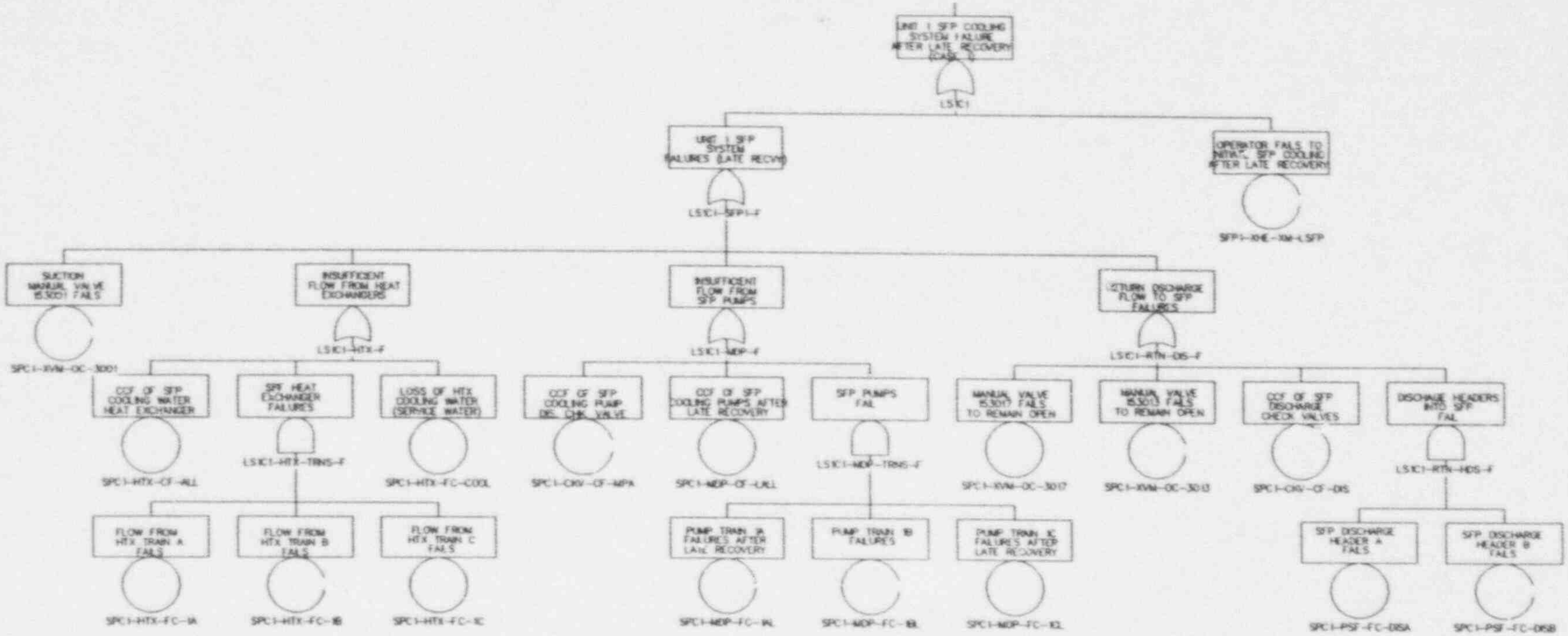
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNITS 1 & 2)
LATE RECOVERY - CASE 1
2-OUT-OF-6 COOLING PUMPS FOR SUCCESS



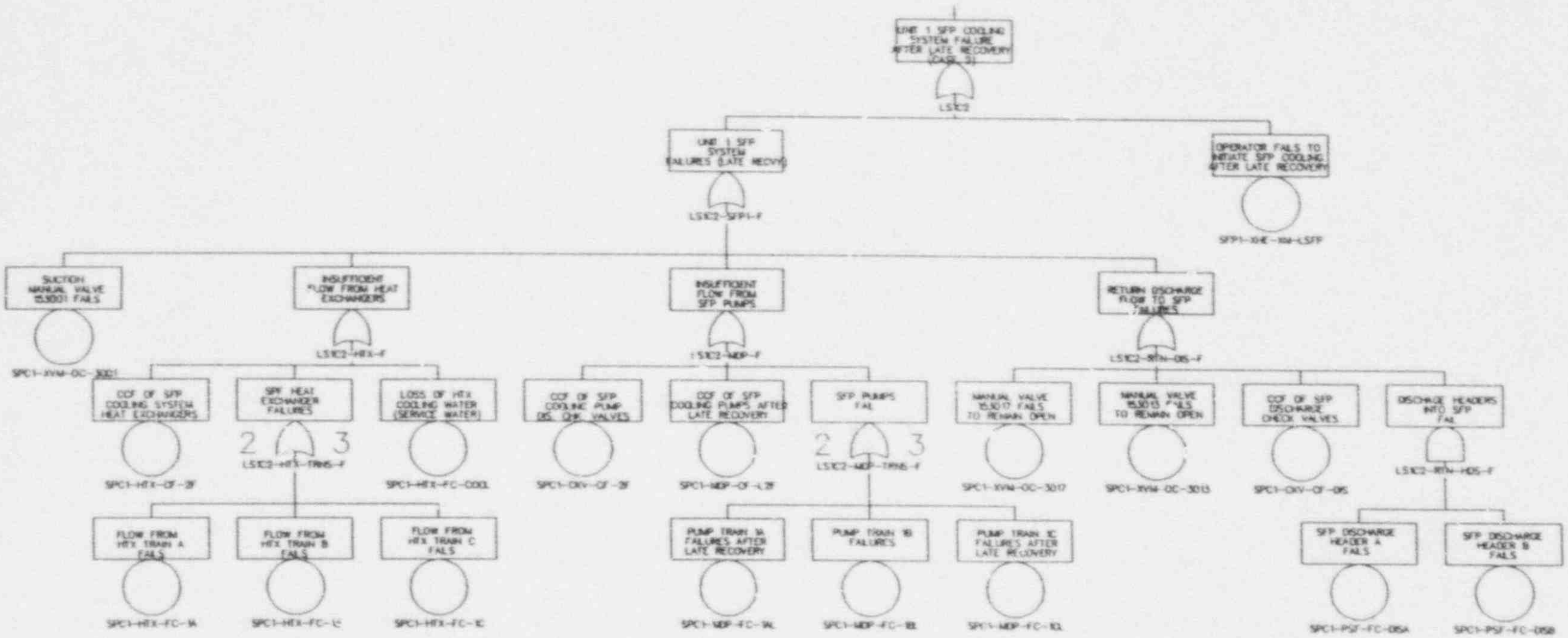
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNITS 1 & 2)
LATE RECOVERY – CASE 2
3-OUT-OF-6 COOLING PUMPS FOR SUCCESS



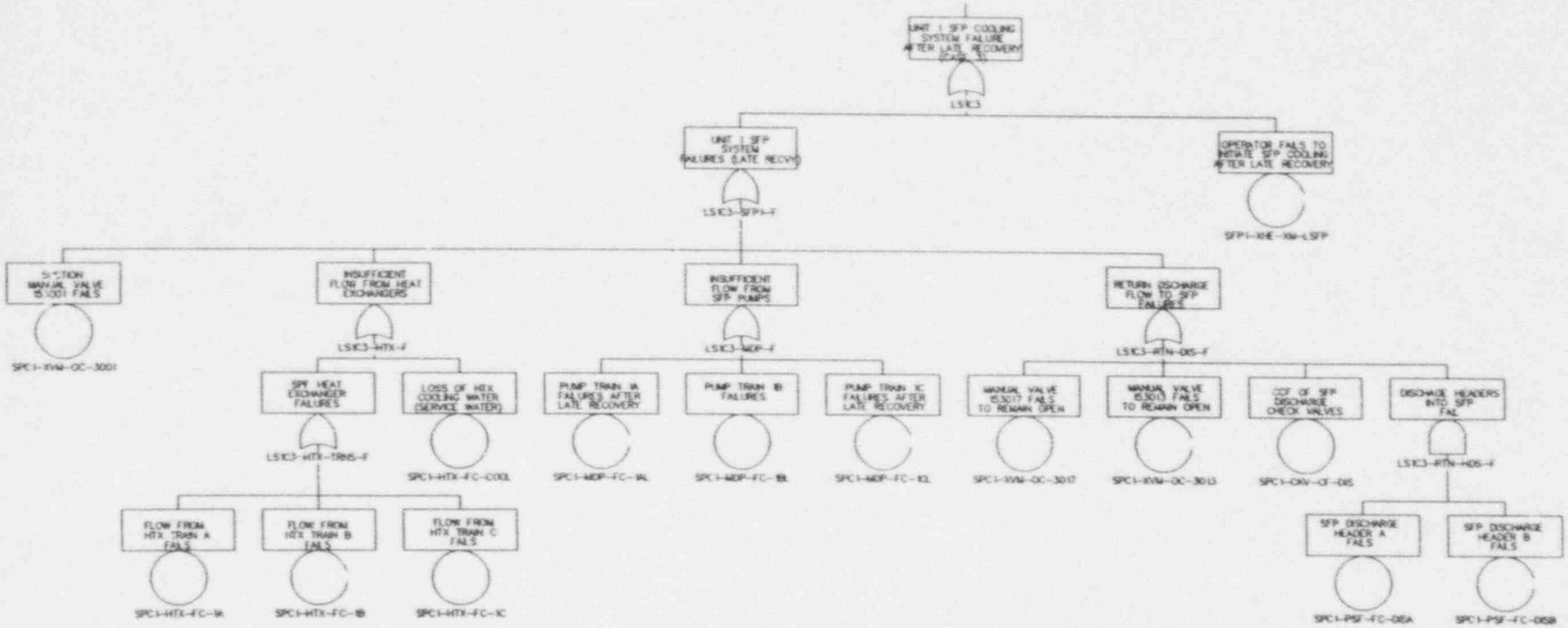
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNITS 1 & 2)
LATE RECOVERY - CASE 3
4-OUT-OF-6 COOLING PUMPS FOR SUCCESS



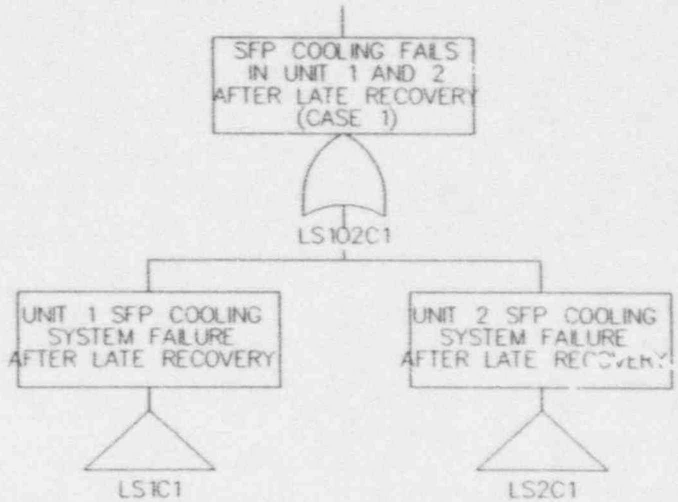
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 1)
LATE RECOVERY – CASE 1
1-OUT-OF-3 COOLING PUMPS AND
1-OUT-OF-3 HEAT EXCHANGERS FOR SUCCESS



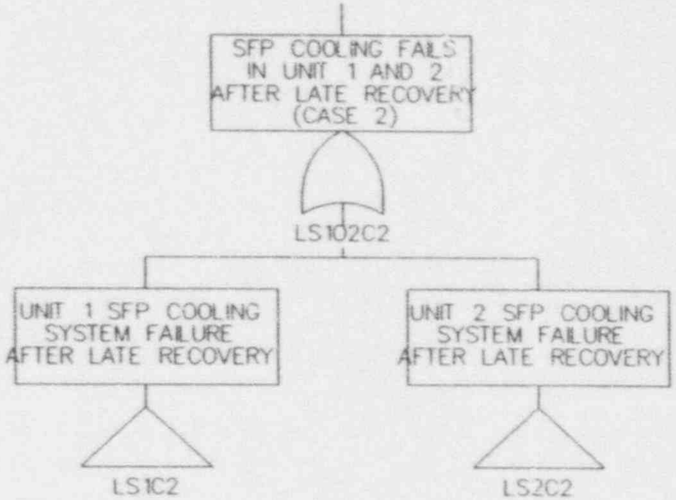
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 1)
LATE RECOVERY – CASE 2
2-OUT-OF-3 COOLING PUMPS AND
2-OUT-OF-3 HEAT EXCHANGERS FOR SUCCESS



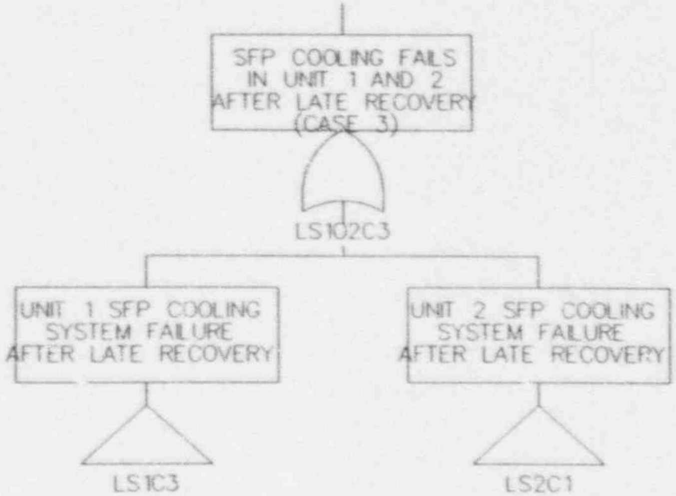
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 1)
LATE RECOVERY - CASE 3
3-OUT-OF-3 COOLING PUMPS AND
3-OUT-OF-3 HEAT EXCHANGERS FOR SUCCESS



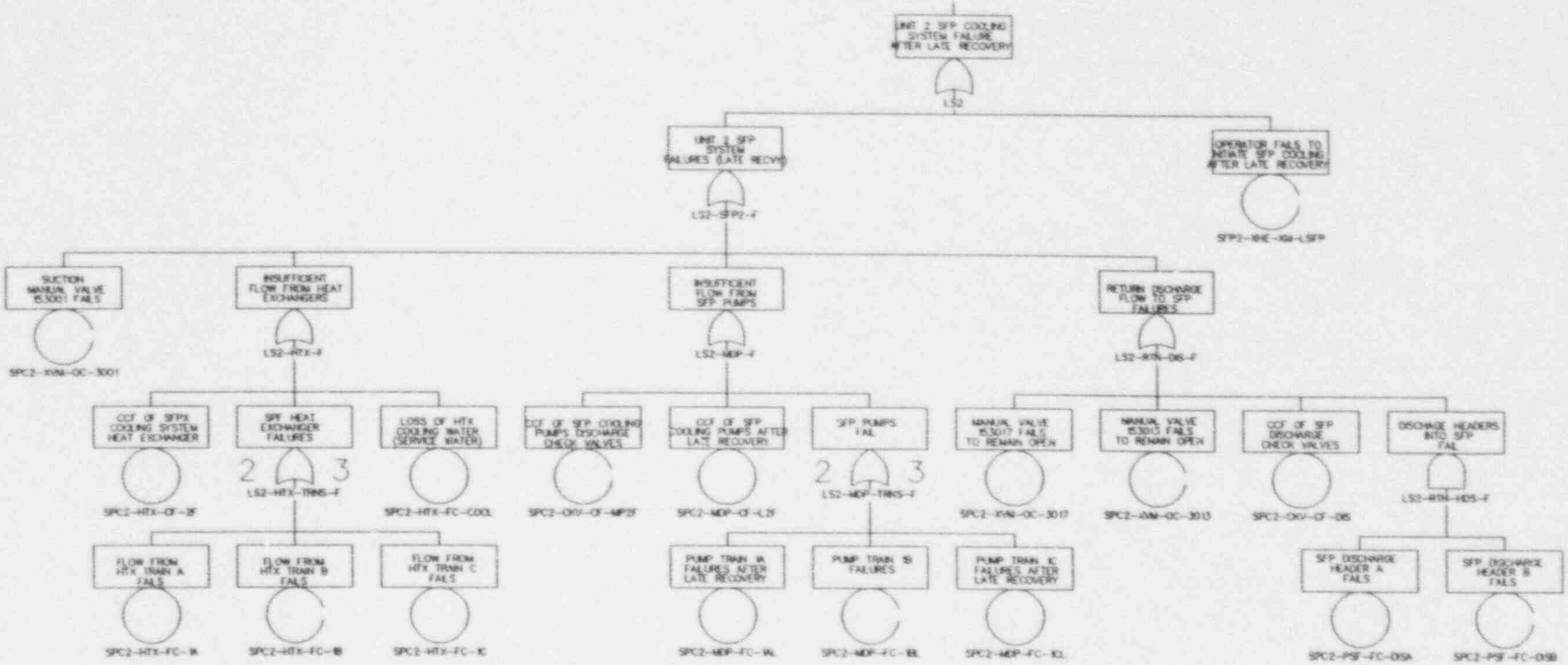
SPENT FUEL POOL COOLING SYSTEMS
FOR UNITS 1 AND 2 (LATE RECOVERY)
SUCCESS REQUIRES 1-OF-3 SFP COOLING TRAINS
FROM BOTH UNIT 1 AND UNIT 2



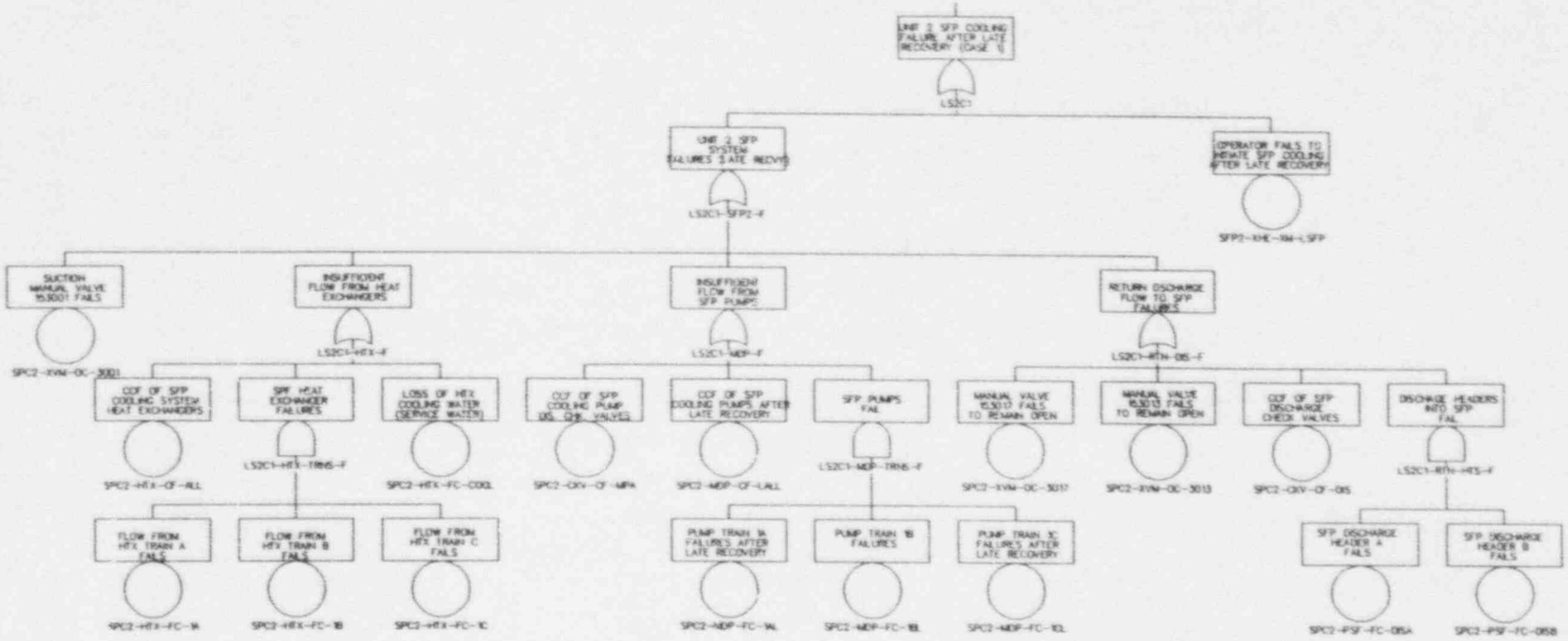
SPENT FUEL POOL COOLING SYSTEMS
FOR UNITS 1 AND 2 (LATE RECOVERY)
SUCCESS REQUIRES 2-OF-3 SFP COOLING
TRAINS FROM BOTH UNIT 1 AND UNIT 2



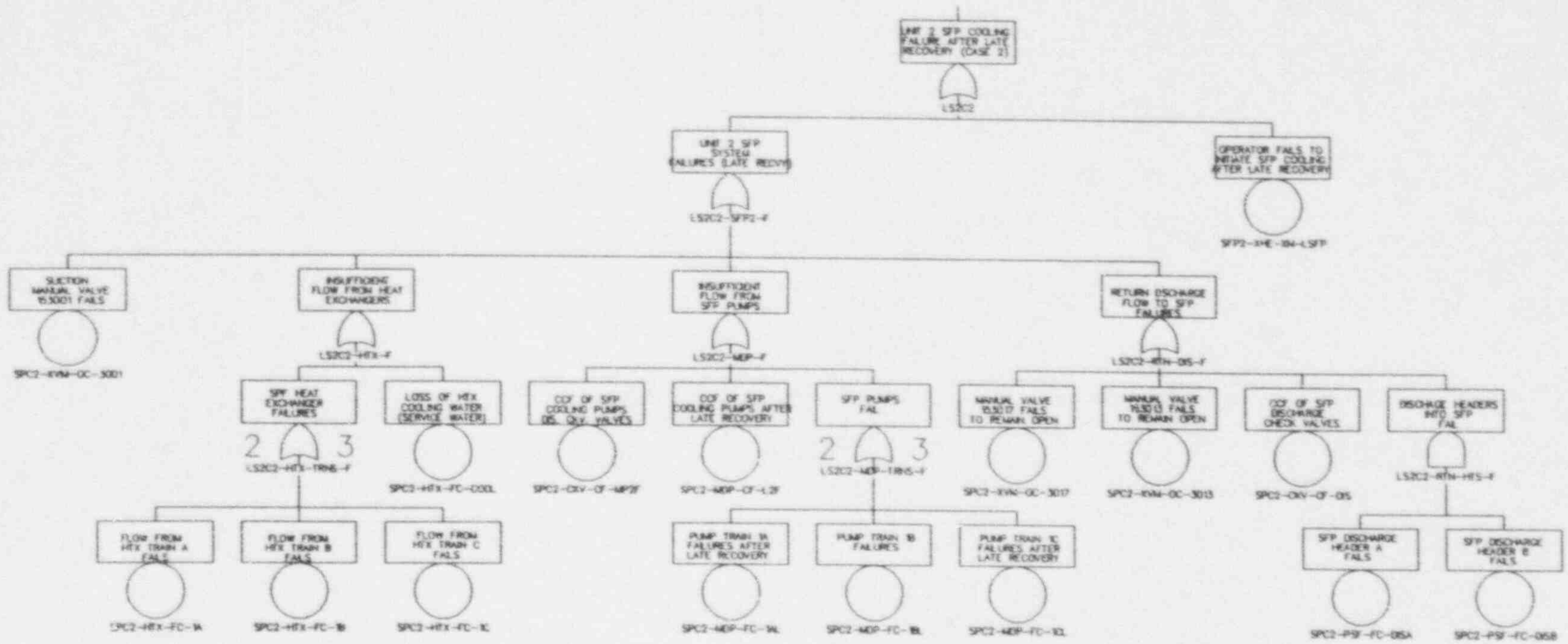
SPENT FUEL POOL COOLING SYSTEMS
FOR UNITS 1 AND 2 (LATE RECOVERY)
SUCCESS REQUIRES 3-OF-3 SFP COOLING TRAINS FROM UNIT 1
AND 1-OF-3 SFP COOLING TRAINS FROM UNIT 2



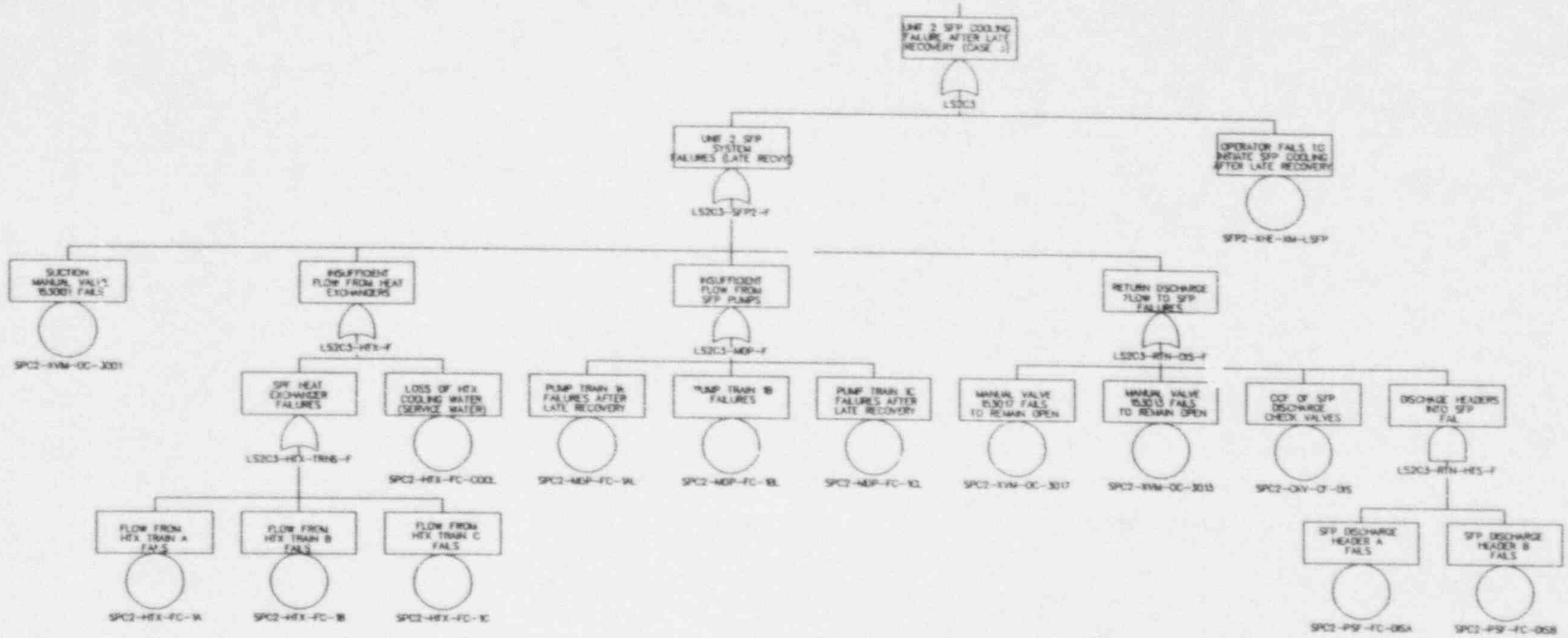
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 2)
LATE RECOVERY
2-OUT-OF-3 COOLING PUMPS AND
2-OUT-OF-3 HEAT EXCHANGERS FOR SUCCESS



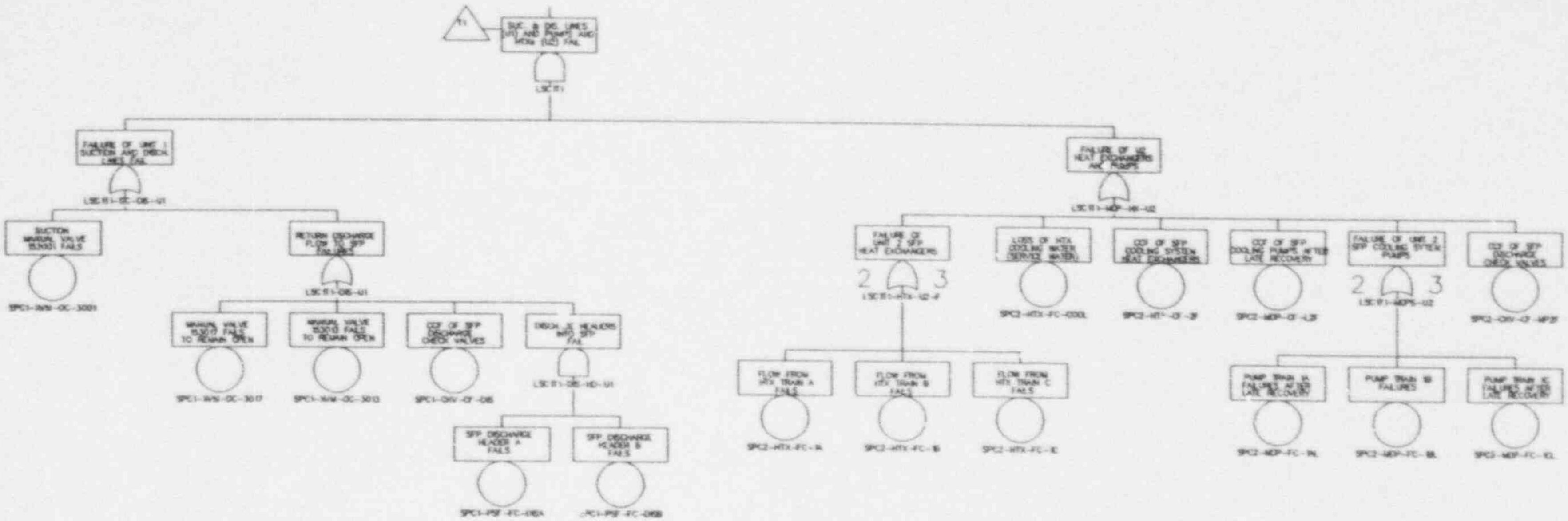
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 2)
LATE RECOVERY - CASE 1
1-OUT-OF-3 COOLING PUMPS AND
1-OUT-OF-3 HEAT EXCHANGERS FOR SUCCESS



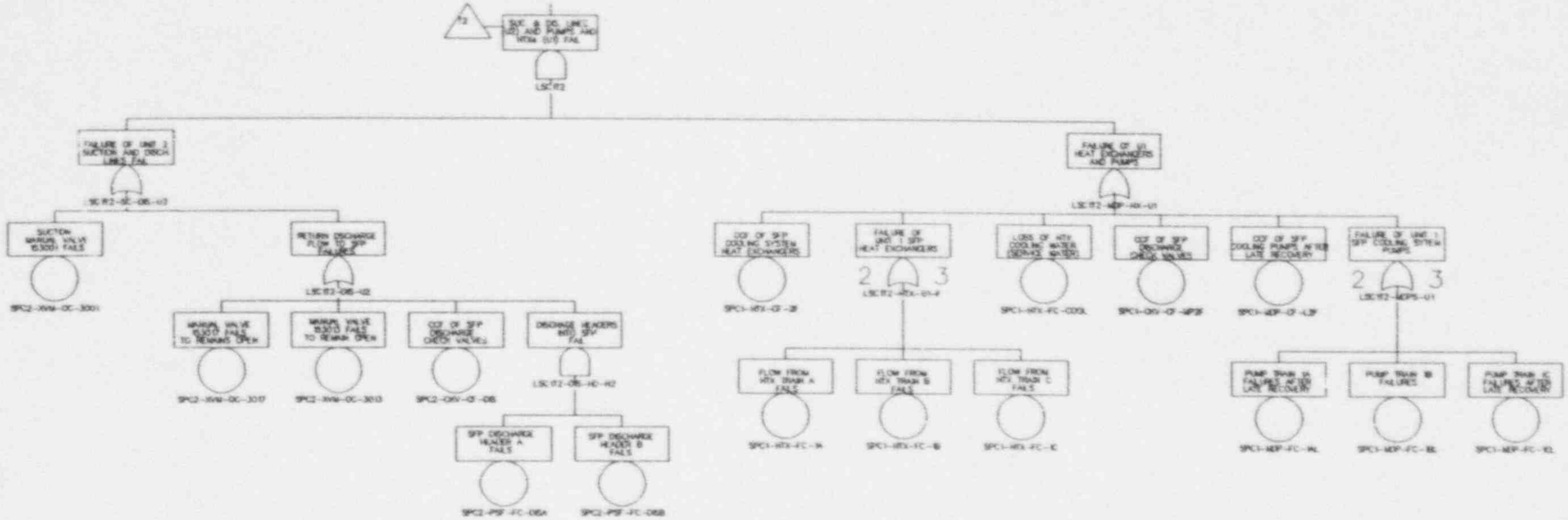
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 2)
LATE RECOVERY – CASE 2
2-OUT-OF-3 COOLING PUMPS AND
2-OUT-OF-3 HEAT EXCHANGERS FOR SUCCESS



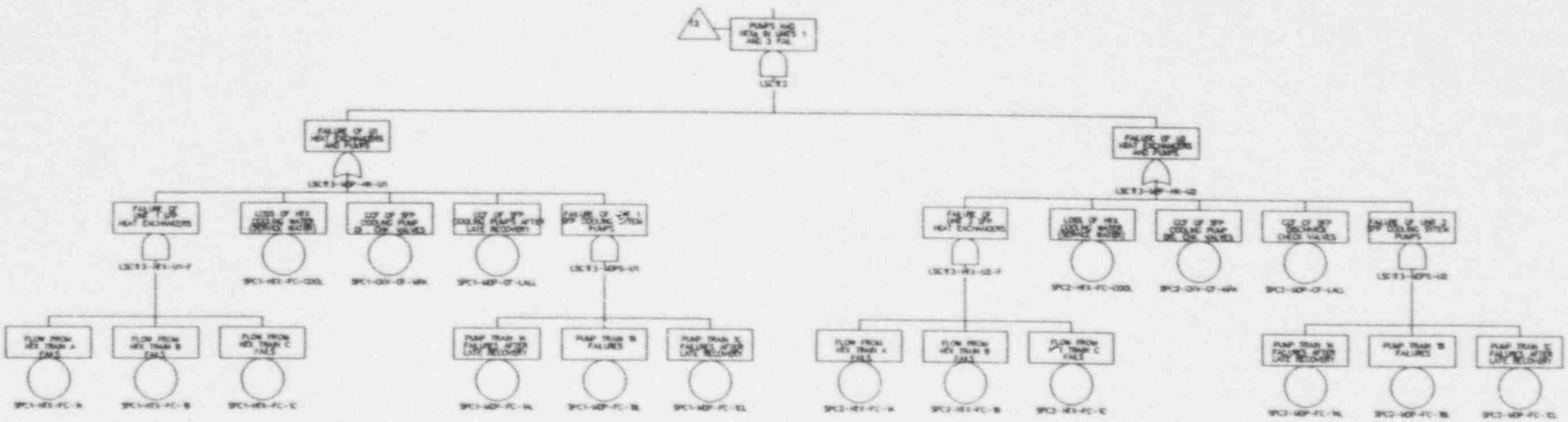
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 2)
LATE RECOVERY - CASE 3
3-OUT-OF-3 COOLING PUMPS AND
3-OUT-OF-3 HEAT EXCHANGERS FOR SUCCESS



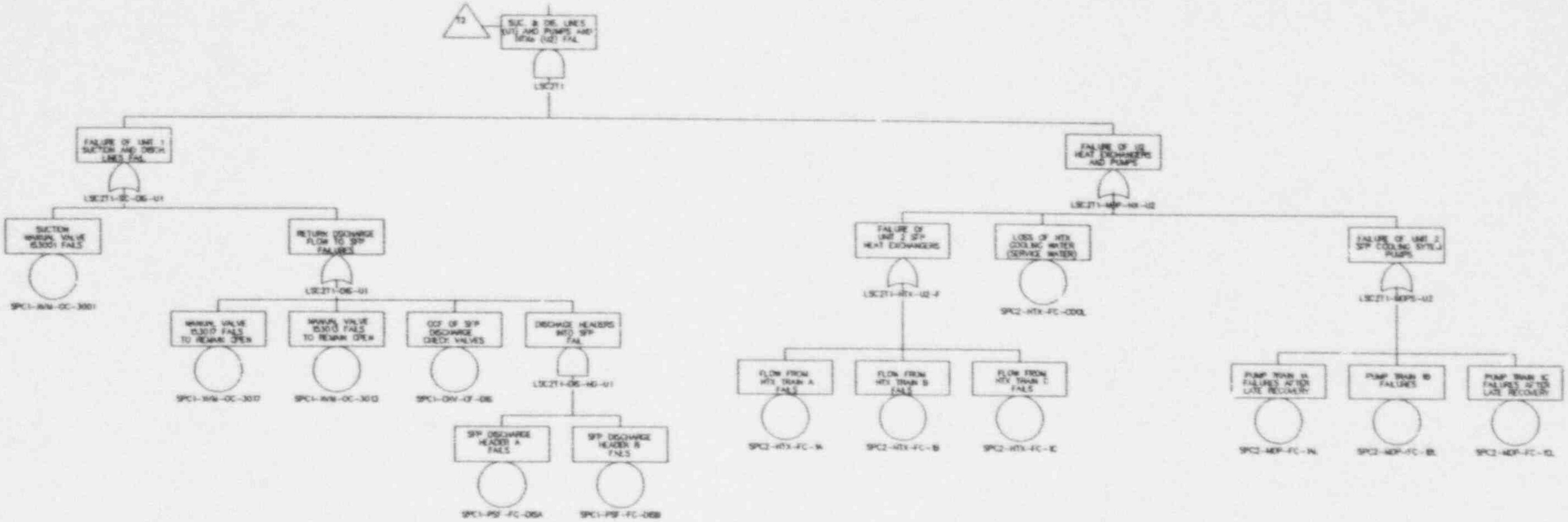
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNITS 1 & 2)
LATE RECOVERY - CASE 1
2-OUT-OF-6 COOLING PUMPS FOR SUCCESS
TRANSFERS TO LS12LPC1



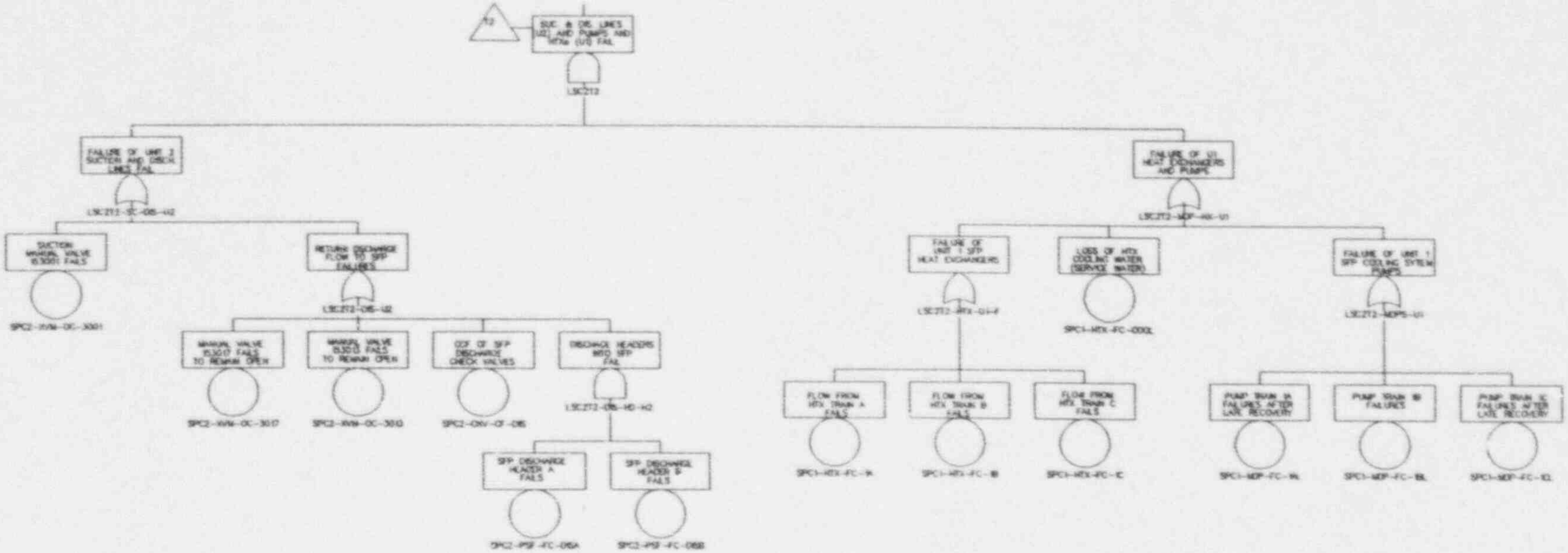
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNITS 1 & 2)
LATE RECOVERY – CASE 1
2-OUT-OF-6 COOLING PUMPS FOR SUCCESS
TRANSFERS TO LS12PC1



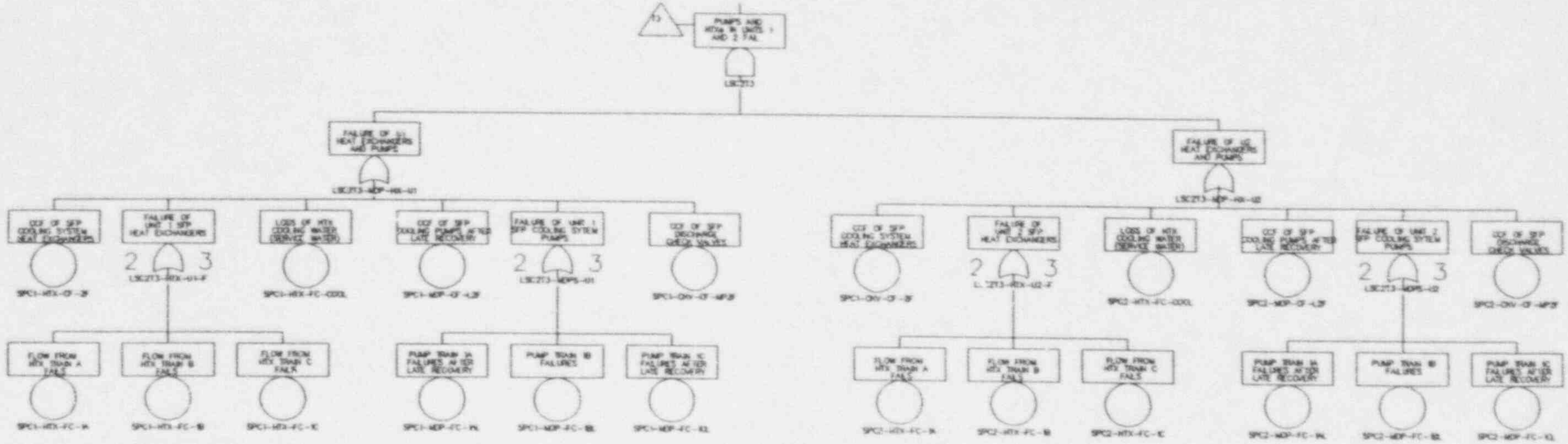
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNITS 1 & 2)
LATE RECOVERY - CASE 1
2-OUT-OF-6 COOLING PUMPS FOR SUCCESS
TRANSFERS TO LS12C1



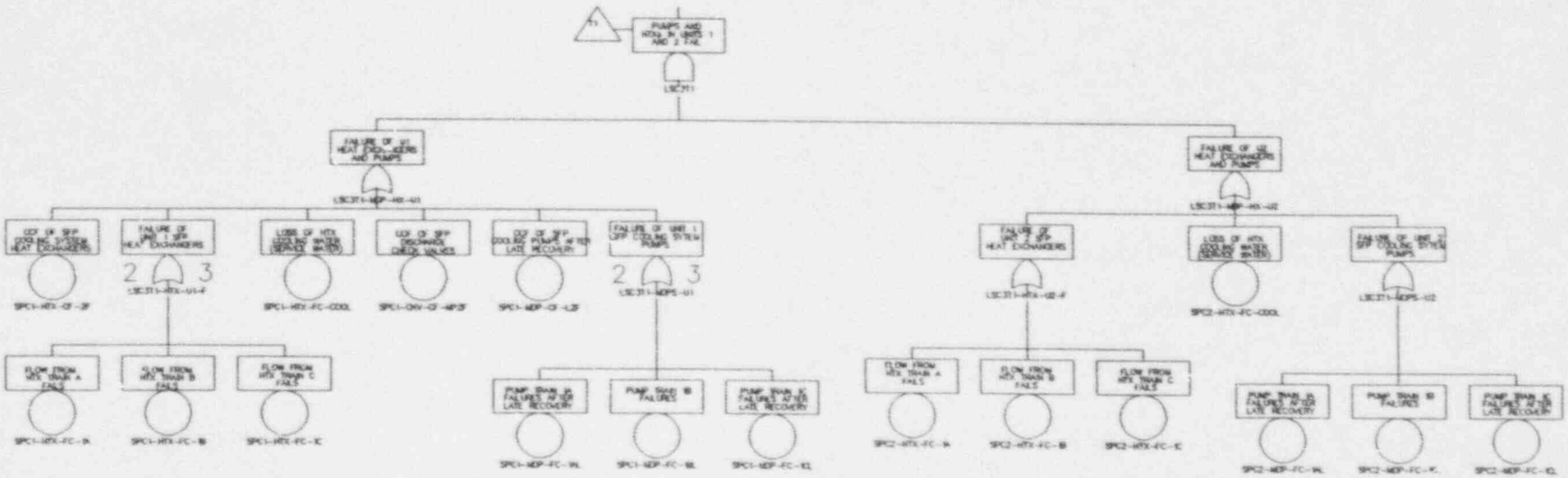
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNITS 1 & 2)
LATE RECOVERY – CASE 2
3-OUT-OF-6 COOLING PUMPS FOR SUCCESS
TRANSFERS TO LS12C2



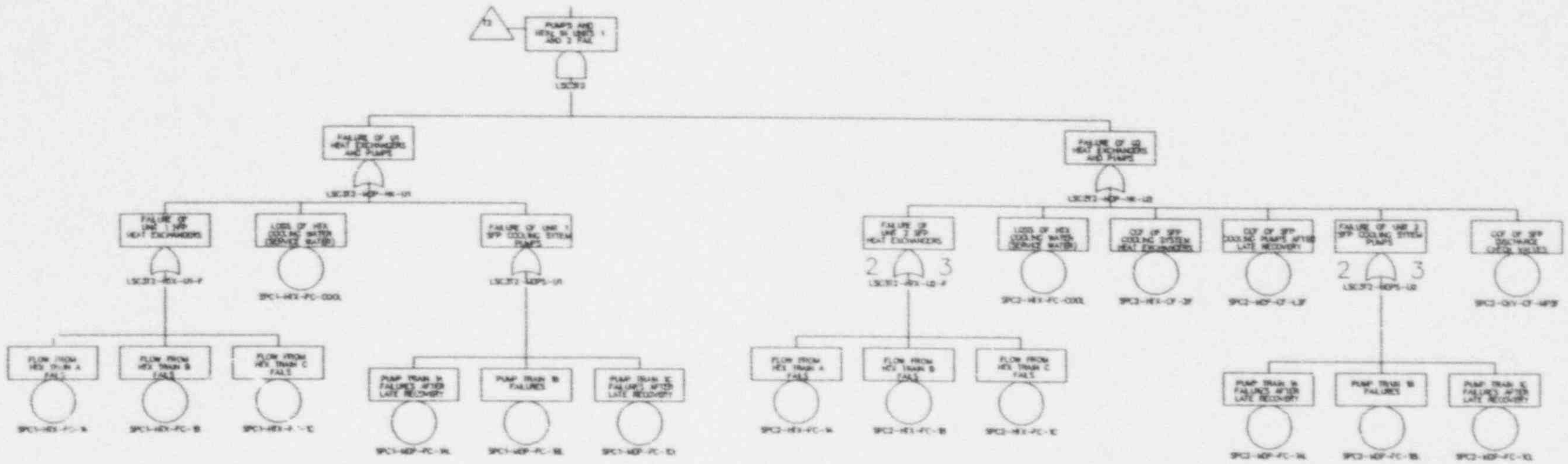
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNITS 1 & 2)
LATE RECOVERY - CASE 2
3-OUT-OF-6 COOLING PUMPS FOR SUCCESS
TRANSFERS TO LS12C2



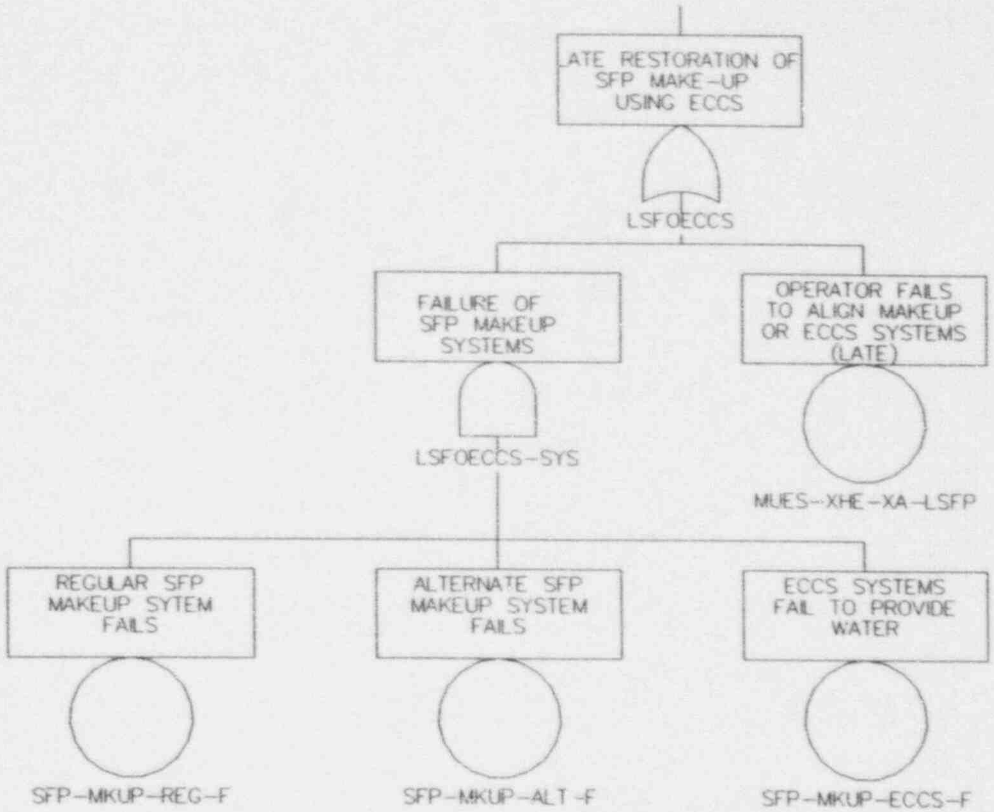
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNITS 1 & 2)
LATE RECOVERY - CASE 2
3-OUT-OF-6 COOLING PUMPS FOR SUCCESS
TRANSFERS TO LS12C2



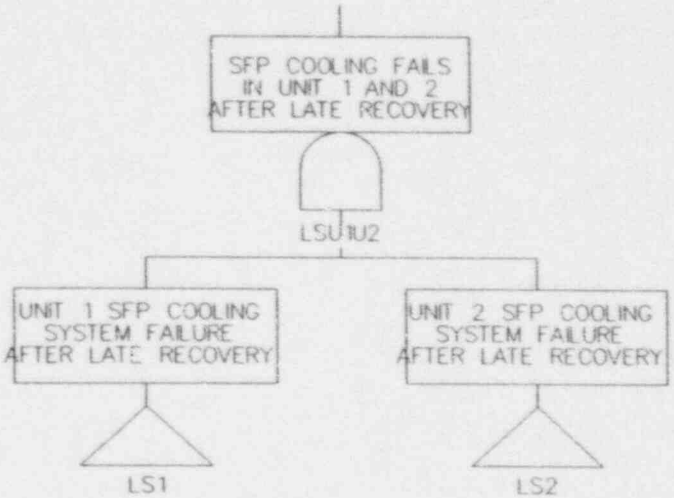
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNITS 1 & 2)
LATE RECOVERY - CASE 3
4-OUT-OF-6 COOLING PUMPS FOR SUCCESS
TRANSFERS TO LS12C3



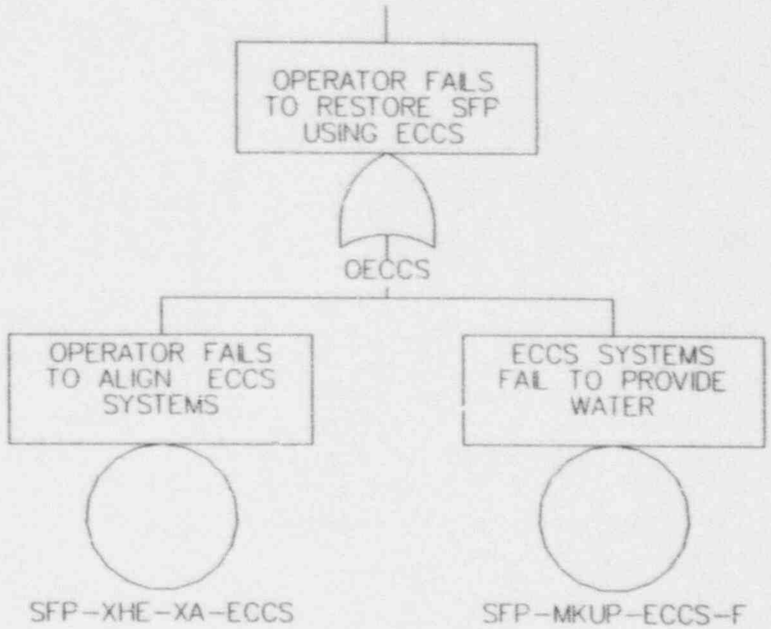
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNITS 1 & 2)
LATE RECOVERY – CASE 3
4–OUT–OF–6 COOLING PUMPS FOR SUCCESS
TRANSFERS TO LS12C3



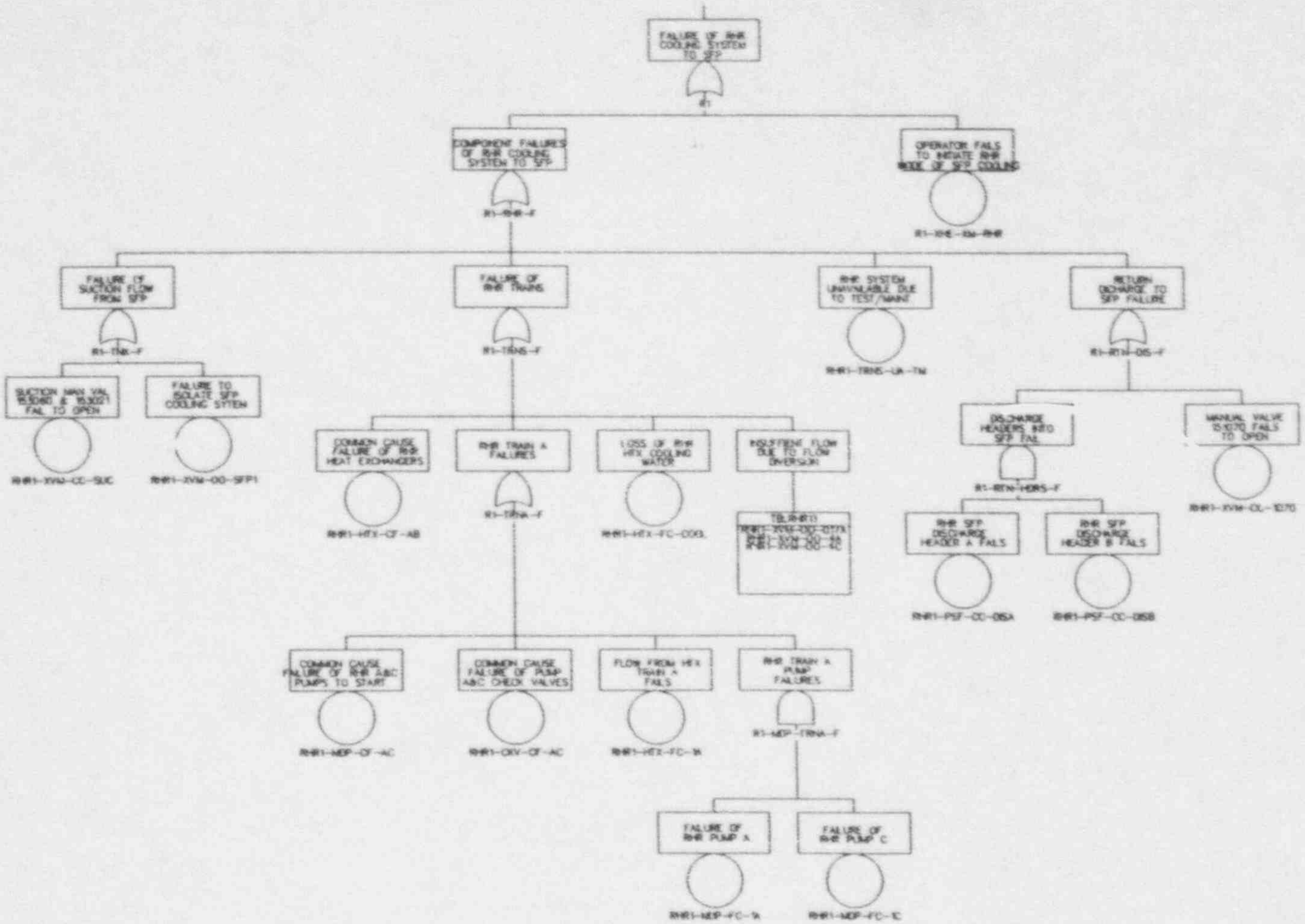
LATE RESTORATION OF
SPENT FUEL POOL MAKE-UP SYSTEMS
USING ECCS



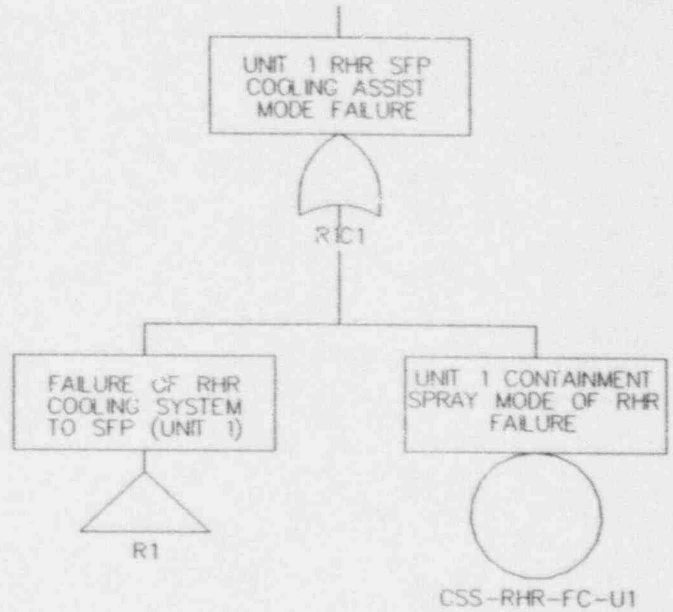
SPENT FUEL POOL COOLING SYSTEMS
FOR UNITS 1 AND 2 (LATE RECOVERY)
SUCCESS REQUIRES ONE OF TWO SPENT FUEL
POOL COOLING SYSTEMS FROM EITHER UNIT



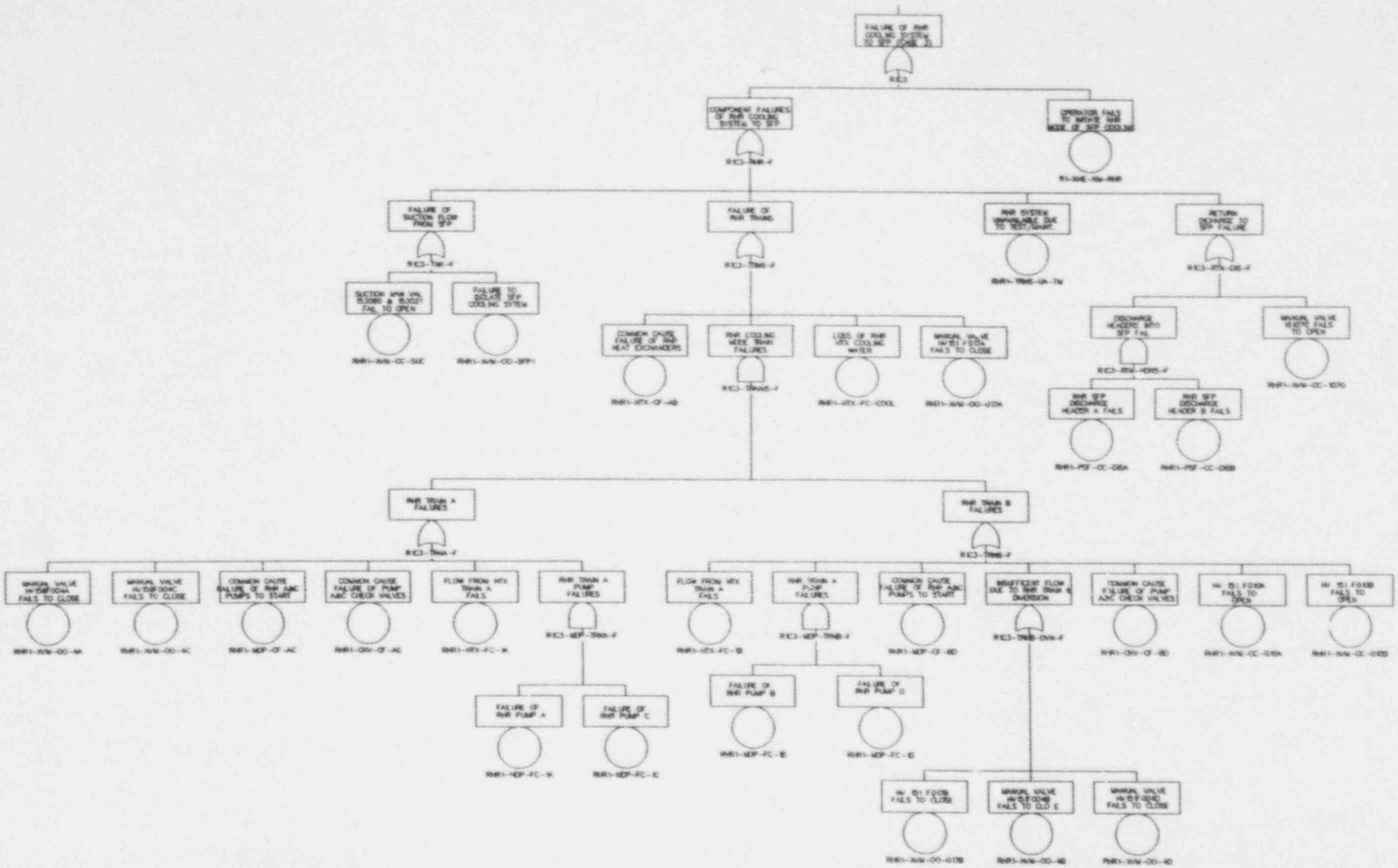
OPERATOR FAILS TO
RESTORE SFP USING ECCS



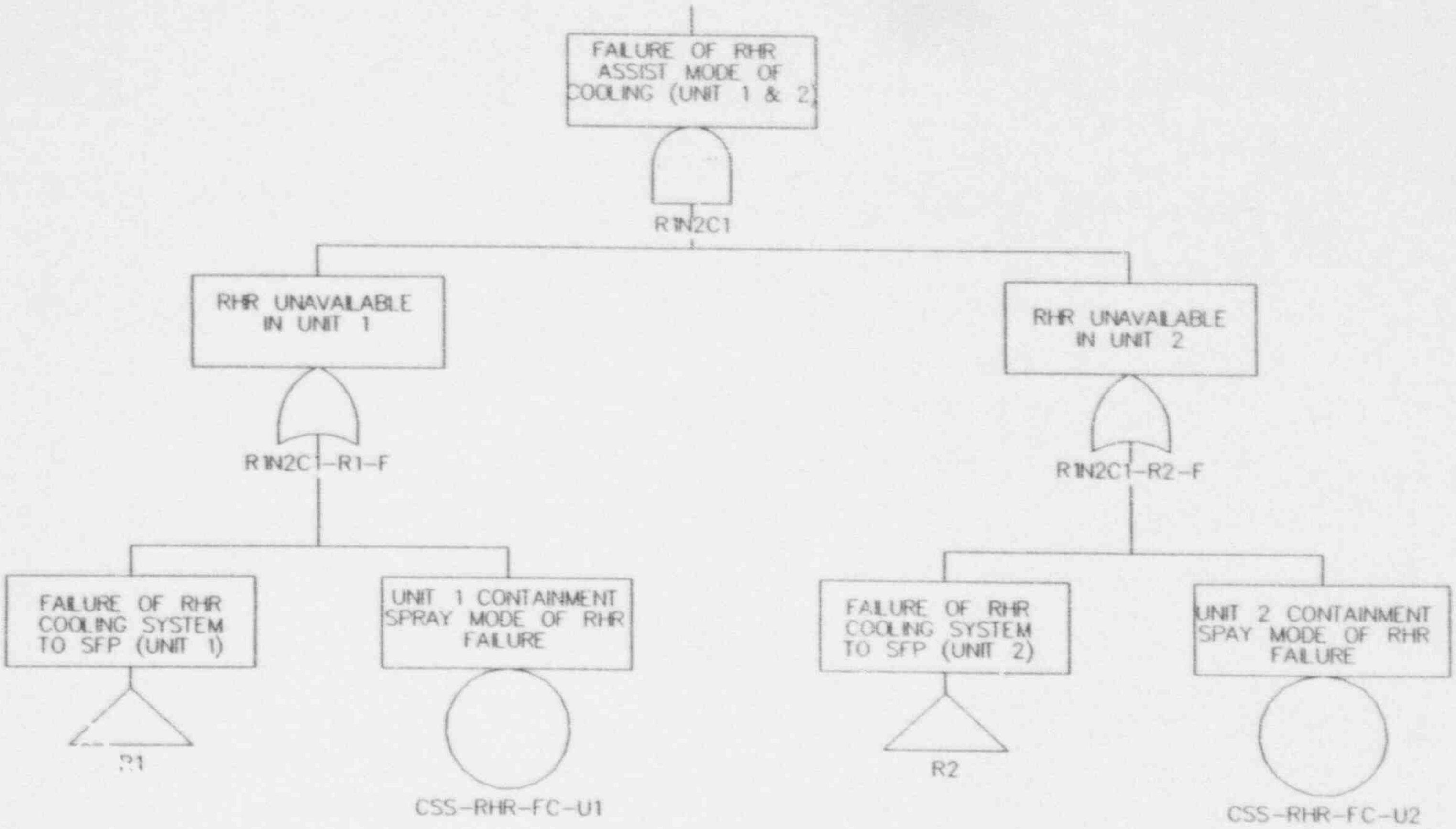
SUSQUEHANNA FUEL POOL COOLING SYSTEM (UNIT 1)
RHR COOLING MODE
ONLY 1 RHR TRAIN AVAILABLE PER UNIT
1-OUT-OF-2 RHR PUMPS AND
1-OUT-OF-1 RHR HEAT EXCHANGERS FOR SUCCESS



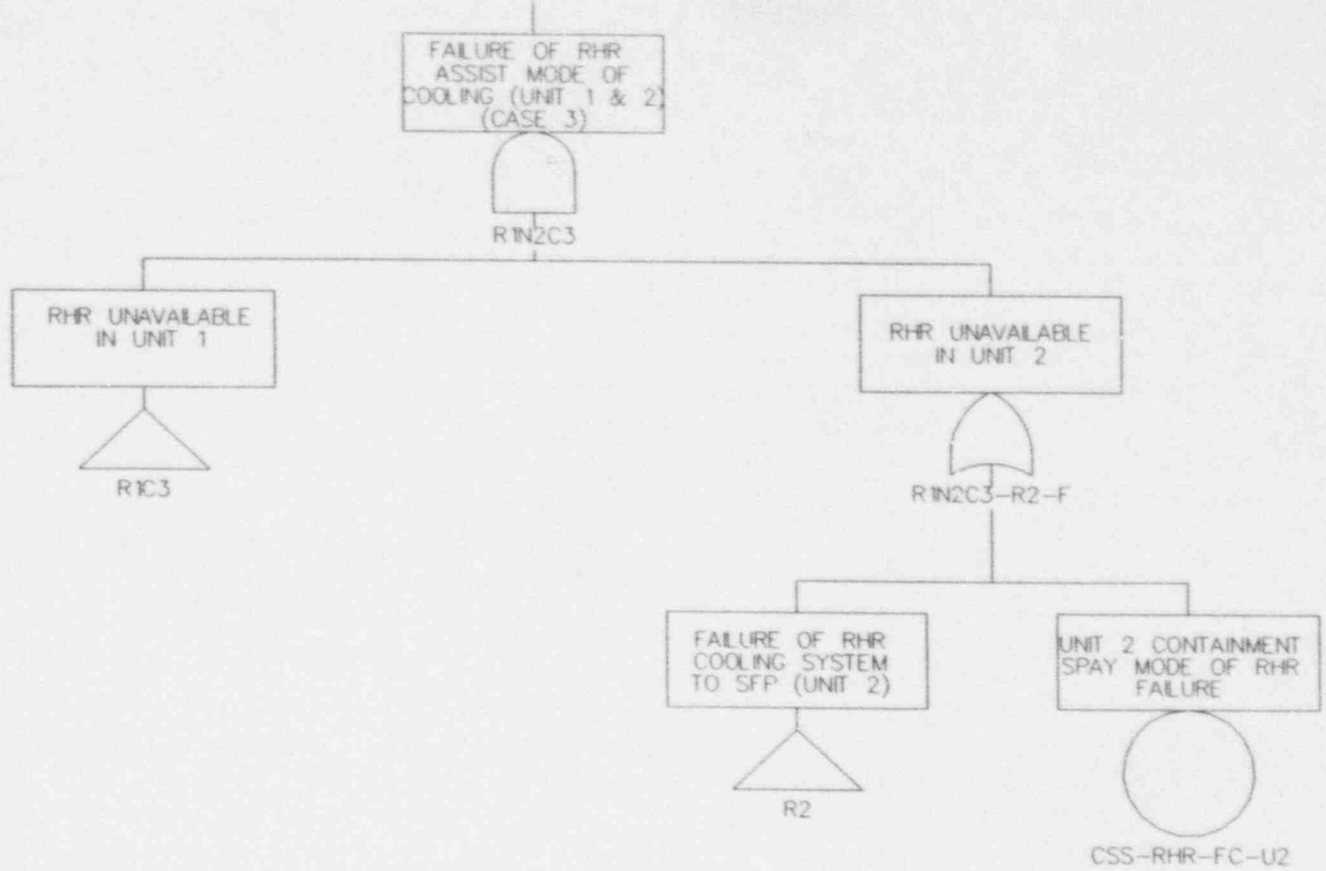
UNIT 1 RHR ASSIST MODE OF SPENT FUEL POOL COOLING (INCLUDES CONTAINMENT SPRAY MODE) 1-OUT-OF-2 RHR PUMPS FOR SUCCESS



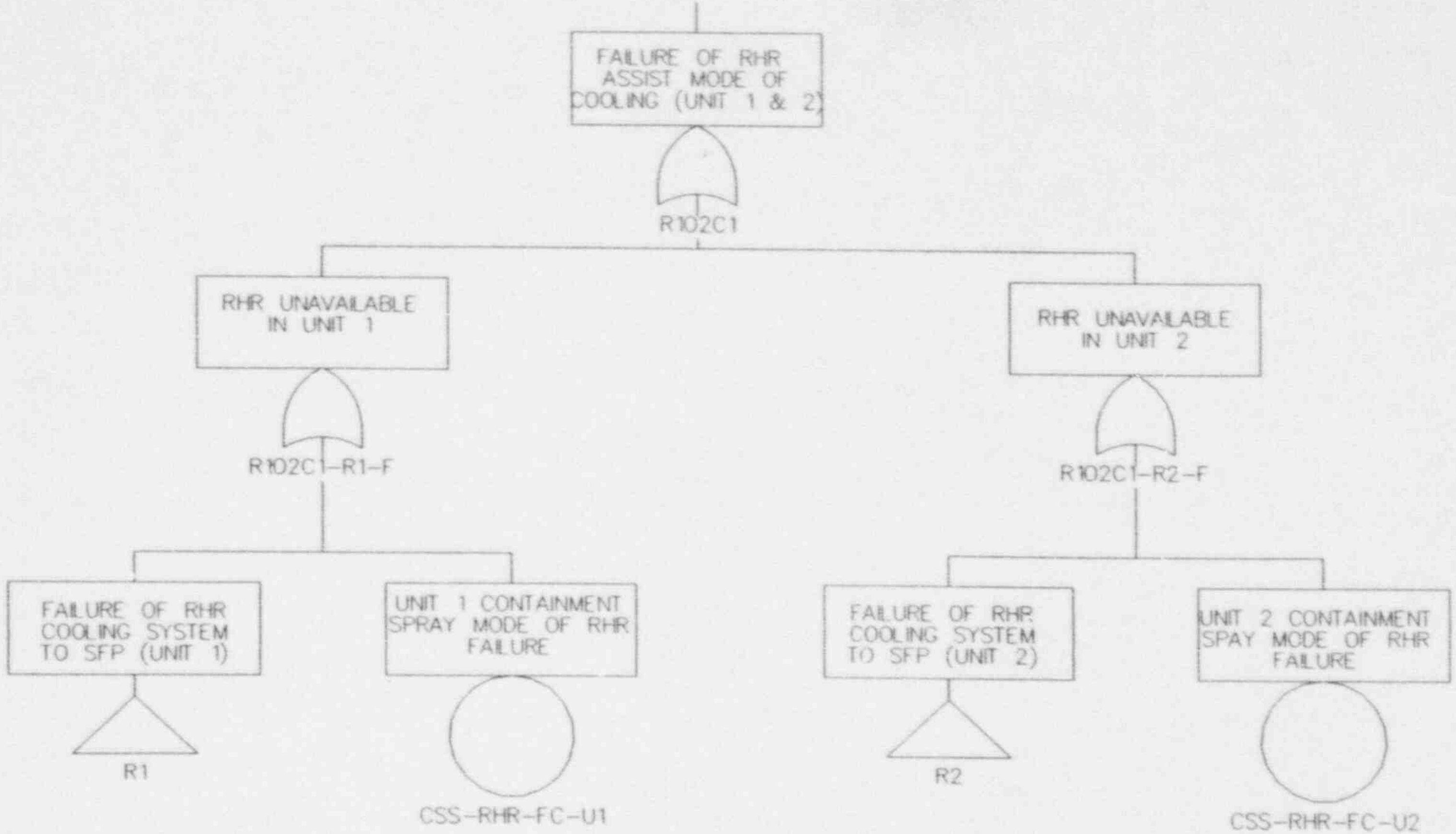
SUSQUEHANNA FUEL POOL COOLING SYSTEM (UNIT 1)
RHR ASSIST COOLING MODE: CASE 3
1-OUT-OF-4 RHR PUMPS AND
1-OUT-OF 2 RHR HEAT EXCHANGERS FOR SUCCESS



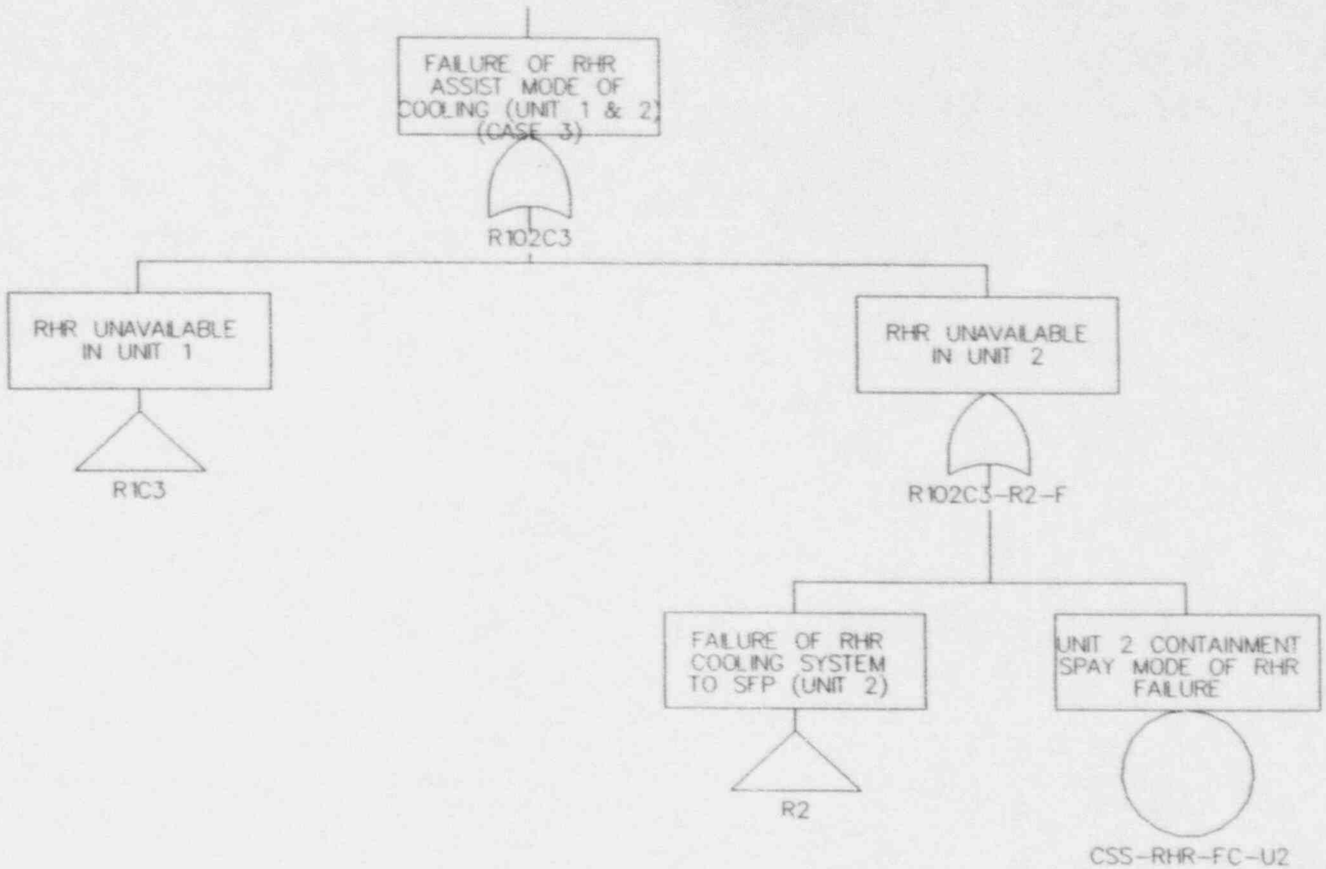
RHR ASSIST MODE OF SPENT FUEL COOLING UNIT 1 AND 2
1-OUT-OF-4 RHR PUMPS FOR SUCCESS
(1-OUT-OF-2 RHR PUMPS FROM UNIT 1 OR 1-OUT-OF-2 RHR PUMPS FROM UNIT 2)



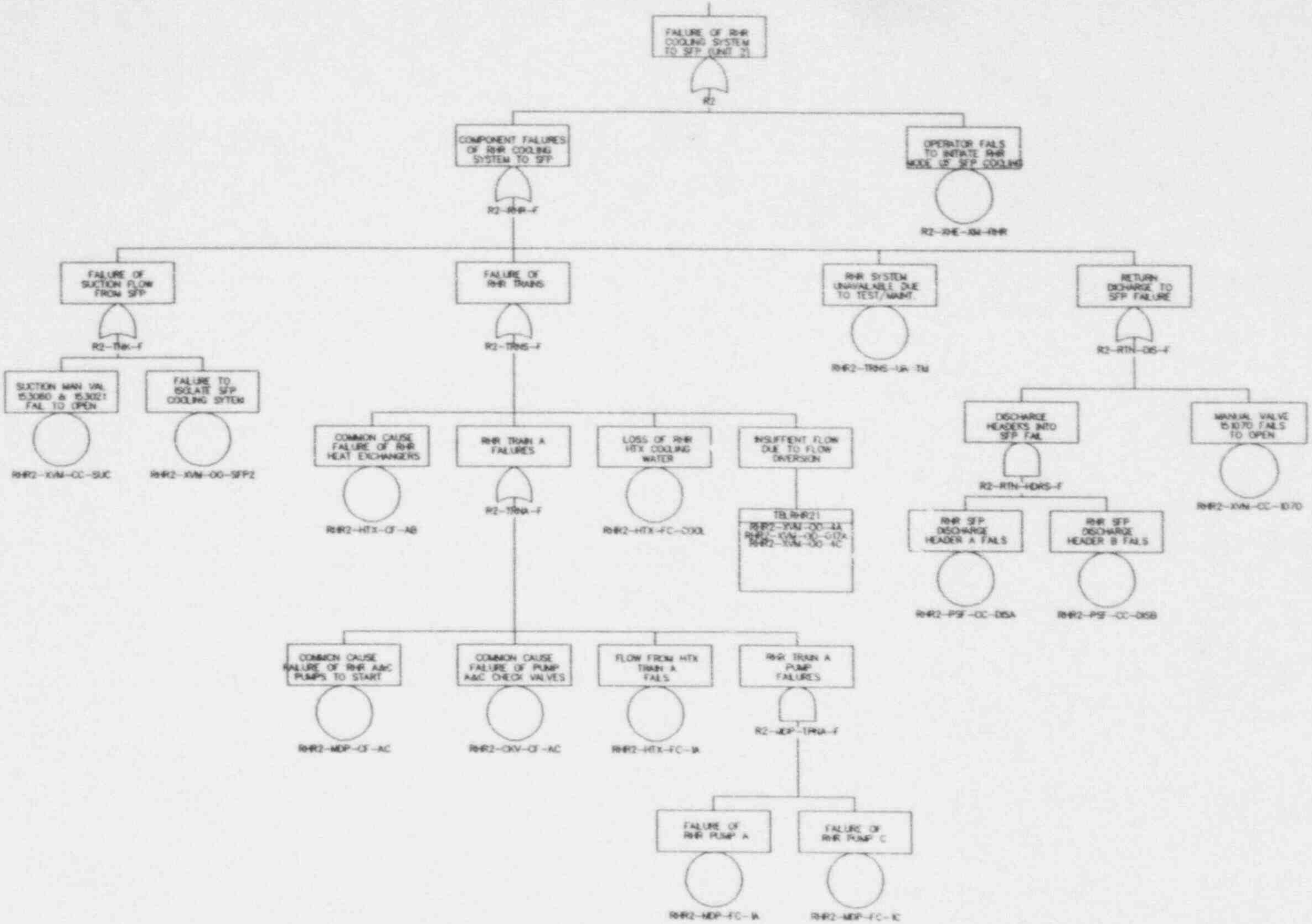
RHR ASSIST MODE OF SPENT FUEL COOLING UNIT 1 AND 2
CASE 3
1-OUT-OF-4 RHR PUMPS FROM UNIT 1 OR
1-OUT-OF-2 RHR PUMPS FROM UNIT 2 FOR SUCCESS



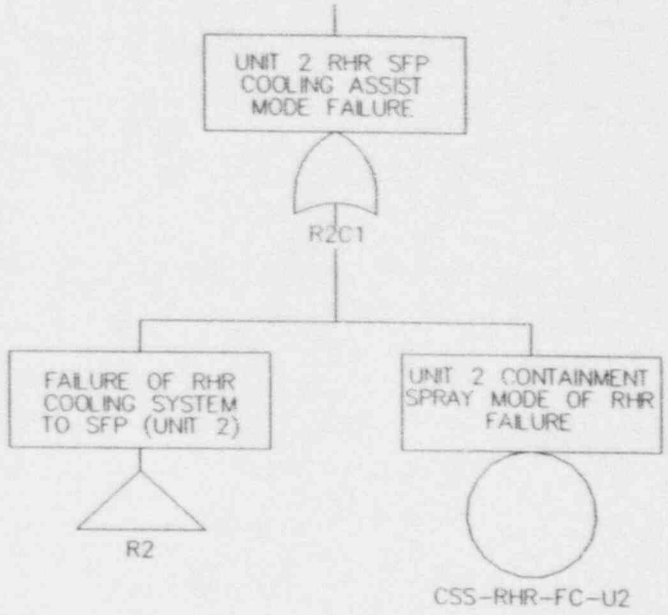
RHR ASSIST MODE OF SPENT FUEL COOLING UNIT 1 AND 2
1-OUT-OF-2 RHR PUMPS REQUIRED
FOR SUCCESS FROM EACH UNIT



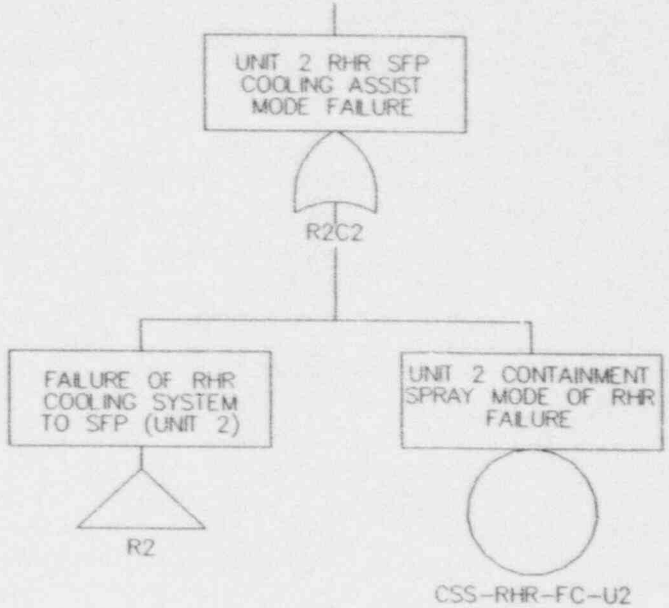
RHR ASSIST MODE OF SPENT FUEL COOLING UNIT 1 AND 2
CASE 3
1-OUT-OF-4 RHR PUMPS FROM UNIT 1 AND
1-OUT-OF 2 RHR PUMPS FROM UNIT 2 FOR SUCCESS



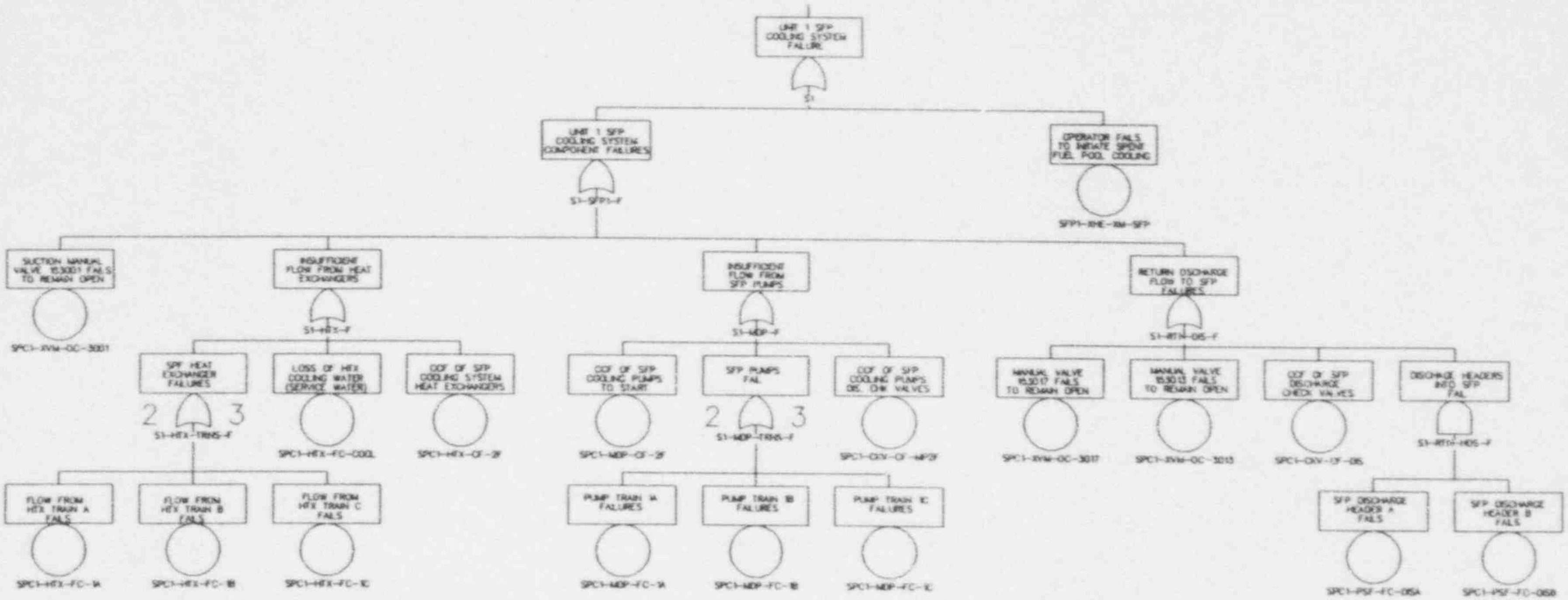
SUSQUEHANNA FUEL POOL COOLING SYSTEM (UNIT 2)
RHR COOLING MODE
ONLY 1 RHR TRAIN AVAILABLE PER UNIT
1-OUT-OF-2 RHR PUMPS AND
1-OUT-OF 1 RHR HEAT EXCHANGERS FOR SUCCESS



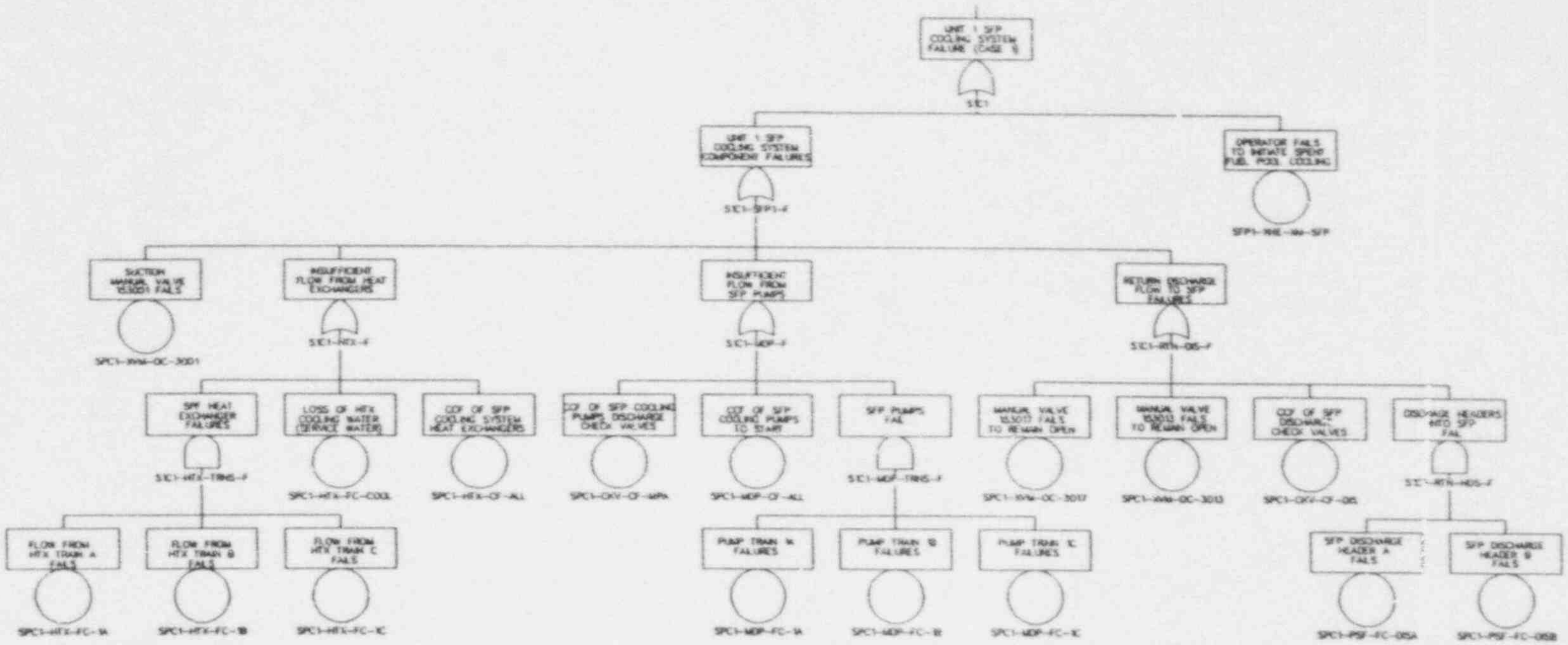
UNIT 2 RHR ASSIST MODE OF SPENT FUEL POOL COOLING (INCLUDES CONTAINMENT SPRAY MODE) 1-OUT-OF-2 RHR PUMPS FOR SUCCESS



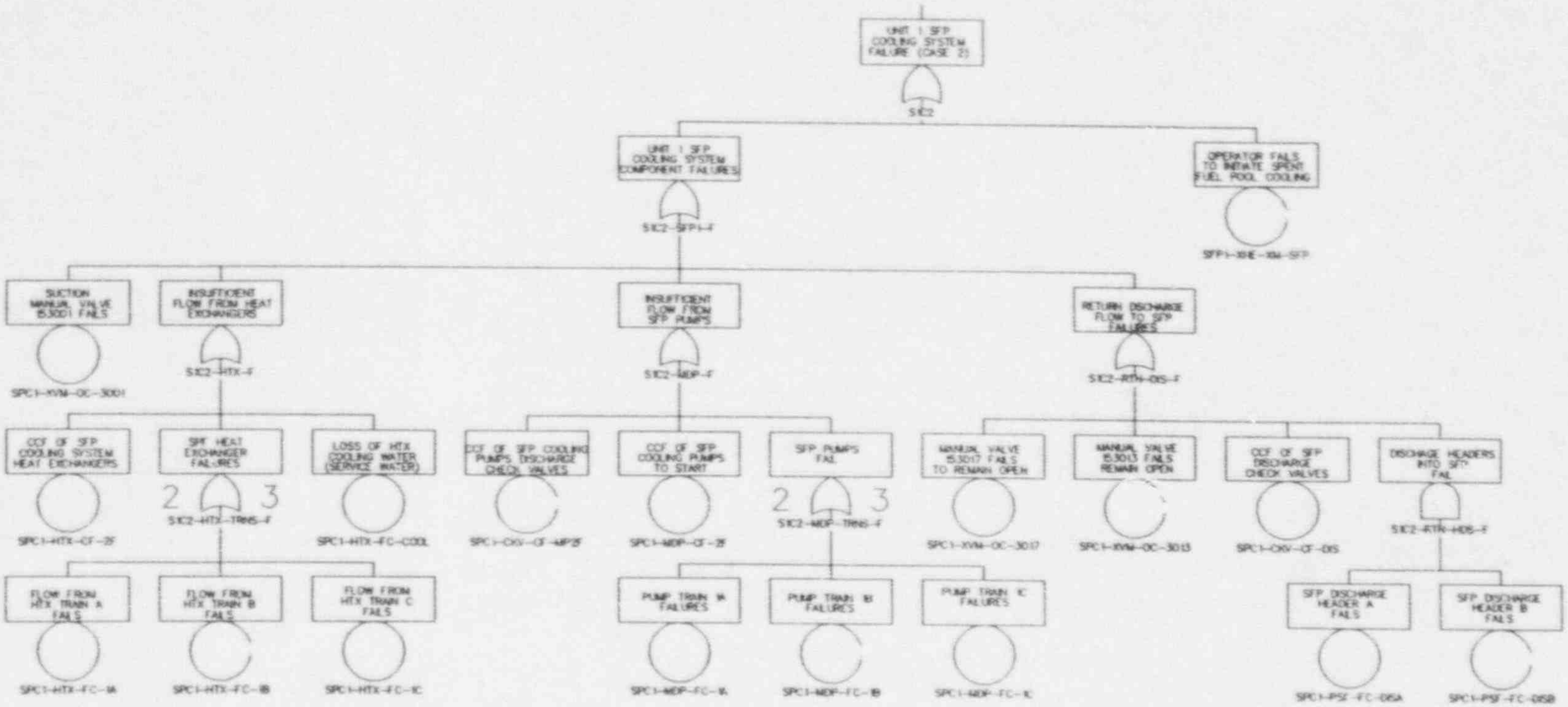
UNIT 2 RHR ASSIST MODE OF SPENT FUEL POOL COOLING (INCLUDES CONTAINMENT SPRAY MODE) 1-OUT-OF-2 RHR PUMPS FOR SUCCESS



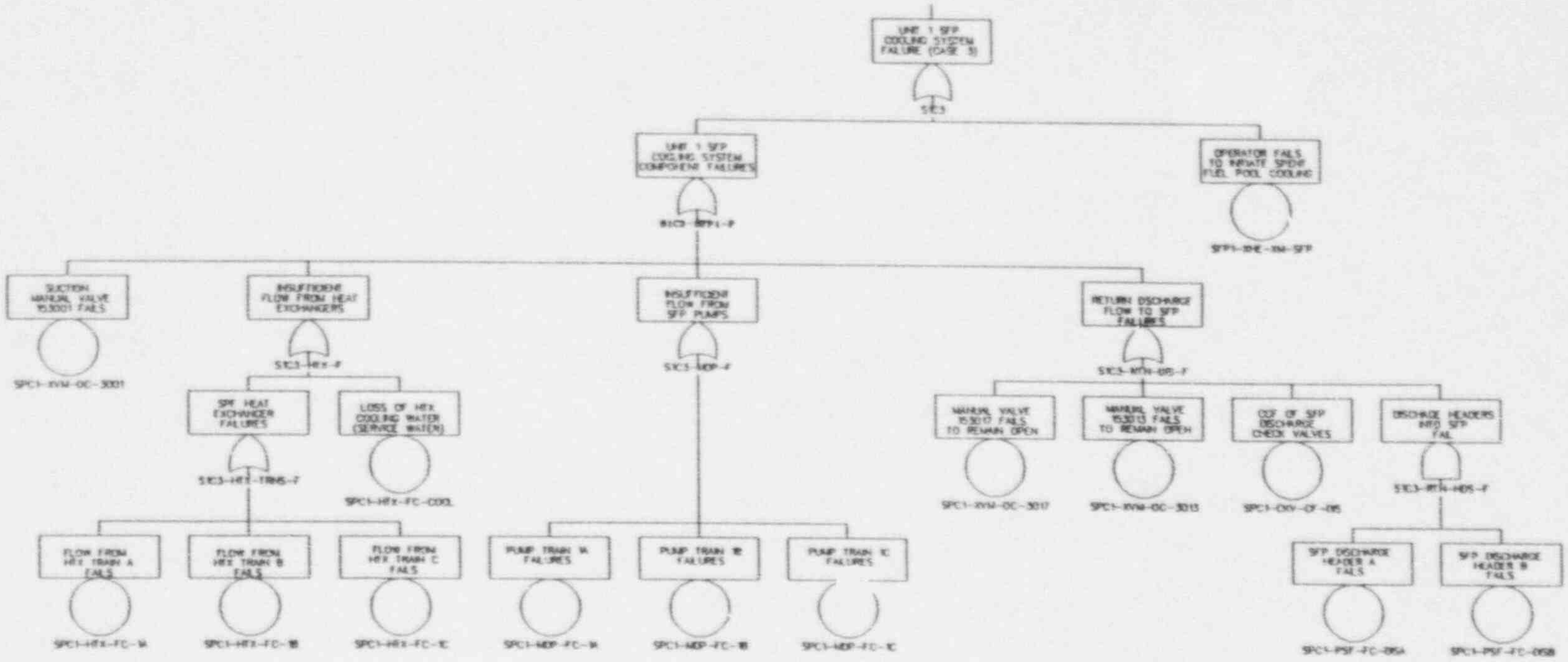
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 1)
ONE REFUELING - ONE OPERATING
2-OUT-OF-3 COOLING PUMPS FOR SUCCESS
2-OUT-OF-3 HEAT EXCHANGERS FOR SUCCESS



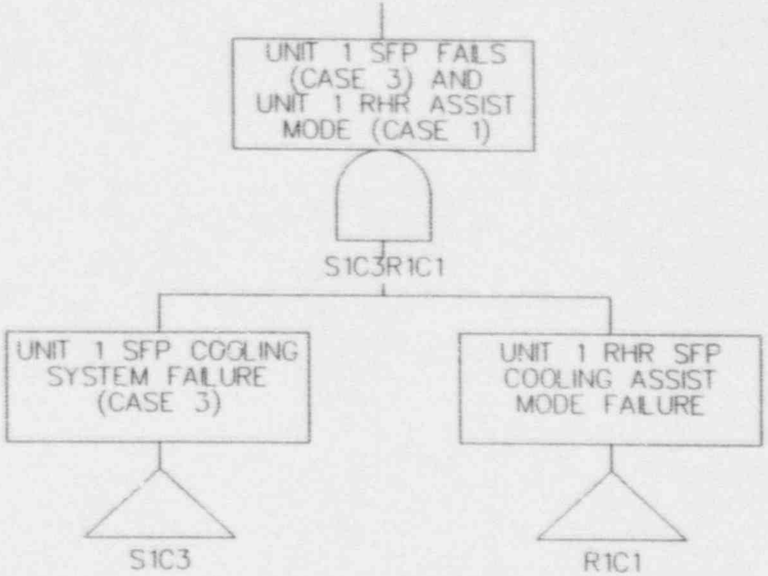
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 1)
CASE 1
1-OUT-OF-3 COOLING PUMPS AND
1-OUT-OF-3 HEAT EXCHANGERS FOR SUCCESS



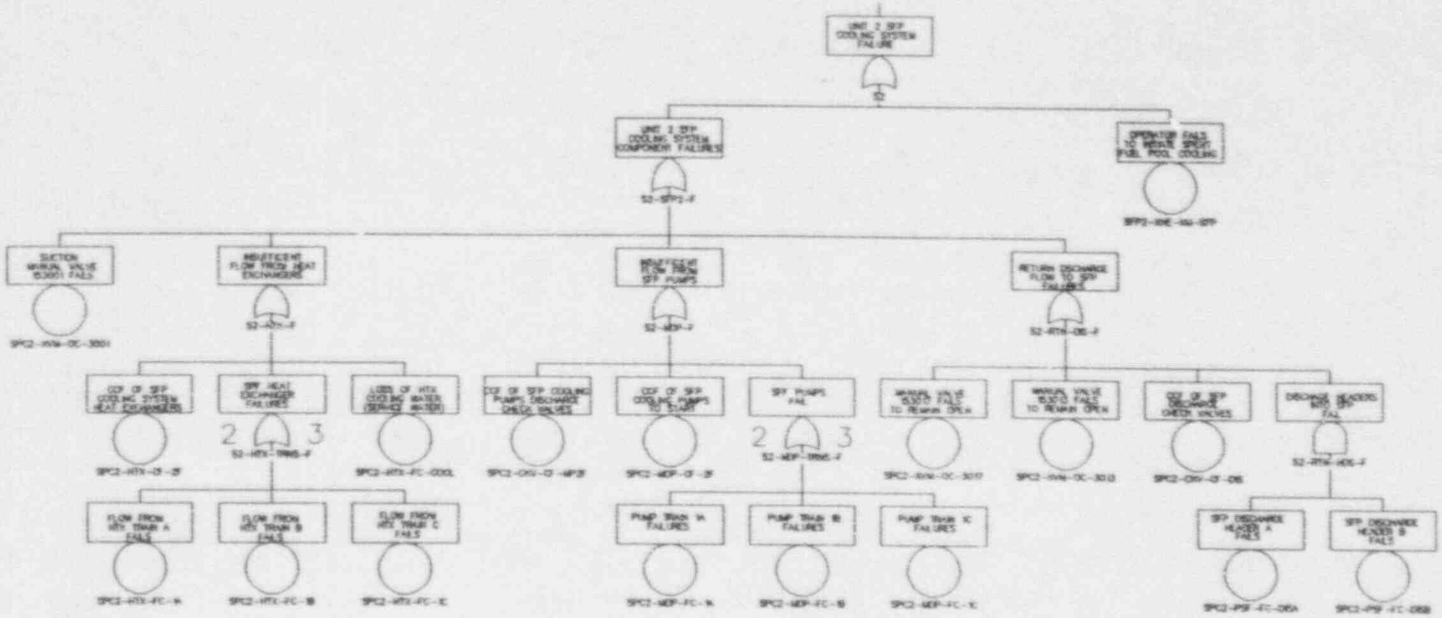
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 1)
CASE 2
2-OUT-OF-3 COOLING PUMPS AND
2-OUT-OF-3 HEAT EXCHANGERS FOR SUCCESS



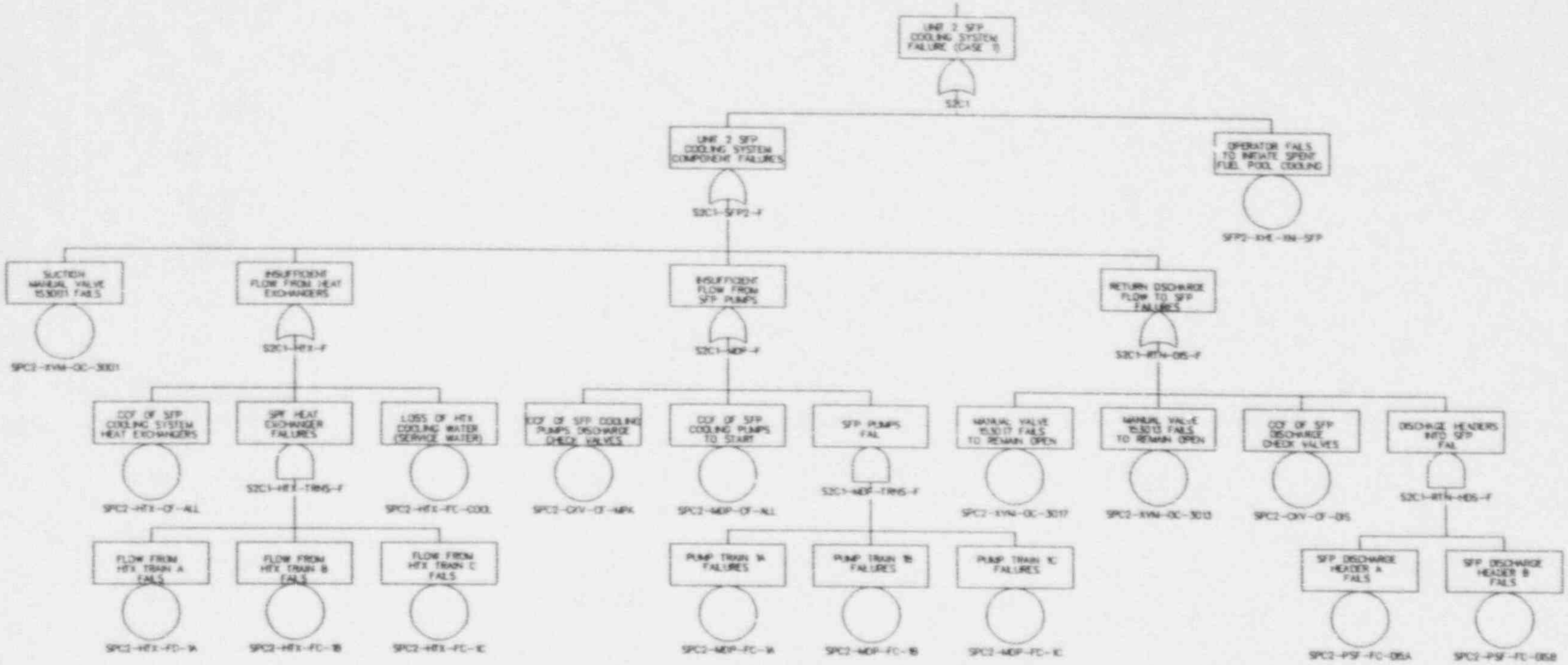
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 1)
CASE 3
3-OUT-OF-3 COOLING PUMPS AND
3-OUT-OF-3 HEAT EXCHANGERS FOR SUCCESS



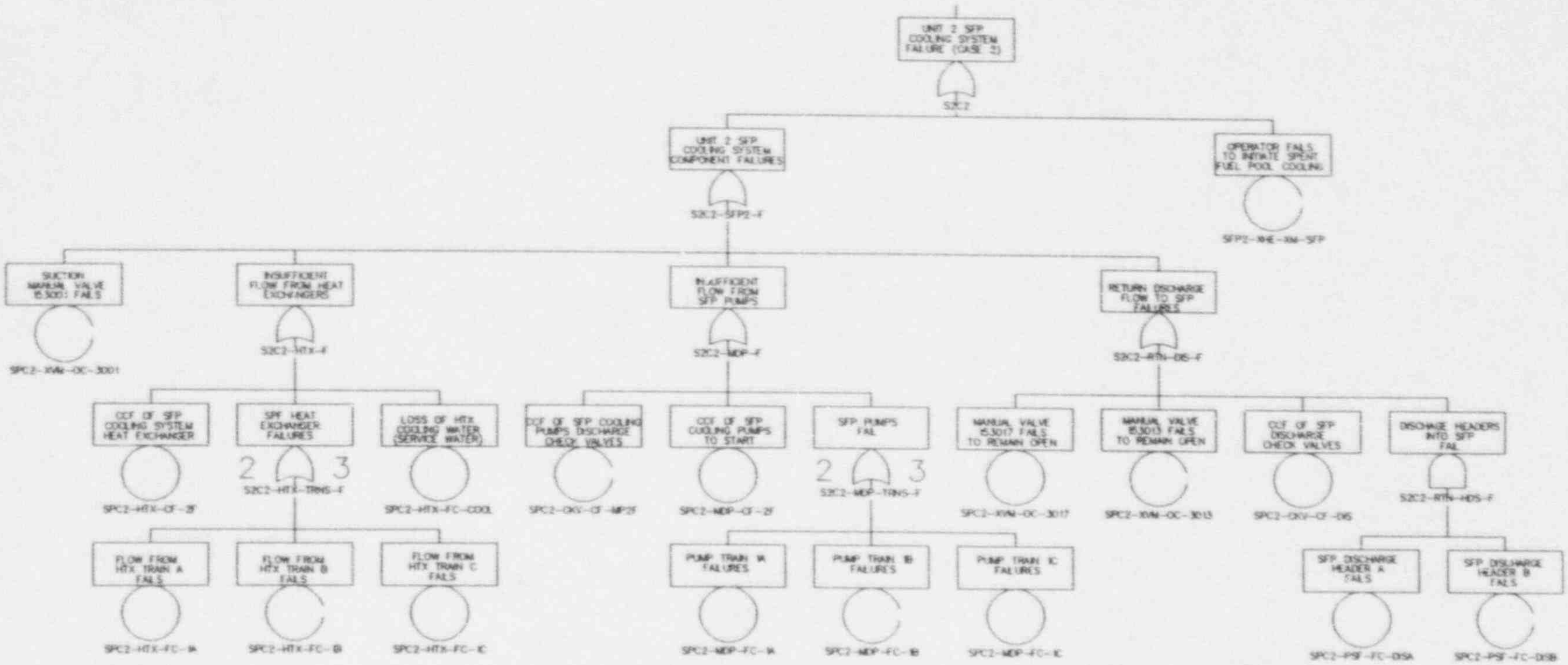
SPENT FUEL POOL COOLING SYSTEMS FOR UNIT 1. SUCCESS REQUIRES UNIT 1 SFP COOLING SYSTEM (CASE 1) OR UNIT 1 RHR ASSIST MODE (CASE 1)



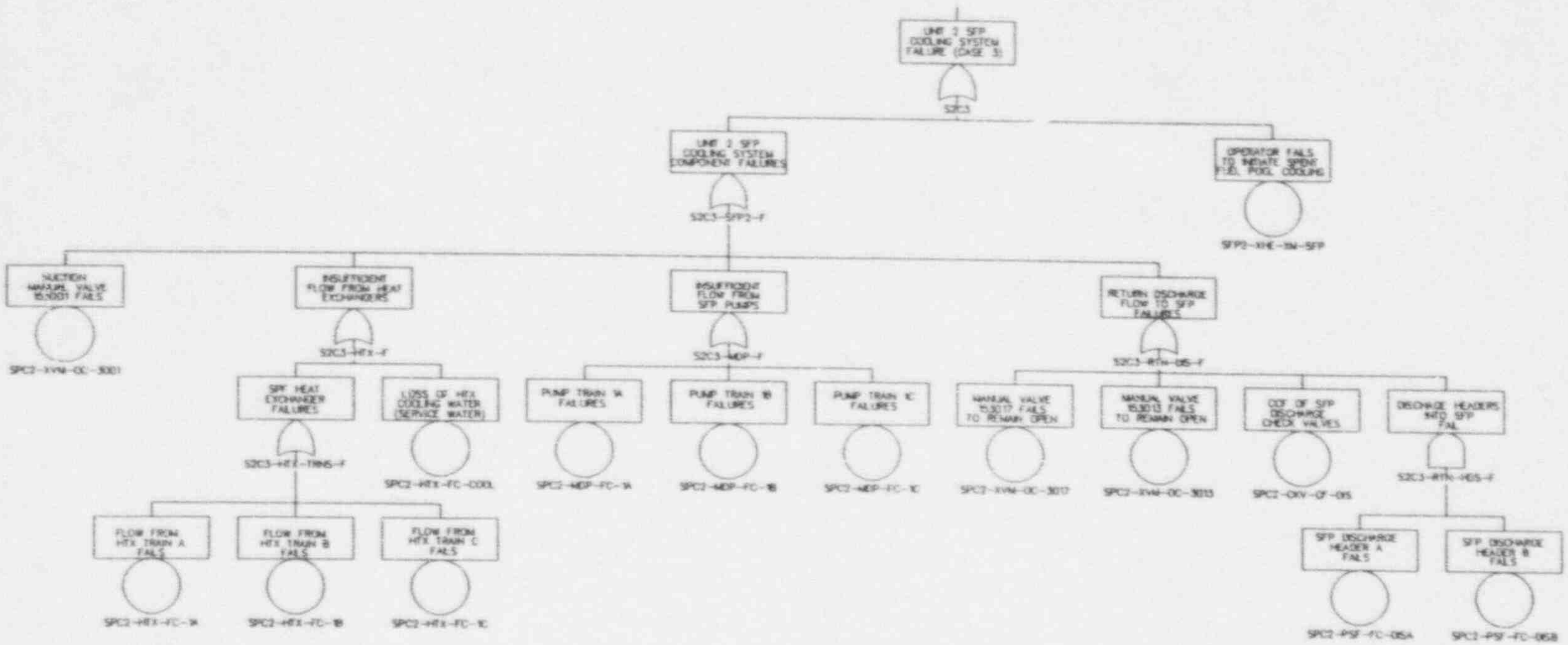
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 2)
ONE REFUELING – ONE OPERATING
2–OUT–OF–3 COOLING PUMPS FOR SUCCESS
2–OUT–OF–3 HEAT EXCHANGERS FOR SUCCESS



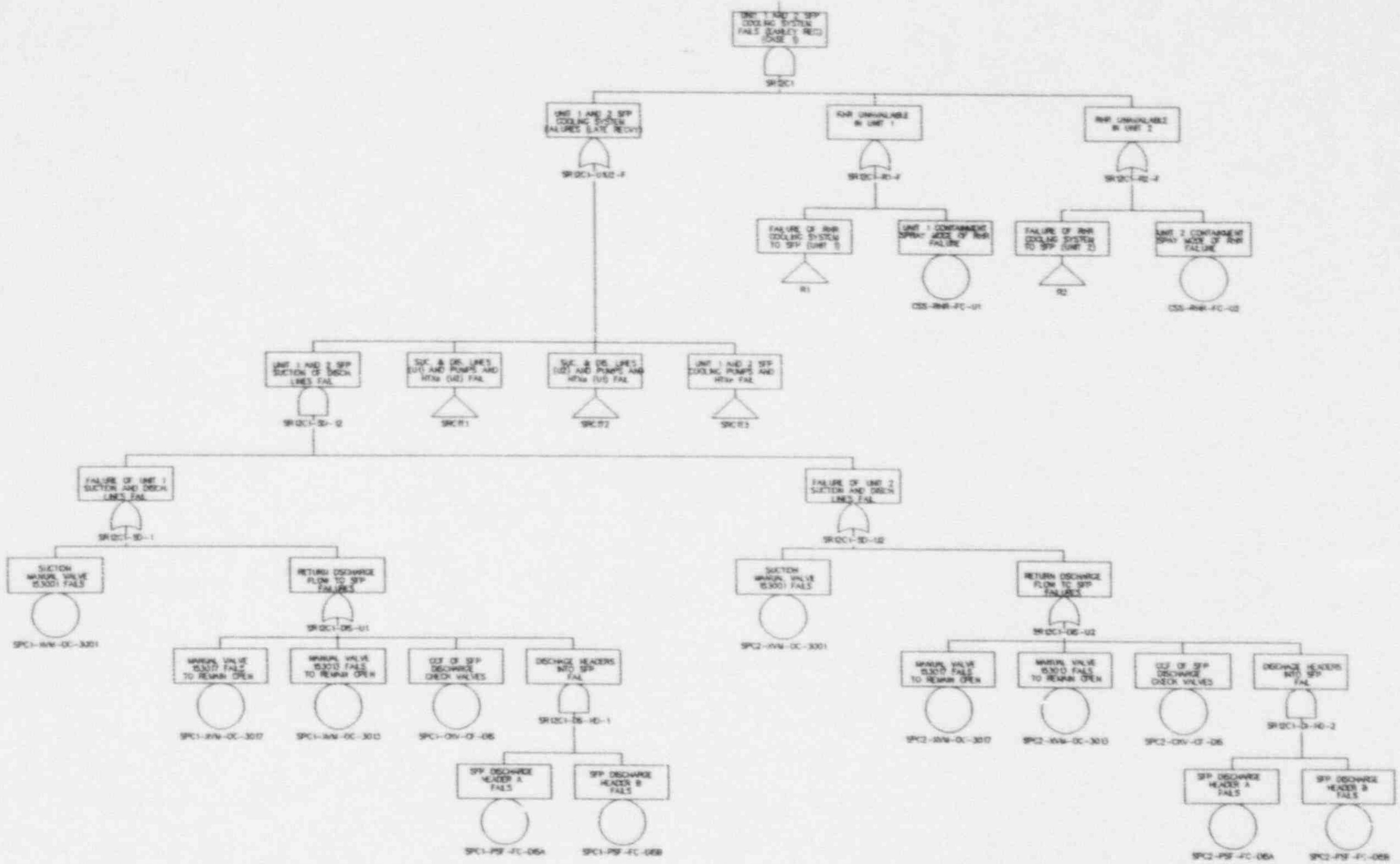
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 2)
CASE 1
1-OUT-OF-3 COOLING PUMPS FOR SUCCESS
1-OUT-OF-3 HEAT EXCHANGERS FOR SUCCESS



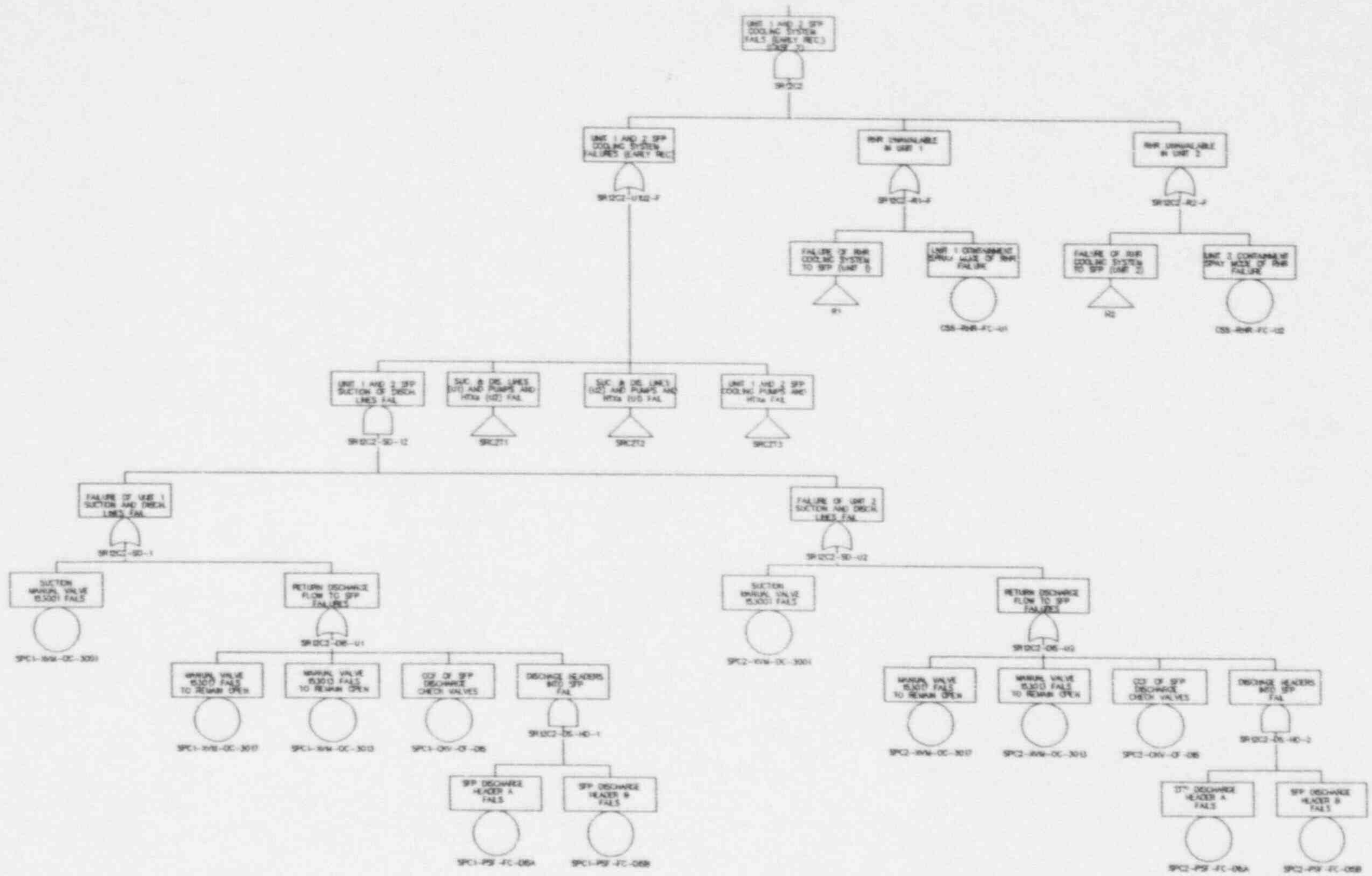
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 2)
CASE 2
2-OUT-OF-3 COOLING PUMPS FOR SUCCESS
2-OUT-OF-3 HEAT EXCHANGERS FOR SUCCESS



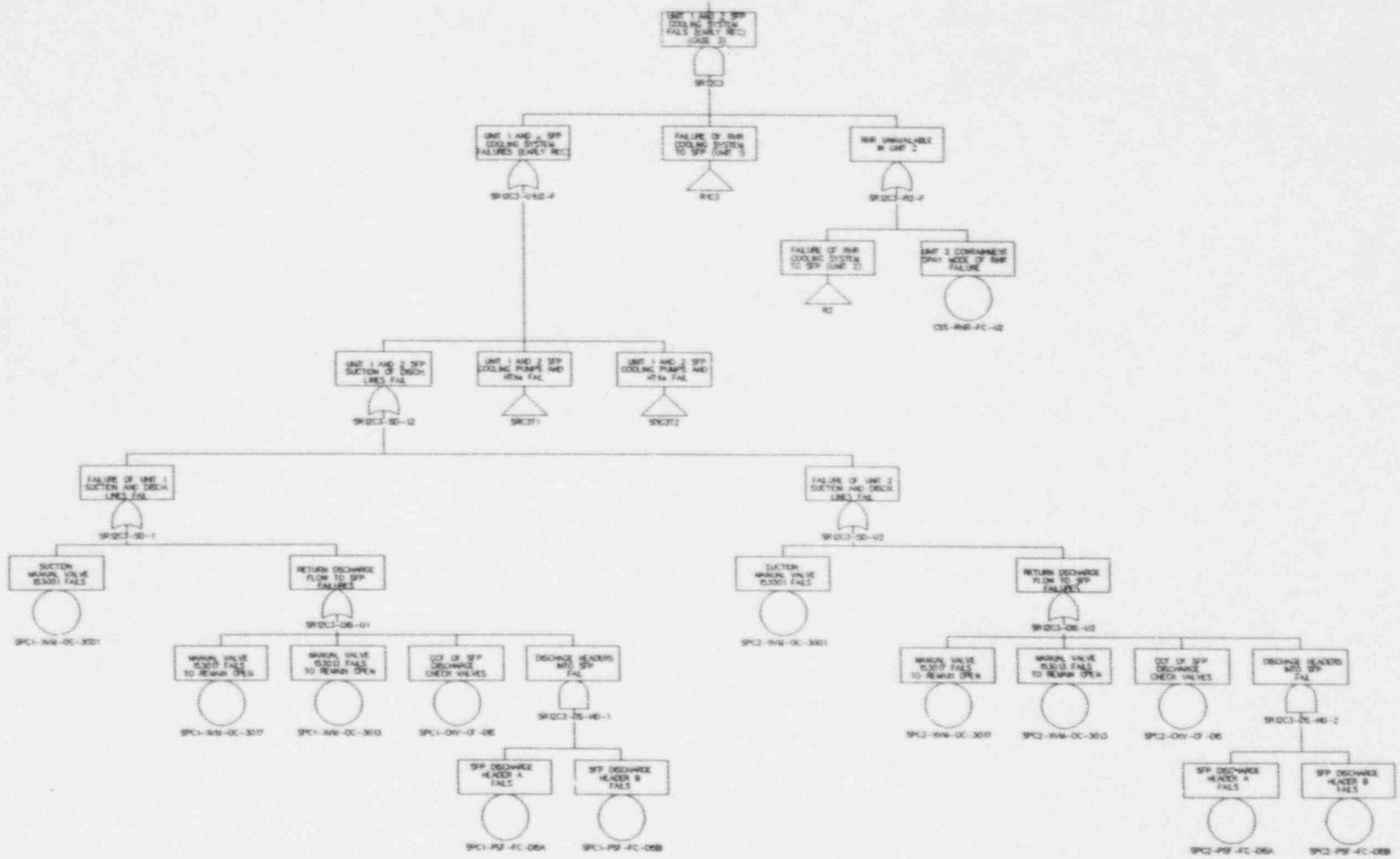
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNIT 2)
CASE 3
3-OUT-OF-3 COOLING PUMPS FOR SUCCESS
3-OUT-OF-3 HEAT EXCHANGERS FOR SUCCESS



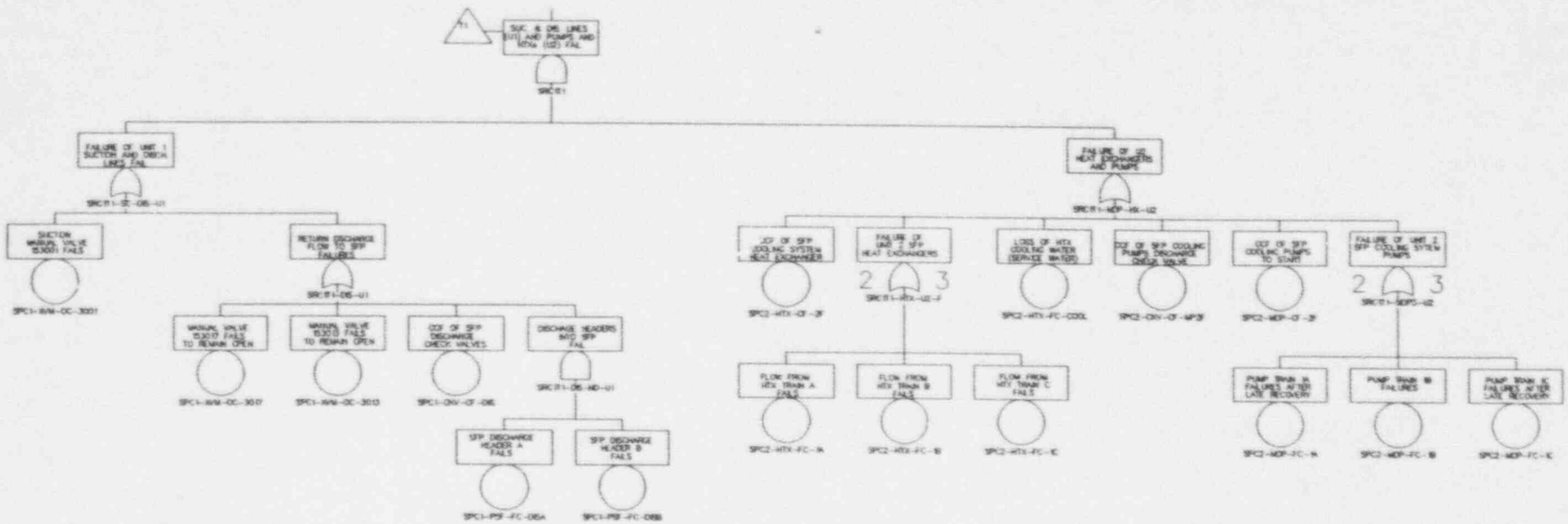
SUSQUEHANNA FUEL POOL COOLING SYSTEM FOR UNITS 1 & 2
EARLEY RECOVERY – CASE 1
2–OUT–OF–6 SPENT FUEL COOLING PUMPS OR
1–OUT–OF–2 RHR PUMPS IN UNIT 1 OR
1–OUT–OF–2 RHR PUMPS IN UNIT 2 FOR SUCCESS



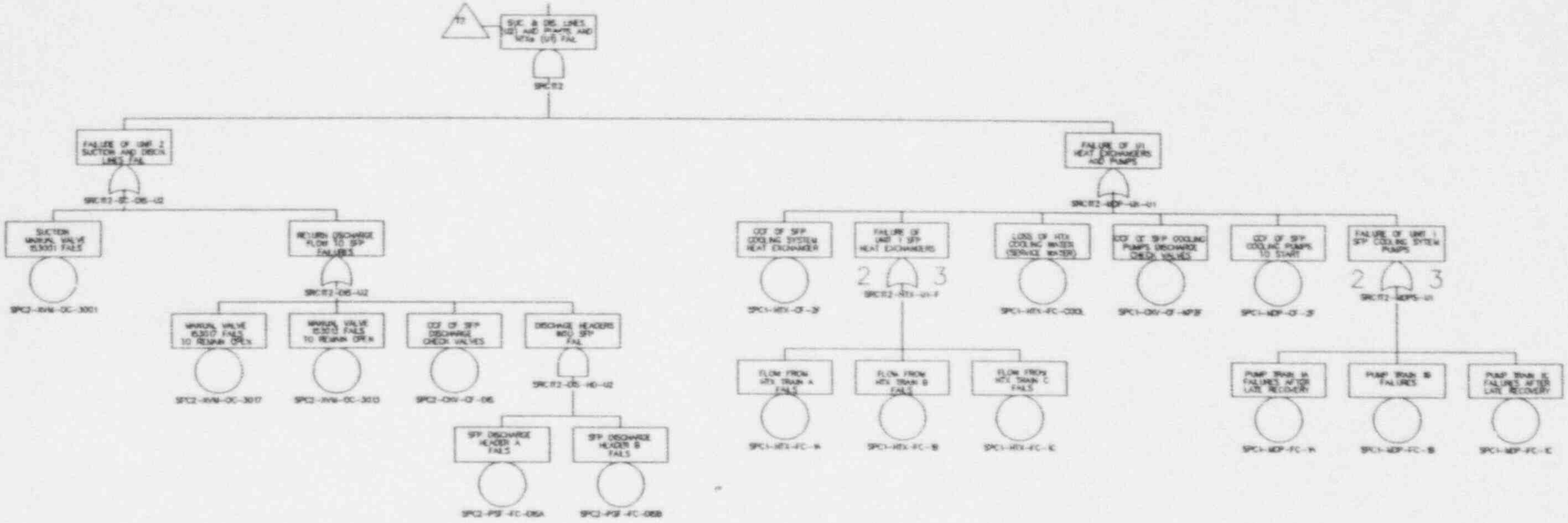
SUSQUEHANNA FUEL POOL COOLING SYSTEM FOR UNITS 1 & 2
EARLY RECOVERY - CASE 2
3-OUT-OF-6 SPENT FUEL COOLING PUMPS OR
1-OUT-OF-2 RHR PUMPS IN UNIT 1 OR
1-OUT-OF-2 RHR PUMPS IN UNIT 1 FOR SUCCESS



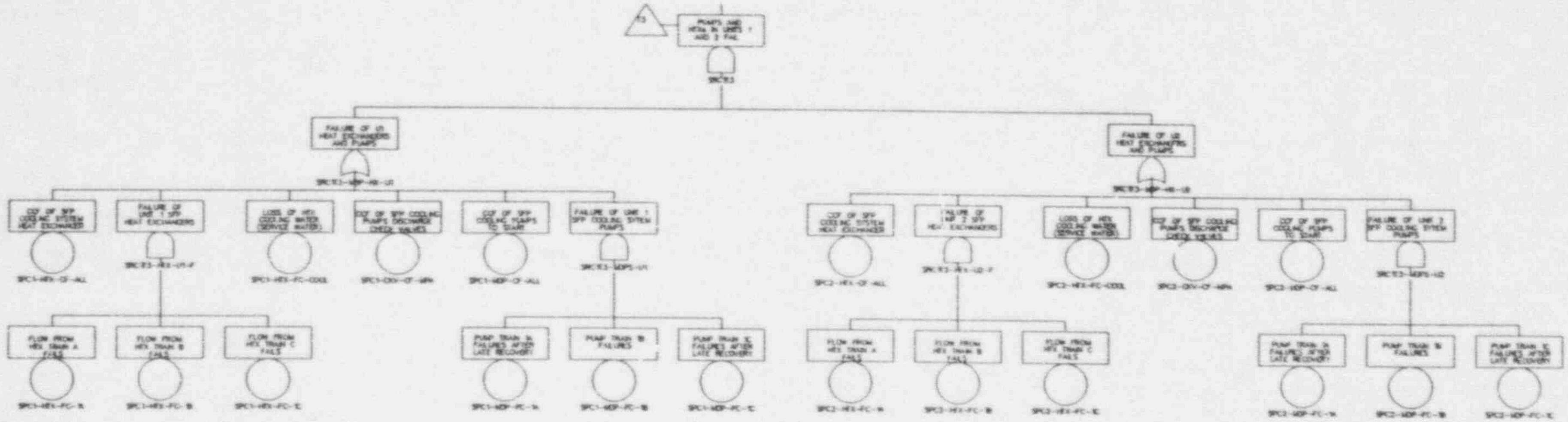
SUSQUEHANNA FUEL POOL COOLING SYSTEM FOR UNITS 1 & 2
EARLY RECOVERY – CASE 3
4–OUT–OF–6 SPENT FUEL COOLING PUMPS OR
1–OUT–OF–4 RHR PUMPS IN UNIT 1 OR
1–OUT–OF–2 RHR PUMPS IN UNIT 2 FOR SUCCESS



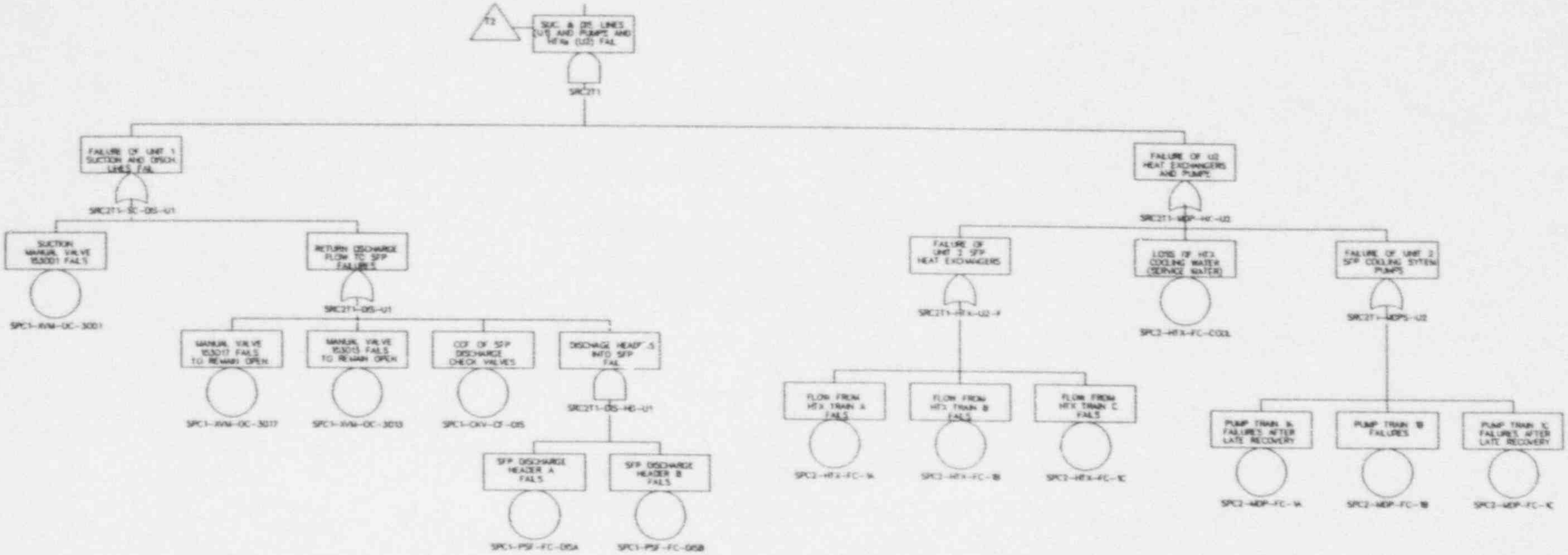
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNITS 1 & 2)
EARLY RECOVERY - CASE 1
2-OUT-OF-6 COOLING PUMPS FOR SUCCESS
TRANSFERS TO SR12C1



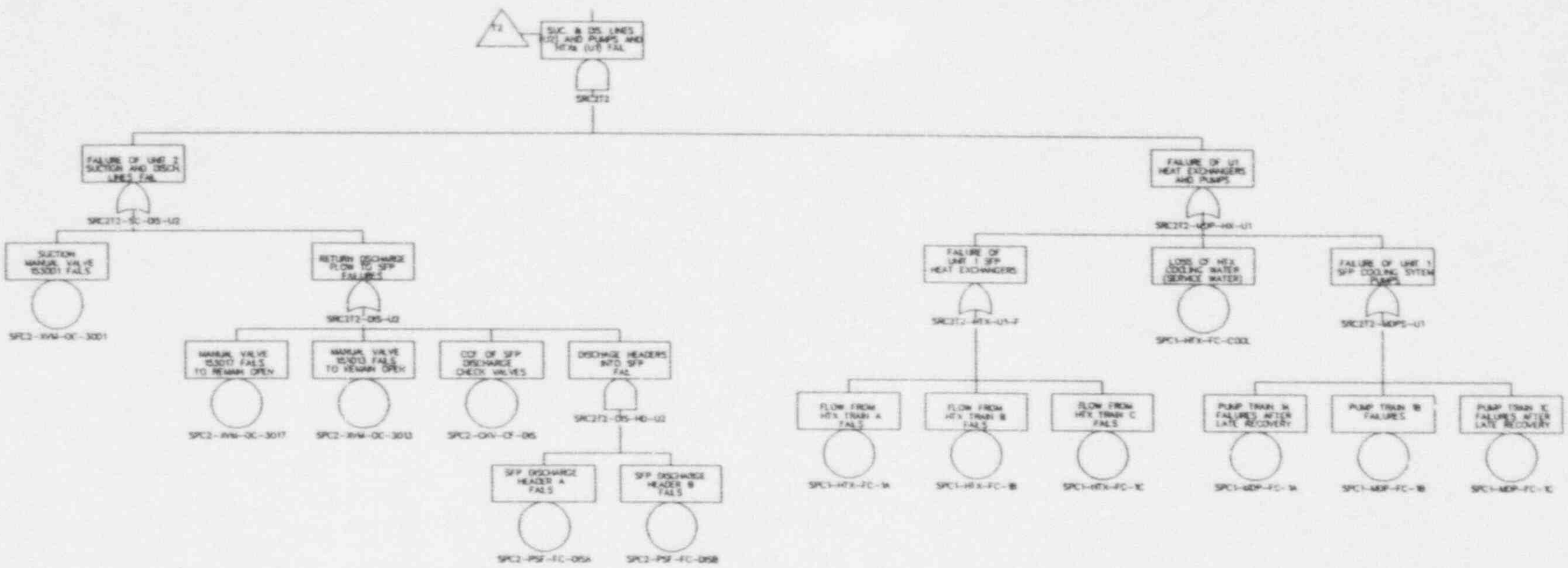
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNITS 1 & 2)
EARLY RECOVERY - CASE 1
2-OUT-OF-6 COOLING PUMPS FOR SUCCESS
TRANSFERS TO SR12C1



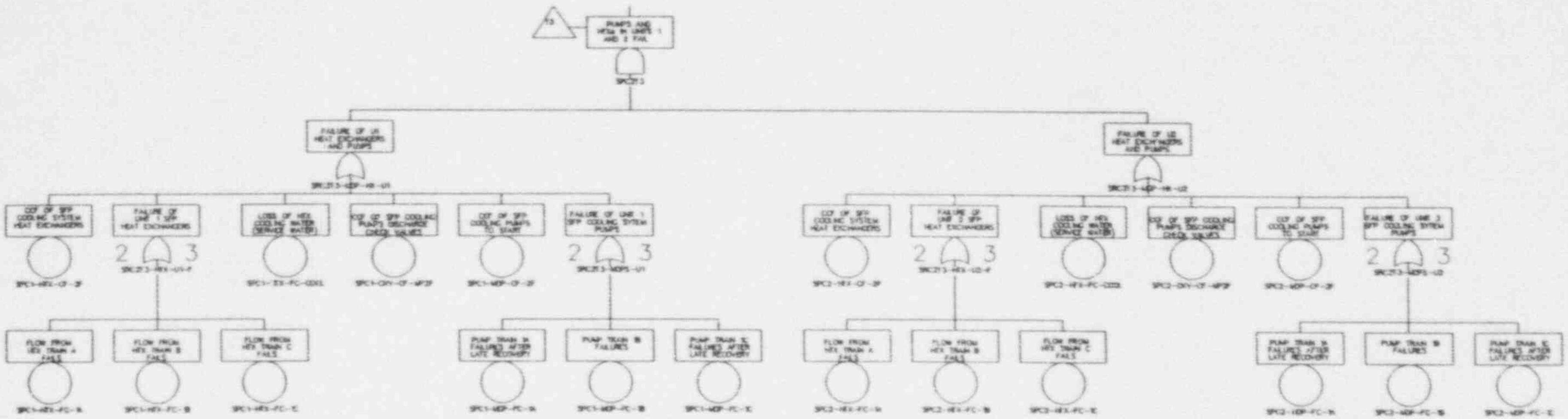
SUSQUEHANNA FUEL POOL COOLING SYSTEM FAILURE (UNITS 1 & 2)
EARLY RECOVERY - CASE 1
2-OUT-OF-6 COOLING PUMPS FOR SUCCESS
TRANSFERS TO SR12C1



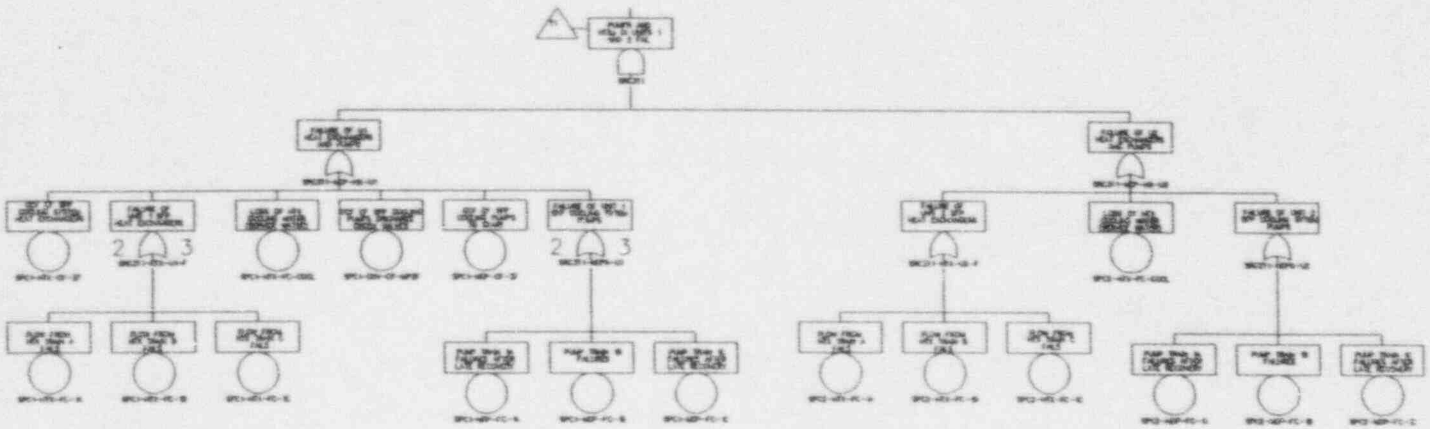
SUSQUEHANNA FUEL POOL COOLING SYSTEM FOR UNITS 1 & 2
EARLY RECOVERY - CASE 2
3-OUT-OF-6 COOLING PUMPS FOR SUCCESS
TRANSFERS TO SR12C2



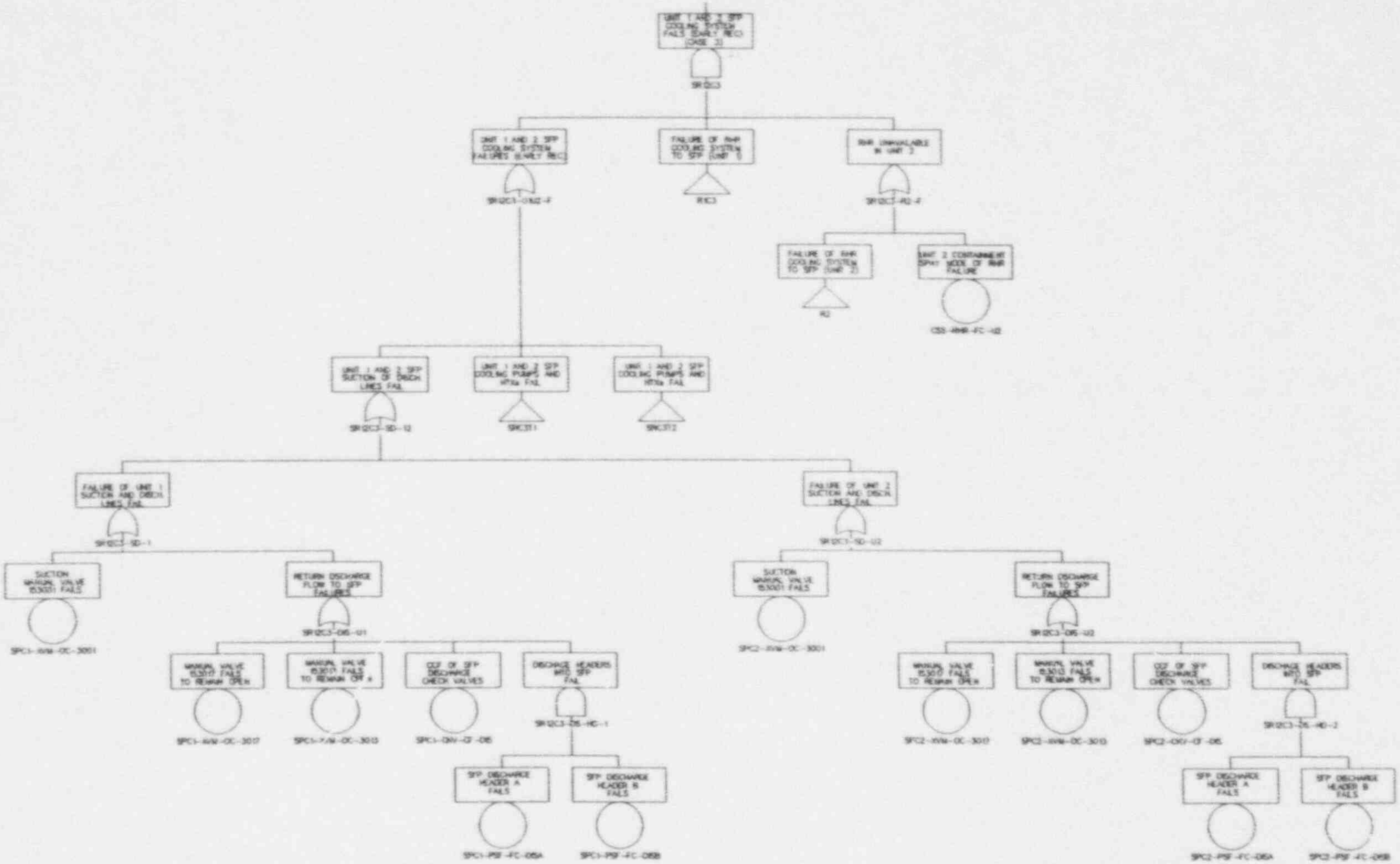
SUSQUEHANNA FUEL POOL COOLING SYSTEM FOR UNITS 1 & 2
EARLY RECOVERY - CASE 2
3-OUT-OF-6 COOLING PUMPS FOR SUCCESS
TRANSFERS TO SR12C2



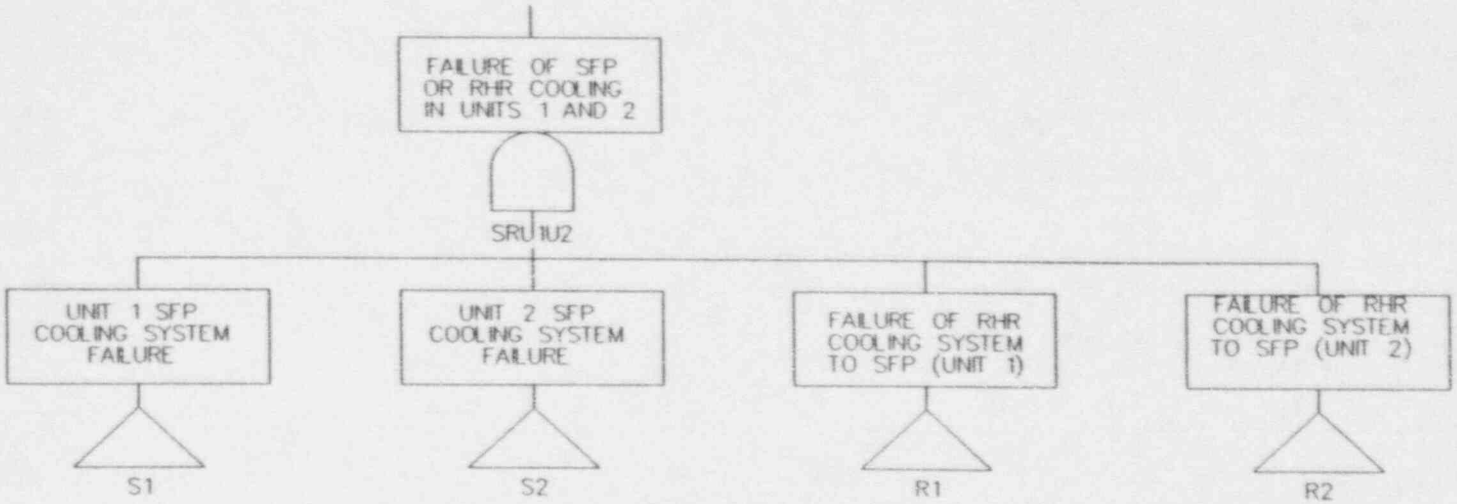
SUSQUEHANNA FUEL POOL COOLING SYSTEM FOR UNITS 1 & 2
EARLY RECOVERY - CASE 2
3-OUT-OF-6 SPENT FUEL PUMPS OR
1-OUT-OF-2 RHR PUMPS FOR SUCCESS
TRANSFERS TO SR12C2



SUSQUEHANNA FUEL POOL COOLING SYSTEM FOR UNITS 1 & 2
EARLY RECOVERY - CASE 3
4-OUT-OF-6 SPENT FUEL COOLING PUMPS OR
1-OUT-OF 2 RHR PUMPS FOR SUCCESS
TRANSFERS TO SR12C3



SUSQUEHANNA FUEL POOL COOLING SYSTEM FOR UNITS 1 & 2
EARLY RECOVERY – CASE 3
4–OUT–OF–6 SPENT FUEL COOLING PUMPS OR
1–OUT–OF–4 RHR PUMPS IN UNIT 1 OR
1–OUT–OF–2 RHR PUMPS IN UNIT 2 FOR SUCCESS



SPENT FUEL POOL COOLING SYSTEMS
FOR UNITS 1 AND 2
SUCCESS REQUIRES AT LEAST ONE SUCCESSFUL SYSTEM
FROM EITHER UNIT

A.7 References

A.1 K.D. Russell, et al., *Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE), Version 5.0: Technical Reference Manual*, NUREG/CR-6116, July 1994.

A.2 T.V. Vo, T.R. Blackburn, T.M. Mitts, H.K. Phan, *Risk Analysis for Spent Fuel Pool Cooling at Susquehanna Electric Power Station (Draft Report)*, Pacific Northwest Laboratory, prepared for the U.S. Nuclear Regulatory Commission Office of Nuclear Reactor Regulation under Contract DE-AC06-76RLO 1830, October 1994.

A.3 U.S. Nuclear Regulatory Commission, *Regulatory Analysis for the Resolution of Generic Issue 82, "Beyond Design Basis Accidents in Spent Fuel Pools"*, NUREG-1353, 1989.

A.4 J.W. Minarick, "Revised LOOP Recovery and PWR Seal LOCA Models," ORNL/NRC/LTR-89/11, technical letter report prepared for the U.S. Nuclear Regulatory Commission, August 1989.

A.5 J.A. Schroeder, *Simplified Plant Risk Model for Susquehanna 1 & 2 (ASP BWR C)*, Rev. 2, prepared for the U.S. Nuclear Regulatory Commission under JCN W6467-5, 1995.

A.6 J. Darby, et al, *Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Grand Gulf, Unit 1*, NUREG/CR-6143, 1994.

A.7 T.L. Chu, et al, *Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Grand Gulf, Unit* 1, NUREG/CR-6144, 1994.

A.8 P. Sobel, *Revised Livermore Seismic Hazard Estimates for 69 Nuclear Power Plant Sites East of the Rocky Mountains, Draft Report for Comment*, NUREG-1488, 1993.

APPENDIX B - EVENT QUANTIFICATION

B.1 Basic Event Probabilities

The fault trees used in this study are super-component based. The unavailability of a given super-component is approximated as the sum of the unavailabilities of the components contained in the super-component definition. The base component unavailabilities, in turn, are the same generic values used in the ASP models [B.1,B.2]. The basic events and associated probabilities used in this study (including a breakdown into components where relevant) are listed in Table B.1.

In some cases, the basic event probabilities (e.g., for the relative frequency of SFPC system leaks versus SFP boundary leaks) are derived. The estimation process used for each of these values is presented in Section B.3 below.

B.2 Initiating Event Frequencies

B.2.1 Loss of SFPC System

Over the time period 1987 through June 1996, the AEOD data base[1] includes 53 LOSPC events (see Table 5.5). Of these, 21 occurred during operation and 31 occurred during refueling. (The plant status for the one remaining event has not been determined.) Noting that the total number of reactor years for this time period is 1005 ry, and assuming 2-month refueling outages,

$$\lambda_{LOSFP}(\text{Operation}) \approx \frac{21}{\left[\frac{16}{18}\cdot 1005\ \text{ry}\right]} = 2.4\times10^{-2}/\text{ry}$$

$$\lambda_{LOSFP}(\text{Refueling}) \approx \frac{21}{\left[\frac{2}{18}\cdot 1005\ \text{ry}\right]} = 2.8\times10^{-1}/\text{ry}$$

B.2.2 Loss of Offsite Power

According to Ref. B.3, the frequency of not recovering power by time t can be modeled using a mixture of exponential distributions:

$$\lambda(t) = \sum_i \lambda_{0i} e^{-\alpha_i t^{\beta_i}}$$

For Susquehanna, i = I1, G1R2, S2R2, SS3 per Table 2 in the above reference. The numerical values for the parameters are listed in Table B.2. (Note that G1R2 corresponds to G5 and S2R2

[1] This study employs the June 13, 1996 version of the database; changes to the database, e.g., additional entries, can affect the conclusions drawn.

corresponds to SR7 in the reference.) The frequency of loss of offsite power (LOOP) is determined by setting $t = 0$; the result is $\lambda_{LOOP} = 0.08/yr$.[2]

B.2.3 Loss of Inventory

Table 5.4 provides a breakdown of loss of inventory events contained in the AEOD database. A categorization of the piping-associated SFP leaks by size and plant status is shown in Table B.3. In that table, 1) the values in parentheses are for the entire database and the numbers outside of the parentheses are for the period 1987 - 6/96; 2) the values in the right-hand column don't add up because the severity of 1 event was not determined, and 3) a "medium" leak is assumed to contribute 0.5 to the count for small leaks and 0.5 to the count for large leaks.

A similar breakdown of seal-associated SFP leaks by size and plant status is shown in Table B.4. Note that in both tables, the counts of non-refueling leakage events could be low (because the leak events are not necessarily reportable).

The evidence is too weak to prove that the frequency of SFP leaks is dependent on the size of the leak or on the plant status (refueling vs. non-refueling). On the other hand, it might be assumed *a priori* that there is such a dependence because: i) mechanisms that lead to small leaks appear to be more likely than mechanisms that lead to large ones; and ii) there is increased activity around the SFP during refueling, which leads to an increased possibility for error. Assuming that the loss of inventory initiating event frequency is dependent on leak size and plant status, the following estimates are used:[3]

$$\lambda_{LINV}(\text{Small Leak, Operation}) \approx \frac{(5+0)}{\left[\frac{16}{18}\cdot 1005\text{ ry}\right]} = 5\times10^{-3}/\text{ry}$$

$$\lambda_{LINV}(\text{Large Leak, Operation}) \approx \frac{(2+0)}{\left[\frac{16}{18}\cdot 1005\text{ ry}\right]} = 2\times10^{-3}/\text{ry}$$

$$\lambda_{LINV}(\text{Small Leak, Refueling}) \approx \frac{(2.5+1)}{\left[\frac{2}{18}\cdot 1005\text{ ry}\right]} = 3\times10^{-2}/\text{ry}$$

$$\lambda_{LINV}(\text{Large Leak, Refueling}) \approx \frac{(1.5+1)}{\left[\frac{2}{18}\cdot 1005\text{ ry}\right]} = 2\times10^{-2}/\text{ry}$$

---

[2] The model of Ref. B.3 is applicable to a single unit. In this analysis, it is used to represent the frequency of LOOP for two units as well, despite the large contribution of plant-centered LOOPs (i = 11). This conservative, simplified treatment is equivalent to assuming that the conditional probability of a LOOP at the second unit is virtually unity, given the occurrence of LOOP at the first unit.

[3] These estimates are based on an earlier categorization of events; a leak now considered to be "small" was categorized as being "large." Changes in the estimates to reflect the categorization shown in Table B.4 will not significantly affect the results of this study.

B.2.4 Loss of Primary Coolant

The frequency of LOCA during operation is obtained from Ref. B.4; the value of 1.5×10^{-2}/ry is appropriate for small LOCAs.

For LOCAs during refueling, Refs. B.5 (NUREG/CR-6143, the Grand Gulf shutdown risk study) and B.6 (NUREG/CR-6144, the Surry shutdown risk study) define the following non-pipe break events:

H LOCA = recoverable diversion of RCS coolant
J LOCA = LOCA in connected system (e.g., RHR)
K LOCA = maintenance-induced LOCA

Ref. B.5 indicates that 4 J LOCAs have been observed in 375 boiling water reactor (BWR) years. Ref. B.6 provides the following frequency estimates for J and K LOCAs:

J LOCA:	8E-3/yr
K LOCA:	3E-3/yr

Noting that the above estimates are annualized, the following estimate for the frequency of a LOCA during refueling is derived. (Note also that H LOCAs are not treated in this study, due to their easy recoverability, and due to the large amount of time generally available for the accidents being analyzed.)

$$\lambda_{J-LOCA}(\text{Refueling Outage}) \approx \frac{4}{\left[\frac{2}{18}\cdot 375\ \text{ry}\right]} = 9.6\times10^{-2}/\text{ry}$$

$$\lambda_{K-LOCA}(\text{Refueling Outage}) \approx 3\text{x}10^{-3}\cdot\frac{18}{2} = 2.7\times10^{-2}/\text{ry}$$

$$\lambda_{LOCA}(\text{Refueling Outage}) = \lambda_{J-LOCA}(\text{Refueling Outage}) + \lambda_{K-LOCA}(\text{Refueling Outage}) = 0.12/\text{ry}$$

B.2.5 Earthquake

According to Ref. B.7, the discrete frequency-magnitude distribution for earthquakes at the Susquehanna site is as shown in Table B.5. Summing the frequencies of earthquakes with peak ground acceleration (PGA) between 0.2g and 0.6g leads to an initiating event frequency estimate of 1.2×10^{-4}/ry. Earthquakes with PGA below 0.2g are assumed to have a negligible impact on the plant; earthquakes with PGA above 0.6 g are assumed to be direct core damage contributors (i.e., they are likely to cause severe damage, regardless of what happens to the spent fuel pool).

B.3 Derived Basic Event Probabilities

Except for the human error probabilities (which are discussed in Appendix C), most of the basic event probabilities listed in Section B.1 are generic values. This section documents the deriviations of the following non-generic basic event probabilities and split fractions[4]: a) the conditional frequency of failure to recover offsite power in 4 hours, b) the fraction of loss of inventory events involving the spent fuel pool cooling system, c) the fraction of events involving a complicated recovery, and d) the fraction of complicated events leading directly to core damage.

B.3.1 Offsite Power Recovery

The conditional frequency of failing to recover offsite power in time t, given a loss of offsite power event, is computed using the following equation.

$$\mathrm{Fr}\{\text{Nonrecovery by t} \mid \text{LOOP}\} = \frac{\sum_i \lambda_{0i} e^{-\alpha_i t^{\beta_i}}}{\sum_i \lambda_{0i}}$$

Using Table B.2 and evaluating the equation at t = 4 hours, the nonrecovery frequency is 0.045.

B.3.2 Loss of Inventory Events Involving SFPC System

The loss of inventory event trees shown in Appendix A distinguish between losses originating from the SFPC system (e.g., valve misalignments) and those originating from the SFP boundary (e.g., pneumatic seal failures). The relative frequencies of these two classes are estimated using the 1987 - 6/96 data shown in Tables B.3 and B.4.

$$\mathrm{Fr}\{\text{SFPC System} \mid \text{Small Leak, Operation}\} \approx \frac{5}{5+1} \approx 0.8$$

$$\mathrm{Fr}\{\text{SFPC System} \mid \text{Large Leak, Operation}\} \approx \frac{2}{2+1} \approx 0.7$$

$$\mathrm{Fr}\{\text{SFPC System} \mid \text{Small Leak, Refueling}\} \approx \frac{3.5}{3.5+1} \approx 0.8$$

$$\mathrm{Fr}\{\text{SFPC System} \mid \text{Large Leak, Refueling}\} \approx \frac{0.5}{0.5+1} \approx 0.3$$

Note that in the case of the estimates for leaks during operation, no seal failures are included in the database for the time period of interest. The crude estimates developed are conservative with respect to the occurrence of seal failures. Note also that the associated basic event probabilities in Table B.1 are the complements of the above estimates.

---

[4] A split fraction is the conditional frequency of taking the upper path at a given event tree branching point, given the sequence of events leading up to that branching point. In this model, split fractions are treated as basic events in trivial (single element) fault trees.

B.3.3 Complicated Scenarios

In this study, it is recognized that complications in responding to a plant-wide event (e.g., a LOOP) can inhibit the operators from devoting sufficient resources to spent fuel pool problems until late in the scenario. This section describes the simple model used to quantify the likelihood of a complicated scenario. The likelihood that operators will not respond promptly, given a complicated scenario, is addressed in Appendix C.

a) Operationalized definition

The scenario is "complicated" when one or more of the following occur:

- Offsite power is unavailable early (including recovery), unless all emergency diesel generators (EDGs) are available
- One or more safety relief valves (SRVs) fail open or closed
- High Pressure Core Injection (HPCI) is unavailable
- RHR is unavailable
- A large seismic event (PGA ≥ 0.2g) occurs

These conditions are based on a consideration of key safety functions. The operators are likely to be in difficulty if they have problems with: i) primary system pressure, temperature, or level control; ii) suppression pool temperature or containment pressure control; iii) establishing shutdown cooling.

b) Scenarios which are "complicated" by definition

- Loss of offsite power, some EDGs available, failure of early offsite power recovery
- Loss of offsite power, no EDGs available (station blackout — SBO)
- All seismic scenarios

c) Scenarios for which split fractions must be computed

- Loss of offsite power
- Primary LOCA

d) Model

- LOOP (non-SBO)

  The scenario is complicated if either RHR, HPCI, or an SRV fails. Note that some power is available.

$$P\{Complicated\} = P\{RHR\} + P\{HPCI\} + P\{SRV\}$$

- LOCA

The scenario is complicated if a LOOP occurs or RHR or HPCI fails.

$$P\{\text{Complicated}\} = P\{\text{LOOP}\} + P\{\text{RHR}\} + P\{\text{HPCI}\}$$

e) Quantification

Using the Accident Sequence Precursor model for Susquehanna [B.4], the following failure probabilities are computed:

Failure	Probability
Offsite Power	2.7E-3[a]
RHR	4.1E-4
HPCI	2.7E-2
SRV	3.2E-2

[a]Based on: i) a consequential LOOP frequency 10 times higher than the base frequency, and ii) a time window of 24 hours.

The resulting split fractions are then as follows.

$P\{\text{Complicated}|\text{LOOP}\} = 5.9\text{E-}2$

$P\{\text{Complicated}|\text{LOCA}\} = 3.0\text{E-}2$

B.3.4 Core Damage Given a Complicated Scenario

If a scenario is complicated, there is a reasonable chance that core damage may occur, regardless of what happens to the spent fuel pool. This section describes the simple model used to quantify the likelihood of this occurrence.

a) Scenarios for which split fractions must be computed

- Loss of offsite power, complicated recovery
- Primary LOCA, Case 1, complicated recovery
- Primary LOCA, Cases 2 and 3
- Seismic event (PGA ≥ 0.2g), complicated recovery

Note that the split fractions need to be quantified conditional on the recovery being complicated, i.e., on one or more of the defining conditions for a complicated scenario being true.

b) Approach

If:

- the conditional core damage probability (CCDP) given an accident scenario,
- the conditional probability of core damage given that the scenario is not complicated, and
- the probability that the scenario is complicated scenario are known,

the conditional probability of core damage given a complicated scenario can be computed. In the following equation, the overbars denote a complemented event. Thus, for example, $P\{\overline{Complicated}\}$ is the probability that the scenario is not complicated.

$$P\{CD\} = P\{CD \mid Complicated\} \cdot P\{Complicated\} + P\{CD \mid \overline{Complicated}\} \cdot P\{\overline{Complicated}\}$$

$$\therefore \; P\{CD \mid Complicated\} = \frac{P\{CD\} - P\{CD \mid \overline{Complicated}\} \cdot P\{\overline{Complicated}\}}{P\{Complicated\}}$$

c) Quantification

Using the Accident Sequence Precursor model for Susquehanna [B.4], the following scenario-dependent probabilities are computed.

Scenario	P{CD}	P{Complicated}	$P\{\overline{Complicated}\}$	$P\{CD \mid \overline{Complicated}\}$	P{CD|Complicated}
LOOP	4.40E-05	5.90E-02	9.41E-01	3.00E-06	6.98E-04
PLOCA	5.80E-06	3.00E-02	9.70E-01	0.00E+00	1.93E-04
Seismic	1.05E-02	1.00E+00	0.00E+00	0.00E+00	1.05E-02

Notes:

1) For LOOP scenarios, the only path to core damage given that RHR, SRVs, HPCI are all successful is station blackout.
2) Seismic events are assumed to be complicated by definition
3) P{CD|EQE} is computed using information from the NUREG-1150 seismic analysis for Peach Bottom [B.9] because the results of the seismic assessment for Susquehanna were not available. The Peach Bottom conditional probabilities of core damage given each of the three earthquake acceleration levels between 0.2g and 0.6g are used as follows. (Note that the g_i in the second equation stands for the ith acceleration level, i = 1, 2, or 3.)

$$P\{CD \mid EQE\} \cdot P\{EQE\} = P\{CD \mid 0.23g\} \cdot P\{0.23g\} + P\{CD \mid 0.37g\} \cdot P\{0.37g\} + P\{CD \mid 0.53g\} \cdot P\{0.53g\}$$

$$P\{CD \mid EQE\} = \frac{\sum_{i=1,2,3} P\{CD \mid g_i\} P\{g_i\}}{\sum_{i=1,2,3} P\{g_i\}}$$

g	P{g} [B.7]	P{CD/g} [B.9]	P{CD/g}*P{g}
0.23	1.02E-04	1.76E-04	1.80E-08
0.37	1.34E-05	2.39E-02	3.20E-07
0.53	3.52E-06	2.59E-01	9.12E-07
TOTALS	1.19E-04		1.25E-06

B.4 References

B.1 M.T. Drouin, F.T. Harper, and A.L. Camp, *Analysis of Core Damage Frequency from Internal Events: Methodology Guidelines*, NUREG/CR-4550, Vol. 1, 1987.

B.2 A. Mosleh, *Procedure for Analysis of Common-Cause Failures in Probabilistic Safety Analysis*, NUREG/CR-5801, 1993.

B.3 J.W. Minarick, "Revised LOOP Recovery and PWR Seal LOCA Models," ORNL/NRC/LTR-89/11, technical letter report prepared for the U.S. Nuclear Regulatory Commission, August 1989.

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B.5 J. Darby, et al, *Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Grand Gulf, Unit 1*, NUREG/CR-6143, 1994.

B.6 T.L. Chu, et al, *Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Grand Gulf, Unit* 1, NUREG/CR-6144, 1994.

B.7 P. Sobel, *Revised Livermore Seismic Hazard Estimates for 69 Nuclear Power Plant Sites East of the Rocky Mountains, Draft Report for Comment*, NUREG-1488, 1993.

B.8 G.M. Grant, et al, *Emergency Diesel Generator Power System Reliability, 1987-1993*, INEL-95/0035, 1996.

B.9 J.A. Lambright, et al, *Analysis of Core Damage Frequency: Peach Bottom, Unit 2, External Events*, NUREG/CR-4550, Vol. 4, Rev. 1, Part 3, December 1990.

Table B.1 - Basic Event Data (Page 1 of 11)

BASIC EVENT NAME	COMPONENT DATA			BASIC EVENT PROB.
	COMPONENT NAME	FAILURE MODE	FAILURE PROB	
ALT-XHE-XM-SFP	Operator Action	Operator fails to establish alternate cooling early	1.0E-2	1.0E-2
ALT-XHE-XM-SFPL	Operator Action	Operator fails to establish alternate cooling late	8.0E-2	8.0E-2
ALT-XHE-XM-SFPP	Operator Action	Operator fails to establish alternate cooling during LOOP	3.0E-2	3.0E-2
CSS-RHR-FC-U1	Core Spray Injection Unit 1	Fails to operate	4.0E-4	4.0E-4
CSS-RHR-FC-U1	Core Spray Injection Unit 2	Fails to operate	4.0E-4	4.0E-4
EPS-DGN-CF-ALL	Diesel generators	CCF to start	1.44E-3	1.44E-3
EPS-DGN-FC-1A	Diesel generator 1A	Fails to start/run	1.1E-1	1.1E-1
EPS-DGN-FC-1ARE	Diesel generator 1A	Fails to start/run (refueling)	1.8E-1	1.8E-1
EPS-DGN-FC-1B	Diesel generator 1B	Fails to start/run	1.1E-1	1.1E-1
EPS-DGN-FC-1BRE	Diesel generator 1B	Fails to start/run (refueling)	1.8E-1	1.8E-1
EPS-DGN-FC-2A	Diesel generator 2A	Fails to start/run	1.1E-1	1.1E-1
EPS-DGN-FC-2ARE	Diesel generator 2A	Fails to start/run (refueling)	1.8E-1	1.8E-1
EPS-DGN-FC-2B	Diesel generator 2B	Fails to start/run	1.1E-1	1.1E-1
EPS-DGN-FC-2BRE	Diesel generator 2B	Faails to start/run (refueling)	1.8E-1	1.8E-1
EPS-XHE-NOREC	Operator Action	Fails to recover emergency power	3.0E-2	3.0E-2
EPWR-XHE-EA-REC	Human Action	Fails to recover offsite power within 4hrs	4.5E-2	4.5E-2
ESA-TRIP	Flag Event	SFP Trips with ESF Actuation	TRUE	TRUE
FVPWR-FC-SFP	Flag Event	Vital Power Available	TRUE	TRUE
GOPEN-AIR-FC	Gate air system	Fails to shut off or deflate	1.0E-6	1.0E-6
GOPEN-FC-CRN1	Crane 1	Fails to operate	6.0E-3	6.0E-3
GOPEN-FC-CRN2	Crane 2	Fails to operate	6.0E-3	6.0E-3
GOPEN-GAT-RL-CRN	Gate 1	Fails to release from crane	1.0E-4	1.0E-4
GOPEN-GATE-FC-1	Gate 1	Fails to remove	1.0E-4	1.0E-4
GOPEN-GATE-FC-2	Gate 2	Fails to remove	1.0E-4	1.0E-4
GOPEN-XHE-XA-INT	Operator Action	Fails to open gate	7.0E-3	7.0E-3
GOPEN-XVM-CO-CP	Cast Pit manual valve	Fails open	5.5E-7	5.5E-7

Table B.1 - Basic Event Data (Page 2 of 11)

BASIC EVENT NAME	COMPONENT DATA			BASIC EVENT PROB.
	COMPONENT NAME	FAILURE MODE	FAILURE PROB	
LMKUP-XHE-XA-SFP	Operator Action	Fails to align Makeup Systems (Late)	1.1E-2	1.1E-2
LPWR-XHE-LA-REC	Operator Action	Fails to recover power (Late)	0.5	0.5
MKP-XHA-XA-CLGIS	Operator Action	Fails to align Makeup Systems (Unit is critical, LINVC, isolated)	5.0E-4	5.0E-4
MKP-XHA-XA-CLGNI	Operator Action	Fails to align Makeup Systems (Unit is critical, LINVC, SFPC system, not isolated)	2.5E-3	2.5E-3
MKP-XHA-XA-CLNIB	Operator Action	Fails to align Makeup Systems (Unit is critical, LINVC, SFP boundary, not isolated)	1.8E-2	1.8E-2
MKP-XHE-XA-CSMIS	Operator Action	Fails to align Makeup Systems (Unit is critical, LINCS, isolated)	5.0E-4	5.0E-4
MKP-XHE-XA-CSMNI	Operator Action	Fails to align Makeup Systems (Unit is critical, LINCS, not isolated)	1.0E-3	1.0E-3
MKP-XHE-XA-RLGIS	Operator Action	Fails to align Makeup Systems or ECCS Systems (Unit is refueling, LINVR, isolated)	5.0E-4	5.0E-4
MKP-XHE-XA-RLGNI	Operator Action	Fails to align Makeup Systems or ECCS Systems (Unit is refueling, LINVR, SFPC system, not isolated)	2.5E-3	2.5E-3
MKP-XHE-XA-RLNIB	Operator Action	Fails to align Makeup Systems or ECCS Systems (Unit is refueling, LINVR, SFP boundary, not isolated)	1.8E-2	1.8E-2
MKP-XHE-XA-RSMIS	Operator Action	Fails to align Makeup Systems or ECCS Systems (Unit is refueling, LINRS, isolated)	5.0E-4	5.0E-4
MKP-XHE-XA-RSMNI	Operator Action	Fails to align Makeup Systems or ECCS Systems (Unit is refueling, LINRS, not isolated)	1.0E-3	1.0E-3
MUES-XHE-XA-LSFP	Operator Action	Fails to align Makeup or ECCS Systems (late)	1.1E-2	1.1E-2
MUES-XHE-XA-SFP	Operator Action	Fails to align Makeup or ECCS Systems	7.0E-3	7.0E-3
NCD-CORE-DM-12	Core Damage	All diesels available	6.98E-4	6.98E-4
NCD-CORE-DM-DGAL	Core Damage	All diesels available	6.98E-4	6.98E-4
NCD-CORE-DM-DGPR	Core Damage	Partial diesels available	6.98E-4	6.98E-4
NCD-CORE-DM-PL	Core Damage	During Primary LOCA	1.93E-4	1.93E-4
NCD-CORE-DM-PR	Core Damage	Primary LOCA during refueling	1.93E-4	1.93E-4
NCD-CORE-DM-SBO	Core Damage	During SBO	6.98E-4	6.98E-4

Table B.1 - Basic Event Data (Page 3 of 11)

BASIC EVENT NAME	COMPONENT DATA			BASIC EVENT PROB.
	COMPONENT NAME	FAILURE MODE	FAILURE PROB	
R1-XHE-XM-RHR	Operator Action	Fails to iniate RHR Assist Mode (unit 1)	7.0E-2	7.0E-2
R2-XHE-XM-RHR	Operator Action	Fails to iniate RHR Assist Mode (unit 2)	7.0E-2	7.0E-2
RHR1-CKV-CF-AC	Check valves 151 F031A and 151 F031C	CCF to open/remain open	2.78E-5	2.78E-5
RHR1-CKV-CF-BD	Check valves 151 F031B and 151 F031D	CCF to open/remain open	2.78E-5	2.78E-5
RHR1-HTX-CF-AB	RHR heat exchangers 1A and 1B	CCF to operate	1.37E-5	1.37E-5
RHR1-HTX-FC-1A	RHR heat exchanger 1A	Plugs	1.37E-4	2.67E-4
	Manual valve HV 151 F047A	Plugs	4.0E-5	
	Manual valve HV 151 F003A	Plugs	4.0E-5	
	Relief valve PSV 151 F066A	Fails open	1.0E-5	
	Manual valve HV 151 F048B	Ruptures/leaks	4.0E-5	
RHR1-HTX-FC-1B	RHR heat exchanger 1B	Plugs	1.37E-4	2.67E-4
	Manual valve HV 151 F047B	Plugs	4.0E-5	
	Manual valve HV 151 F003B	Plugs	4.0E-5	
	Relief valve PSV 151 F066B	Fails open	1.0E-5	
	Manual valve HV 151 F048B	Ruptures/leaks	4.0E-5	
RHR1-HTX-FC-COOL	RHR HTX cooling system	Fails to operate	2.4E-4	2.4E-4
RHR1-MDP-CF-AC	RHR pumps 1A and 1C	CCF to start	4.5E-5	4.5E-5
RHR1-MDP-CF-BD	RHR pumps 1B and 1D	CCF to start	4.5E-5	4.5E-5
RHR1-MDP-FC-1A	RHR motor driven pump 1A	Fails to start	3.0E-3	4.0E-3
	RHR motor driven pump 1A	Fails to run	7.2E-4	
	Manual valve HV 151 F006A	Fails to open/remain open	1.4E-4	
	Check valve 151 F031A	Fails to open/remain open	1.0E-4	
	Manual valve 151 F034A	Fails to remain open	4.0E-5	
RHR1-MDP-FC-1B	RHR motor driven pump 1B	Fails to start	3.0E-3	4.0E-3
	RHR motor driven pump 1B	Fails to run	7.2E-4	
	Manual valve HV 151 F006B	Fails to open	1.4E-4	
	Check valve 151 F031B	Fails to open/remain open	1.0E-4	
	Manual valve 151 F034B	Fails to remain open	4.0E-5	

Table B.1 - Basic Event Data (Page 4 of 11)

BASIC EVENT NAME	COMPONENT DATA			BASIC EVENT PROB.
	COMPONENT NAME	FAILURE MODE	FAILURE PROB	
RHR1-MDP-FC-1C	RHR motor driven pump 1C	Fails to start	3.0E-3	4.0E-3
	RHR motor driven pump 1C	Fails to run	7.2E-4	
	Manual valve HV 151 F006C	Fails to open	1.4E-4	
	Check valve 151 F031C	Fails to open/remain open	1.0E-4	
	Manual valve 151 F034C	Fails to remain open	4.0E-5	
RHR1-MDP-FC-1D	RHR motor driven pump 1D	Fails to start	3.0E-3	4.0E-3
	RHR motor driven pump 1D	Fails to run	7.2E-4	
	Manual valve HV 151 F006D	Fails to open	1.4E-5	
	Check valve 151 F031D	Fails to open/remain open	1.0E-4	
	Manual valve 151 F034D	Fails to remain open	4.0E-5	
RHR1-PSF-CC-DISA	Manual valve 153070A	Fails to open/remain open	1.4E-4	2.4E-4
	Check valve 153071A	Fails to open/remain open	1.0E-4	
RHR1-PSF-CC-DISB	Manual valve 153070B	Fails to open/remain open	1.4E-4	2.4E-4
	Check valve 153071B	Fails to open/remain open	1.0E-4	
RHR1-TRNS-UA-TM	RHR trains A and B	Unavailable due to Test/Maintenance	1.3E-1	1.3E-1
RHR1-XVM-CC-010A	Manual valve 151 F010A	Fails to open/remain open	1.4E-4	1.4E-4
RHR1-XVM-CC-010B	Manual valve 151 F010B	Fails to open/remain open	1.4E-4	1.4E-4
RHR1-XVM-CC-1070	Manual valve 151070	Fails to open/remain open	1.4E-4	1.4E-4
RHR1-XVM-CC-SUC	Manual valve 153021	Fails to open/remain open	1.4E-4	2.8E-4
	Manual valve 153060	Fails to open/remain open	1.4E-4	
RHR1-XVM-OO-017A	Manual valve HV 151 F017A	Fails to close	1.0E-4	1.0E-4
RHR1-XVM-OO-017B	Manual valve HV 151 F017B	Fails to close	1.0E-4	1.0E-4
RHR1-XVM-OO-4A	Manual valve HV 151 F004A	Fails to close	1.0E-4	1.0E-4
RHR1-XVM-OO-4B	Manual valve HV 151 F004B	Fails to close	1.0E-4	1.0E-4
RHR1-XVM-OO-4C	Manual valve HV 151 F004C	Fails to close	1.0E-4	1.0E-4
RHR1-XVM-OO-4D	Manual valve HV 151 F004D	Fails to close	1.0E-4	1.0E-4
RHR1-XVM-OO-SFP1	Manual valve 153001	Fails to close	1.0E-4	1.0E-4
RHR2-CKV-CF-AC	Check valves 151 F031A and 151 F031C	CCF to open/remain open	2.78E-5	2.78E-5
RHR2-HTX-CF-AB	RHR heat exchangers 1A and 1B	CCF to operate	1.37E-5	1.37E-5

Table B.1 - Basic Event Data (Page 5 of 11)

BASIC EVENT NAME	COMPONENT DATA			BASIC EVENT PROB.
	COMPONENT NAME	FAILURE MODE	FAILURE PROB	
RHR2-HTX-FC-1A	RHR heat exchanger 1A	Plugs	1.37E-4	2.67E-4
	Manual valve HV 151 F047A	Plugs	4.0E-5	
	Manual valve HV 151 F003A	Plugs	4.0E-5	
	Relief valve PSV 151 F066A	Fails open	1.0E-5	
	Manual valve HV 151 F048B	Ruptures/leaks	4.0E-5	
RHR2-HTX-FC-COOL	RHR HTX cooling system	Fails to operate	2.4E-4	2.4E-4
RHR2-MDP-CF-AC	RHR pumps 1A and 1C	CCF to start	4.5E-5	4.5E-5
RHR2-MDP-FC-1A	RHR motor driven pump 1A	Fails to start	3.0E-3	4.0E-3
	RHR motor driven pump 1A	Fails to run	7.2E-4	
	Manual valve HV 151 F006A	Fails to open/remain open	1.4E-4	
	Check valve 151 F031A	Fails to open/remain open	1.0E-4	
	Manual valve 151 F034A	Fails to remain open	4.0E-5	
RHR2-MDP-FC-1C	RHR motor driven pump 1C	Fails to start	3.0E-3	4.0E-3
	RHR motor driven pump 1C	Fails to run	7.2E-4	
	Manual valve HV 151 F006C	Fails to open	1.4E-4	
	Check valve 151 F031C	Fails to open/remain open	1.0E-4	
	Manual valve 151 F034C	Fails to remain open	4.0E-5	
RHR2-PSF-CC-DISA	Manual valve 153070A	Fails to open/remain open	1.4E-4	2.4E-4
	Check valve 153071A	Fails to open/remain open	1.0E-4	
RHR2-PSF-CC-DISB	Manual valve 153070B	Fails to open/remain open	1.4E-4	2.4E-4
	Check valve 153071B	Fails to open/remain open	1.0E-4	
RHR2-TRNS-UA-TM	RHR trains A and B	Unavailable due to Test/Maintenance	3.0E-3	3.0E-3
RHR2-XVM-CC-1070	Manual valve 151070	Fails to open/remain open	1.4E-4	1.4E-4
RHR2-XVM-CC-SUC	Manual valve 153021	Fails to open/remain open	1.4E-4	2.8E-4
	Manual valve 153060	Fails to open/remain open	1.4E-4	
RHR2-XVM-OO-017A	Manual valve HV 151 F017A	Fails to close	1.0E-4	1.0E-4
RHR2-XVM-OO-4A	Manual valve HV 151 F004A	Fails to close	1.0E-4	1.0E-4
RHR2-XVM-OO-4C	Manual valve HV 151 F004C	Fails to close	1.0E-4	1.0E-4
RHR2-XVM-OO-SFP1	Manual valve 153001	Fails to close	1.0E-4	1.0E-4
SFP-LEAK-AUTOISO	SFP Isolation	Automatic Isolation	6.0E-6	6.0E-6

Table B.1 - Basic Event Data (Page 6 of 11)

BASIC EVENT NAME	COMPONENT DATA			BASIC EVENT PROB.
	COMPONENT NAME	FAILURE MODE	FAILURE PROB	
SFP-MKUP-ALT-F	System Failure	Alternate SFP Makup System fails	1.0E-2	1.0E-2
SFP-MKUP-ECCS-F	System Failure	ECCS Systems fail to provide water	1.0E-1	1.0E-1
SFP-MKUP-REG-F	System Failure	Regular SFP Makup System fails	1.0E-1	1.0E-1
SFP-MKUP-U2-F	System Failure	Unit 2 makup system fail to provide water	5.0E-2	5.0E-2
SFP-OP-GATE	Flag Event	SFPs are connectable	TRUE	TRUE
SFP-OPEN-GATE	Gate Status	Open gate status of transfer gate between pools	1.0E-1	1.0E-1
SFP-XHE-ISO-LK	Operator Action	Fails to isolate leak during Primary LOCA	7.0E-3	7.0E-3
SFP-XHE-MANISO-E	Operator Action	Fails to isolate small SFP boundary leak (early)	7.0E-3	7.0E-3
SFP-XHE-MANIOS-L	Operator Action	Fails to isolate small SFP boundary leak (late)	8.0E-2	8.0E-2
SFP-XHE-XA-ECCS	Operator Action	Fails to align ECCS	1.0E-3	1.0E-3
SFP-XHE-XE-LINVC	Operator Action	Fails to restore SFP (Loss of Inventory) Unit is critical	7.0E-2	7.0E-2
SFP-XHE-XE-LINVR	Operator Action	Fails to restore SFP (Loss of Inventory) Unit is refueling	4.0E-3	4.0E-3
SFP-XHE-XE-LP	Operator Action	Fails to restore SFP Cooling during loss of power	7.0E-2	7.0E-2
SFP-XHE-XE-PLC	Operator Action	Fails to restore SFP Cooling during Primary LOCA (Unit is critical)	7.0E-2	7.0E-2
SFP-XHE-XE-PLR	Operator Action	Fails to restore SFP Cooling during Primary LOCA (Unit is refueling)	4.0E-3	4.0E-3
SFP-XHE-XE-UC	Operator Action	Fails to restore SFP Cooling (unit is critical)	4.0E-2	4.0E-2

Table B.1 - Basic Event Data (Page 7 of 11)

BASIC EVENT NAME	COMPONENT DATA			BASIC EVENT PROB.
	COMPONENT NAME	FAILURE MODE	FAILURE PROB	
SFP-XHE-XE-UR	Operator Action	Fails to restore SFP Cooling (unit is refueling)	4.0E-2	4.0E-2
SFP1-XHE-XM-LSFP	Operator Action	Fails to iniate SFP Cooling after late recovery (unit 1)	8.0E-2	8.0E-2
SFP1-XHE-XM-SFP	Operator Action	Fails to iniate SFP Cooling (early, unit 1)	7.0E-3	7.0E-3
SFP2-XHE-XM-LSFP	Operator Action	Fails to iniate SFP Cooling after late recovery (unit 2)	8.0E-2	8.0E-2
SFP2-XHE-XM-SFP	Operator Action	Fails to initate SFP Cooling (early, unit 2)	3.0E-2	3.0E-2
SFPS-XHE-XM-LSFP	Operator Action	Fails to initate SFP Cooling (late, unit 1 and 2)	1.1E-2	1.1E-2
SPC1-CKV-CF-2F	SFP heat exchanger dis. chk valves	CCF to open/remain open	1.87E-5	1.87E-5
SPC1-CKV-CF-DIS	SFP discharge check valves	CCF to open/remain open	2.67E-5	2.67E-5
SPC1-CKV-CF-MP2F	SFP pump discharge check valves	CCF (2-of-3) to open/remain open	3.16E-5	3.16E-5
SPC1-CKV-CF-MPA	SFP pump discharge check valves	CCF (all 3) to open/remain open	1.69E-5	1.69E-5
SPC1-HTX-CF-2F	SFP heat exchangers	CCF (2-of-3) HTXs	1.87E-5	1.87E-5
SPC1-HTX-CF-ALL	SFP heat exchangers	CCF (all 3) HTXs	3.7E-6	3.7E-6
SPC1-HTX-FC-1A	Manual valve 153002A Heat exchanger 1A Manual valve 153004A	Plugs Plugs Plugs	4.0E-5 1.37E-5 4.0E-5	2.17E-5
SPC1-HTX-FC-1B	Manual valve 153002B Heat exchanger 1B Manual valve 153004B	Plugs Plugs Plugs	4.0E-5 1.37E-5 4.0E-5	2.17E-5
SPC1-HTX-FC-1C	Manual valve 153002C Heat exchanger 1C Manual valve 153004C	Plugs Plugs Plugs	4.0E-5 1.37E-5 4.0E-5	2.17E-5
SPC1-HTX-FC-COOL	SFP HTX cooling system	Fails to operate	2.4E-4	2.4E-4
SPC1-MDP-CF-2F	SFP MDP (early)	CCF to start/run (2-of-3)	5.86E-4	5.86E-4

Table B.1 - Basic Event Data (Page 8 of 11)

BASIC EVENT NAME	COMPONENT DATA			BASIC EVENT PROB.
	COMPONENT NAME	FAILURE MODE	FAILURE PROB	
SPC1-MDP-CF-ALL	SFP MDP (early)	CCF to start/run (all 3)	2.72E-4	2.72E-4
SPC1-MDP-CF-L2F	SFP MDP (late)	CCF to start/run (2-of-3)	5.86E-4	5.86E-4
SPC1-MDP-CF-LALL	SFP MDP (late)	CCF to start/run (all 3)	2.72E-4	2.72E-4
SPC1-MDP-FC-1A	Manual valve 153006A	Fails to remain open	4.0E-5	3.88E-3
	Motor driven pump 1A	Fails to start/run	3.7E-3	
	Check valve 153009A	Fails to open/remain open	1.0E-4	
	Manual valve 153010A	Fails to remain open	4.0E-5	
SPC1-MDP-FC-1AL (late)	Manual valve 153006A	Fails to remain open	4.0E-5	3.88E-3
	Motor driven pump 1A	Fails to start/run	3.7E-3	
	Check valve 153009A	Fails to open/remain open	1.0E-4	
	Manual valve 153010A	Fails to remain open	4.0E-5	
SPC1-MDP-FC-1B	Manual valve 153006B	Fails to remain open	4.0E-5	3.88E-3
	Motor driven pump 1B	Fails to start/run	3.7E-3	
	Check valve 153009B	Fails to open/remain open	1.0E-4	
	Manual valve 153010B	Fails to remain open	4.0E-5	
SPC1-MDP-FC-1BL (late)	Manual valve 153006B	Fails to remain open	4.0E-5	3.88E-3
	Motor driven pump 1B	Fails to start/run	3.7E-3	
	Check valve 153009B	Fails to open/remain open	1.0E-4	
	Manual valve 153010B	Fails to remain open	4.0E-5	
SPC1-MDP-FC-1C	Manual valve 153006C	Fails to remain open	4.0E-5	3.88E-3
	Motor driven pump 1C	Fails to start/run	3.7E-3	
	Check valve 153009C	Fails to open/remain open	1.0E-4	
	Manual valve 153010C	Fails to remain open	4.0E-5	
SPC1-MDP-FC-1CL (late)	Manual valve 153006C	Fails to remain open	4.0E-5	3.88E-3
	Motor driven pump 1C	Fails to start/run	3.7E-3	
	Check valve 153009C	Fails to open/remain open	1.0E-4	
	Manual valve 153010C	Fails to remain open	4.0E-5	
SPC1-PSF-FC-DISA	Manual valve 153018A	Plugs	4.0E-5	1.4E-4
	Check valve 153019A	Fails to open/remain open	1.0E-4	
SPC1-PSF-FC-DISB	Manual valve 153018B	Plugs	4.0E-5	1.4E-4
	Check valve 153019B	Fails to open/remain open	1.0E-4	

Table B.1 - Basic Event Data (Page 9 of 11)

BASIC EVENT NAME	COMPONENT DATA			BASIC EVENT PROB.
	COMPONENT NAME	FAILURE MODE	FAILURE PROB	
SPC1-XVM-OC-3001	Manual valve 153001	Plugs	4.0E-5	4.0E-5
SPC1-XVM-OC-3013	Manual valve 153013	Fails to remain open/Plugs	4.0E-5	4.0E-5
SPC1-XVM-OC-3017	Manual valve 153017	Fails to remain open/Plugs	4.0E-5	4.0E-5
SPC2-CKV-CF-DIS	SFP discharge check valves	CCF to open/remain open	2.67E-5	2.67E-5
SPC2-CKV-CF-MP2F	SFP pump discharge check valves	CCF (2-of-3) to open/remain open	3.16E-5	3.16E-5
SPC2-CKV-CF-MPA	SFP pump discharge check valves	CCF (all 3) to open/remain open	1.69E-5	1.69E-5
SPC2-HTX-CF-2F	SFP heat exchangers	CCF (2-of-3) HTXs	1.87E-5	1.87E-5
SPC2-HTX-CF-ALL	SFP heat exchangers	CCF (all 3) HTXs	3.7E-6	3.7E-6
SPC2-HTX-FC-1A	Manual valve 153002A	Plugs	4.0E-5	2.17E-5
	Heat exchanger 1A	Plugs	1.37E-5	
	Manual valve 153004A	Plugs	4.0E-5	
SPC2-HTX-FC-1B	Manual valve 153002B	Plugs	4.0E-5	2.17E-5
	Heat exchanger 1B	Plugs	1.37E-5	
	Manual valve 153004B	Plugs	4.0E-5	
SPC2-HTX-FC-1C	Manual valve 153002C	Plugs	4.0E-5	2.17E-5
	Heat exchanger 1C	Plugs	1.37E-5	
	Manual valve 153004C	Plugs	4.0E-5	
SPC2-HTX-FC-COOL	SFP HTX cooling system	Fails to operate	2.4E-4	2.4E-4
SPC2-MDP-CF-2F	SFP MDP (early)	CCF to start/run (2-of-3)	5.86E-4	5.86E-4
SPC2-MDP-CF-ALL	SFP MDP (early)	CCF to start/run (all 3)	2.72E-4	2.72E-4
SPC2-MDP-CF-L2F	SFP MDP (late)	CCF to start/run (2-of-3)	5.86E-4	5.86E-4
SPC2-MDP-CF-LALL	SFP MDP (late)	CCF to start/run (all 3)	2.72E-4	2.72E-4
SPC2-MDP-FC-1A	Manual valve 153006A	Fails to remain open	4.0E-5	3.88E-3
	Motor driven pump 1A	Fails to start/run	3.7E-3	
	Check valve 153009A	Fails to open/remain open	1.0E-4	
	Manual valve 153010A	Fails to remain open	4.0E-5	
SPC2-MDP-FC-1AL (late)	Manual valve 153006A	Fails to remain open	4.0E-5	3.88E-3
	Motor driven pump 1A	Fails to start/run	3.7E-3	
	Check valve 153009A	Fails to open/remain open	1.0E-4	
	Manual valve 153010A	Fails to remain open	4.0E-5	

Table B.1 - Basic Event Data (Page 10 of 11)

BASIC EVENT NAME	COMPONENT DATA			BASIC EVENT PROB.
	COMPONENT NAME	FAILURE MODE	FAILURE PROB	
SPC2-MDP-FC-1B	Manual valve 153006B	Fails to remain open	4.0E-5	3.88E-3
	Motor driven pump 1B	Fails to start/run	3.7E-3	
	Check valve 153009B	Fails to open/remain open	1.0E-4	
	Manual valve 153010B	Fails to remain open	4.0E-5	
SPC2-MDP-FC-1BL (late)	Manual valve 153006B	Fails to remain open	4.0E-5	3.88E-3
	Motor driven pump 1B	Fails to start/run	3.7E-3	
	Check valve 153009B	Fails to open/remain open	1.0E-4	
	Manual valve 153010B	Fails to remain open	4.0E-5	
SPC2-MDP-FC-1C	Manual valve 153006C	Fails to remain open	4.0E-5	3.88E-3
	Motor driven pump 1C	Fails to start/run	3.7E-3	
	Check valve 153009C	Fails to open/remain open	1.0E-4	
	Manual valve 153010C	Fails to remain open	4.0E-5	
SPC2-MDP-FC-1CL (late)	Manual valve 153006C	Fails to remain open	4.0E-5	3.88E-3
	Motor driven pump 1C	Fails to start/run	3.7E-3	
	Check valve 153009C	Fails to open/remain open	1.0E-4	
	Manual valve 153010C	Fails to remain open	4.0E-5	
SPC2-PSF-FC-DISA	Manual valve 153018A	Plugs	4.0E-5	1.4E-4
	Check valve 153019A	Fails to open/remain open	1.0E-4	
SPC2-PSF-FC-DISB	Manual valve 153018B	Plugs	4.0E-5	1.4E-4
	Check valve 153019B	Fails to open/remain open	1.0E-4	
SPC2-XVM-OC-3001	Manual valve 153001	Plugs	4.0E-5	4.0E-5
SPC2-XVM-OC-3013	Manual valve 153013	Fails to remain open/Plugs	4.0E-5	4.0E-5
SPC2-XVM-OC-3017	Manual valve 153017	Fails to remain open/Plugs	4.0E-5	4.0E-5
SSNV-SS-NV	Safety Systems	Not vulnerable to steam/flood prop.	1.0E-1	1.0E-1
SSV-XVM-NOREC	Operator Action	Fails to recover systems from steam/flood prop.	1.0E-1	1.0E-1
STM-XVM-XM-F	Steam isolation	Systems are not isolated from steam/flood prop.	1.0E-1	1.0E-1
TGATE-STAT	Gate Status	Fraction of time transfer gate is open during refueling	1.0	1.0

Table B.1 - Basic Event Data (Page 11 of 11)

BASIC EVENT NAME	COMPONENT DATA			BASIC EVENT PROB.
	COMPONENT NAME	FAILURE MODE	FAILURE PROB	
UNREC-XHE-RECV-1	Complicated Recovery of Core Cooling, LOOP, EP recovered early		5.9E-2	5.9E-2
UNREC-XHE-RECV-2	Complicated Recovery of Core Cooling, LOOP, EP not recovered		5.9E-2	5.9E-2
UNREC-XHE-RECV-P	Complicated Recovery of Core Cooling during Primary LOCA		3.0E-2	3.0E-2
LKSMR	Leak fraction	Fraction of small eaks in SFP boundary (operation and refueling)	2.0E-1	2.0E-1
LKLGC	Leak fraction	Fraction of large leaks in SFP boundary (operation)	3.0E-1	3.0E-1
LKLGR	Leak fraction	Fraction of large leaks in SFP boundary (refueling)	7.0E-1	7.0E-1
MISLLGE	Operator Action	Fails to isolate large SFP boundary leak (early)	1.8E-1	1.8E-1
MISLLGL	Operator Action	Fails to isolate large SFP boundary leak (late)	8.0E-1	8.0E-1
MISLSPCE	Operator Action	Fails to isolate SFPC system leak (refueling)	8.0E-2	8.0E-2
MISLSPHN	Operator Action	Fails to isolate SFPC system leak (critical)	8.0E-2	8.0E-2

Table B.2 - LOOP Model Parameters for Susquehanna

i	λ_0	α	β
I1	0.0797	3.3136	0.7837
G1R2	0.01	1.4697	0.9899
S2R2	0.005	0.1985	0.9759
SS3	0.002	0	0

Table B.3 - Breakdown of Piping-Associated SFP Leaks

	Refueling	Non-Refueling	
Small	3.5 (3.5)	5 (5)	8.5 (8.5)
Large	0.5 (1.5)	2 (2)	2.5 (3.5)
	4 (5)	8 (8)	

Table B.4 - Breakdown of Seal-Associated SFP Leaks

	Refueling	Non-Refueling	
Small	1 (1)	0 (1)	1 (2)
Large	1 (2)	0 (0)	1 (3)
	4 (7)	1 (2)	

Table B.5 - Frequency-Magnitude Relationship for Earthquakes at the Susquehanna Site

g level	Mean Frequency (/yr)
0.15	1.47E-04
0.26	5.29E-05
0.31	3.49E-05
0.41	1.71E-05
0.51	9.28E-06
0.66	4.26E-06
0.82	2.19E-06
1.02	1.02E-06

APPENDIX C - HUMAN RELIABILITY ANALYSIS

C.1 Approach

In keeping with the simple modeling approach used in other parts of the analysis, a simple human reliability analysis (HRA) technique is employed. This technique, documented in Ref. C.1, is a worksheet-based approach developed for the Accident Sequence Precursor (ASP) program. A sample worksheet for a single action is shown in Figure C.1. The worksheet requires the analyst to evaluate performance shaping factors (PSFs) relevant to a given action and then to modify base human error probabilities (HEPs) based on the evaluation.

The likelihood of failure of subsequent actions is treated using a second worksheet (see Figure C.2). This worksheet addresses issues that could increase the dependency between actions. This study treats multiple unit actions (e.g., failure of operators at Unit 2 to restore spent fuel pool makeup using Unit 2 systems, given that operators at Unit 1 have failed using the Unit 1 systems) using the worksheet. In general, the result is that there is a moderate level of dependency between actions.

The base HEPS and modification factors used in this procedure are derived from the widely used Technique for Human Error Prediction (THERP) [C.2] methodology. Thus, the approach does not represent a fundamentally different approach to dealing with human errors; rather it is a consistent psychology- and human factors-based compilation which allows relatively quick (if sometimes conservative) estimates of HEPs under a wide variety of conditions.

C.2 Performance Shaping Factors

There are six performance shaping factors required by the ASP HRA technique and used in this analysis. The performance shaping factors are:

1. Complexity, stress, and workload
2. Experience /training
3. Procedures
4. Ergonomics
5. Fitness for Duty
6. Crew dynamics.

The first four PSFs are of special interest to this study, due to the nature of the spent fuel pool accident scenarios hypothesized.

Plant:________ **Scenario:** _______ **Sequence Number:**______ **Cutset:**_______________

Task Error Description:____

1. Complexity, stress, and workload

		Processing	Response
high threat & stress	inadequate time	∞	∞
	adequate time	5	5
	expansive time	2	2
low threat & stress	inadequate time	∞	∞
	adequate time	1	1
	expansive time	1	1

2. Experience/training

		Processing	Response
low experience	poor training	10	10
	good training	1	1
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	5
	good procedures	1	1

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	3
	good ergonomics	0.7	0.7
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	1

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	1

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics			
Processing: 10 E-2	x	_______	x	_______	x	_______	x	_______	x	_______	x	_______	=		_______Processing Failure Probability
Response: 10 E-3	x	_______	x	_______	x	_______	x	_______	x	_______	x	_______	=	+	_______Response Failure Probability

________Task Failure Probability Without Formal Dependence

Figure C.1 - ASP HRA Worksheet (Sheet 1 of 2)

DEPENDENCY CONDITION TABLE

Condition Number	Crew (same or different)	System (same or different)	Location (same or different)	Time (close in time or not close in time	Cues (additional or not additional)	Dependency	Number of Human Action Failures
1	s	s	s	c	-	complete	if this
2	s	s	s	nc	na	high	
3	s	s	s	nc	a	moderate	error is the
4	s	s	d	c	-	high	
5	s	s	d	nc	na	moderate	third error
6	s	s	d	nc	a	low	
7	s	d	s	c	-	moderate	in the
8	s	d	s	nc	na	low	
9	s	d	s	nc	a	low	sequence
10	s	d	d	c	-	moderate	
11	s	d	d	nc	na	low	then the
12	s	d	d	nc	a	low	
13	d	s	s	c	-	moderate	dependency
14	d	s	s	nc	na	low	
15	d	s	s	nc	a	zero	is moderate,
16	d	s	d	c	-	zero	
17	d	s	d	nc	na	zero	if it is the
18	d	s	d	nc	a	zero	
19	d	d	s	c	-	low	fourth error
20	d	d	s	nc	na	zero	
21	d	d	s	nc	a	zero	dependency
22	d	d	d	c	-	zero	
23	d	d	d	nc	na	zero	is high
24	d	d	d	nc	a	zero	

Using N=Task Failure Probability Without Formal Dependence (calculated on previous page):

For Complete Dependence the probability of failure is 1.
For High Dependence the probability of failure is (1+N)/2
For Moderate Dependence the probability of failure is (1+6N)/7
For Low Dependence the probability of failure is (1+19N)/20
For Zero Dependence the probability of failure is N

(1 + (___*_______))/___ = _________ Task Failure Probability With Formal Dependence

Figure C.2 - ASP HRA Worksheet (page 2 of 2)

1. Complexity, stress, and workload. For this PSF several different conditions would exist for the hypothesized scenarios. For example, actions modeled such as placing RHR in a spent fuel pool assist cooling mode can be fairly complex and time consuming. That is, operators are engaged in multiple tasks which require a good deal of time to complete. In addition, variations in scenario timing occur due to different decay heat loads that can affect the time available, size of leaks etc., in turn affecting workload and the operators' stress. The number of personnel available in refueling vs. non fueling conditions can also be a factor.

2. Experience/training. For this PSF we needed to consider the interaction of the operators' training on events of this type, with the novelty of the particular scenario. For example, in some cases, operators have literally never taken the actions described. Whatever historical evidence existed was brought into consideration for this factor. Also, the procedures we reviewed were of a generic nature rather than a step-by-step prescription.

3. Procedures. This PSF is particularly important because procedures may not be well developed for some spent fuel pool scenarios as they have not received as much attention as direct core damage scenarios. Thus a distinction was made between those actions covered by either the plant EOPs or plant NOPs, and those covered by the non-specific Fuel Pool cooling procedures we had reviewed.

4. Ergonomics. This PSF is important in several ways. First, some of the needed accident mitigation equipment may not be accessible during the scenario (e.g., elevated radiation levels near the pool during a severe draining event). Another important ergonomics issue concerns the human-machine interface, as this affects how operators are informed of spent fuel pool conditions and how they manipulate components in response to their indications. Also, many actions are required outside of the control where typically the Human Machine Interface (HMI) is not as cleanly designed and controlled as in the reactor control room. The number and type of manual actions, and leak location also play a role.

5 & 6. Fitness for Duty and Crew dynamics. Due to the generic aspect of this analysis these factors were assumed to have no impact.

C.3 Key Assumptions

A number of assumptions were made to facilitate the analysis. These assumptions were made to assure consistencies across the human actions in the scenarios.

1. Operators all have good training
2. Procedures are generic
3. Ergonomics inside the control room are good
4. Ergonomics outside the control room are poor (as defined by the ASP HRA worksheet)
5. Operators are fit for duty
6. Crew dynamics are good

These assumptions were then modified based upon the factors of event timing, type of leak, scenario complexity, reactor state, need for manual actions outside the control room,

environmental concerns, and the possibility for second checks and recovery. Each of these issues were considered in completing the ASP quantification form. In general the kinds of considerations made for these factors are listed in Table C.1 below.

We also attempted to consider the known operating experience. Operating experience played a role in checking the reasonableness of the human error probabilities, as well as understanding how the factors in Table C.1 above might impact performance.

Table C.2 below shows the final results of the human reliability analysis. For each human error basic event, the failure mode, a description of what factors were considered in the quantification, and the resulting HEP are listed. Section C.4 of this appendix contains the ASP HRA worksheets for each of the human error. The worksheets occur in the approximate order of Table C.2.

Table C.1 - Factors and Considerations Influencing Human Error Probabilities

Factor	**Considerations/Assumptions**
Event timing	Affected by leak size, location
Type of leak	Large leaks are more easily detected, but give less time to act. Seal leaks are more easily detected than spent fuel pool cooling system leaks.
Scenario complexity	A non-isolated leak will increase event complexity and stress.
Reactor state	If the reactor is refueling personnel are more likely to be around increasing chance of detection of problems outside the control room. However extra personnel and workload can decrease vigilance
Actions outside control room	Generally ergonomics are less favorable in the plant
Environmental factors	Radiation, high temperature, high humidity can negatively impact performance
Second checks and recovery	Second unit can serve as possible source of recovery

Table C.2 - Results of the Human Reliability Analysis (HRA) (page 1 of 4)

Basic Event Name	Failure Mode	Description	Human Error Probability (HEP)
ALT-XHE-XM-SFP	Operator Fails to establish ALT cooling early	early, procedures non-specific, no degradation of conditions	.01
ALT-XHE-XM-SFPL	Operator fails to establish ALT cooling late	late, reduced time available, more stress, poor environmental factors possible	.08
ALT-XHE-XM-SFPP	Operator fails to establish ALT cooling during LOOP- **uncomplicated**	uncomplicated, expansive time, actions outside control	.03
ALT-XHE-XM-SFPP	Operator fails to establish ALT cooling during LOOP- **complicated**	complicated, increases stress, moderates expansive time, actions outside control room	.08
MKP-XHA-XA-CSMIS	Operator fails to align makeup systems early	actions outside control room, early, reactor critical, small leak isolated	.0035 2nd Unit Recovery .0035*.14=.0005
MKP-XHA-XA-RSMIS	Operator fails to align makeup systems early	actions outside control room, early, refueling, small leak isolated	.0035 2nd Unit Recovery .0035*.14=.0005
MKP-XHA-XA-CLGIS	Operator fails to align makeup systems early	actions outside control room, early, reactor critical, large leak isolated	.0035 2nd Unit Recovery .0035*.14=.0005
MKP-XHA-XA-RLGIS	Operator fails to align makeup systems early	actions outside control room, early, refueling, large leak isolated	.0035 2nd Unit Recovery .0035*.14=.0005
Basic Event Name	Failure Mode	Description	HEP
MKP-XHE-XA-CSMNI	Operator fails to align makeup systems early	actions outside control room, early, reactor critical, small leak, not isolated	.007 2nd Unit Recovery .007*.14=.001
MKP-XHE-XA-RSMNI	Operator fails to align makeup systems early	actions outside control room, early, refueling, small leak, not isolated	.007 2nd Unit Recovery .007*.14=.001

Table C.2 - Results of the Human Reliability Analysis (HRA) (page 2 of 4)

Basic Event Name	Failure Mode	Description	Human Error Probability (HEP)
MKP-XHA-XA-CLGNI	Operator fails to align makeup systems early	actions outside control room, early, reactor critical, large leak, not isolated	.018 2nd Unit Recovery .018*.14=.0025
MKP-XHA-XA-CLNIB	Operator fails to align makeup systems early	actions outside control room, early, reactor critical, large leak- boundary, not isolated	.018
MKP-XHE-XA-RLGNI	Operator fails to align makeup systems early	actions outside control room, early, refueling, large leak, not isolated	.018 2nd Unit Recovery .018*.14=.0025
MKP-XHE-XA-RLNIB	Operator fails to align makeup systems early	actions outside control room, early, refueling, large leak-boundary, not isolated	.018
EPS-XHE-NOREC	Operator fails to recover emergency power	actions outside control room	.03
GOPEN-XHE-XA-INT	Operators fail to open gate	early, actions outside control room	.007
LMKUP-XHE-XA-SFP	Operator fails to align makeup systems late	late, reduces time, more stress	.08 2nd Unit Recovery .08 * .14= .011

Table C.2 - Results of the Human Reliability Analysis (HRA) (page 3 of 4)

Basic Event Name	Failure Mode	Description	HEP
MUES-XHE-XA-SFP	Operator fails to align makeup or ECCS systems early	early	.007
MUES-XHE-XA-LSFP	Operator fails to align makeup or ECCS systems late	late, reduces time, more stress	.08 2nd Unit Recovery .08 * .14= .011
SFP-XHE-XE-UC	Operator fails to restore SFP Cooling System	decision only, reactor critical, leak location	.035
SFP-XHE-XE-UR	Operator fails to restore SFP Cooling System	decision only, reactor refueling, leak location	.035
SFP-XHE-XE-LP	Operator fails to restore SFP Cooling System	decision only, loss of power, leak location	.07
SFP-XHE-XE-LINVR	Operator fails to restore SFP Cooling System	decision only, reactor refueling, greater number of staff in plant, leak location	.0035
SFP-XHE-XE-LINVC	Operator fails to restore SFP Cooling System	decision only, reactor critical, leak location	.07
SFP-XHE-XE-PLR	Operator fails to restore SFP Cooling System	decision only, reactor refueling, greater number of staff in plant, leak location	0035
SFP-XHE-XE-PLC	Operator fails to restore SFP Cooling System	decision only, reactor critical, leak location	.07
R1-XHE-XM-RHR	Operator fails to initiate RHR mode of SFP cooling-Unit 1	early, uncomplicated, actions never performed, manual actions outside control room	.07
R2-XHE-XM-RHR	Operator fails to initiate RHR mode of SFP cooling-Unit 2	early, uncomplicated, actions never performed, manual actions outside control room	.07
SFP-XHE-ISO-LK	Operator fails to isolate leak during primary LOCA	potential environmental factors	.05

Table C.2 - Results of the Human Reliability Analysis (HRA) (page 4 of 4)

Basic Event Name	Failure Mode	Description	HEP
MISLSPHN	Operator fails to isolate SFP boundary leak, early	early, pipe leak, reactor critical, non-specific procedures, actions outside control room	.008
MISLSPCE	Operator fails to isolate SFP boundary leak, early	early, pipe leak, refueling, non-specific procedures, actions outside control room	.008
MISLLGE	Operator fails to isolate SFP boundary leak, early	early, large seal leak (reducing time available), difficult to mitigate, procedures non-specific, actions outside control room	.18
MISLLGL	Operator fails to isolate SFP boundary leak, late	late, large leak, procedures non-specific, poor environmental factors possible, actions outside control room	.8
SFP-XHE-MANISO-E	Operator fails to isolate SFP, early	early, small seal leak, non-specific procedures, actions outside control room	.007
SFP-XHE-MANISO-L	Operator fails to isolate SFP boundary Leak, late	late, non-specific procedures, poor environmental factors possible, outside control room	.08
SFP-XHE-XA-ECCS	Operator fails to align ECCS systems	well trained action	.001
SFP1-XHE-XM-SFP (Unit 1) SFP2-XHE-XM-SFP (Unit 2)	Operator fails to initiate SFP cooling- early	early, actions outside control room	.007
SFP1-XHE-XM-LSFP(Unit 1) SFP2-XHE-XM-LSFP (Unit 2)	Operator fails to initiate SFP cooling after late recovery	late, actions outside control room	.08

C.4 HRA Worksheets

The worksheets used to generate the results shown in Table C.2 are shown in the following pages.

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) ALT-XHE-XM-SFP

Plant:________ Scenario: ________________________ Sequence Number:______

Task Error Description: Operator Fails to Establish ALT Cooling Early

1. Complexity, stress, and workload

		Processing	Response
high threat & stress	inadequate time	∞	∞
	adequate time	5	5
	expansive time	2	2
low threat & stress	inadequate time	∞	∞
	adequate time	1	1
	expansive time	1	1

2. Experience/training

		Processing	Response
low experience	poor training	10	10
	good training	1	1
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	5
	good procedures	1	1

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	3
	good ergonomics	0.7	0.7
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	1

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	1

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2	x ____		x ____		x ____		x ____		x ____		x ____	=	____ Processing Failure Probability
Response:	10 E-3	x 1		x 1		x 5		x .7		x 1		x 1	=	+ .01 Response Failure Probability
														____ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) ALT-XHE-XM-SFPL

Plant:________ **Scenario:** ____________________ **Sequence Number:**______

Task Error Description: Operator Fails to Establish ALT Cooling Late

1. Complexity, stress, and workload

		Processing	Response
high threat & stress	inadequate time	∞	∞
	adequate time	5	(5)
	expansive time	2	2
low threat & stress	inadequate time	∞	∞
	adequate time	1	1
	expansive time	1	1

2. Experience/training

		Processing	Response
low experience	poor training	10	10
	good training	1	(1)
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	(5)
	good procedures	1	1

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	(3)
	good ergonomics	0.7	0.7
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	(1)

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	(1)

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics			
Processing:	10 E-2	x ____		x ____		x ____		x ____		x ____		x ____	=	____	Processing Failure Probability
Response:	10 E-3	x 5		x 1		x 5		x 3		x 1		x 1	=	+ .075	Response Failure Probability
														____	Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) ALT-XHE-XM-SFPP

Plant:________ **Scenario:** ________________________ **Sequence Number:**______

Task Error Description: Operator Fails to Establish ALT Cooling During LOOP, uncomplicated

Factor			Processing	Response
1. Complexity, stress, and workload	high threat & stress	inadequate time	∞	∞
		adequate time	5	5
		expansive time	2	(2)
	low threat & stress	inadequate time	∞	∞
		adequate time	1	1
		expansive time	1	1
2. Experience/training	low experience	poor training	10	10
		good training	1	(1)
	high experience	poor training	5	5
		good training	0.5	0.5
3. Procedures	procedures absent		10	10
	procedures present	poor procedures	5	(5)
		good procedures	1	1
4. Ergonomics	old plant	poor ergonomics	5	5
		good ergonomics	1	1
	retrofit plant	poor ergonomics	3	(3)
		good ergonomics	0.7	0.7
	new plant	poor ergonomics	2	2
		good ergonomics	0.4	0.4
5. Fitness for duty	unfit		25	25
	fit		1	(1)
6. Crew dynamics	poor crew dynamics		10	10
	good crew dynamics		1	(1)

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics			
Processing:	10 E-2	x ____	x	____	x	____	x	____	x	____	x	____	=		____ Processing Failure Probability
Response:	10 E-3	x 2	x	1	x	5	x	3	x	1	x	1	=	+	.03 Response Failure Probability
															____ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) ALT-XHE-XM-SFPP

Plant:________ **Scenario:** ______________________ **Sequence Number:**______

Task Error Description: Operator Fails to Establish ALT cooling during LOOP, complicated

Factor			Processing	Response
1. Complexity, stress, and workload	high threat & stress	inadequate time	∞	∞
		adequate time	5	5
		expansive time	2	2
	low threat & stress	inadequate time	∞	∞
		adequate time	1	1
		expansive time	1	1
2. Experience/training	low experience	poor training	10	10
		good training	1	1
	high experience	poor training	5	5
		good training	0.5	0.5
3. Procedures	procedures absent		10	10
	procedures present	poor procedures	5	5
		good procedures	1	1
4. Ergonomics	old plant	poor ergonomics	5	5
		good ergonomics	1	1
	retrofit plant	poor ergonomics	3	3
		good ergonomics	0.7	0.7
	new plant	poor ergonomics	2	2
		good ergonomics	0.4	0.4
5. Fitness for duty	unfit		25	25
	fit		1	1
6. Crew dynamics	poor crew dynamics		10	10
	good crew dynamics		1	1

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2	x ____	x	____	x	____	x	____	x	____	x	____	=	____ Processing Failure Probability
Response:	10 E-3	x 5	x	1	x	5	x	3	x	1	x	1	=	+ .075 Response Failure Probability
														____ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2)

Plant:________ **Scenario:** ______________ ________ **Sequence Number:**______

Task Error Description: Operator Fails to Align Makeup Systems Early- ~~small leak isolated~~, large leak isolated.

Factor	Branch	Sub-branch	Processing	Response
1. Complexity, stress, and workload	high threat & stress	inadequate time	∞	∞
		adequate time	5	5
		expansive time	2	2
	low threat & stress	inadequate time	∞	∞
		adequate time	1	1
		expansive time	1	(1)
2. Experience/training	low experience	poor training	10	10
		good training	1	(1)
	high experience	poor training	5	5
		good training	0.5	0.5
3. Procedures	procedures absent		10	10
	procedures present	poor procedures	5	(5)
		good procedures	1	1
4. Ergonomics	old plant	poor ergonomics	5	5
		good ergonomics	1	1
	retrofit plant	poor ergonomics	3	3
		good ergonomics	0.7	(0.7)
	new plant	poor ergonomics	2	2
		good ergonomics	0.4	0.4
5. Fitness for duty	unfit		25	25
	fit		1	(1)
6. Crew dynamics	poor crew dynamics		10	10
	good crew dynamics		1	(1)

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2	x ______	x	______	x	______	x	______	x	______	x	______	=	______ Processing Failure Probability
Response:	10 E-3	x 1	x	1	x	5	x	.7	x	1	x	1	=	+ .0035 Response Failure Probability

________ Task Failure Probability Without Formal Dependence

Multiply by .14 for moderate dependency with Unit Two Recovery

ASP HUMAN ERROR WORKSHEET (Page 1 of 2)

MKP-XHE-XA-CSMNI
MKP-XHE-XA-RSMNI

Plant:________ **Scenario:** ____________________ **Sequence Number:**______

Task Error Description: Operator fails to align makeup system early- small leak not isolated

1. Complexity, stress, and workload

			Processing	Response
1. Complexity, stress, and workload	high threat & stress	inadequate time	∞	∞
		adequate time	5	5
		expansive time	2	2 (circled)
	low threat & stress	inadequate time	∞	∞
		adequate time	1	1
		expansive time	1	1

2. Experience/training

			Processing	Response
2. Experience/training	low experience	poor training	10	10
		good training	1	1 (circled)
	high experience	poor training	5	5
		good training	0.5	0.5

3. Procedures

			Processing	Response
3. Procedures	procedures absent		10	10
	procedures present	poor procedures	5	5 (circled)
		good procedures	1	1

4. Ergonomics

			Processing	Response
4. Ergonomics	old plant	poor ergonomics	5	5
		good ergonomics	1	1
	retrofit plant	poor ergonomics	3	3
		good ergonomics	0.7	0.7 (circled)
	new plant	poor ergonomics	2	2
		good ergonomics	0.4	0.4

5. Fitness for duty

		Processing	Response
5. Fitness for duty	unfit	25	25
	fit	1	1 (circled)

6. Crew dynamics

		Processing	Response
6. Crew dynamics	poor crew dynamics	10	10
	good crew dynamics	1	1 (circled)

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics			
Processing:	10 E-2	x ____		x ____		x ____		x ____		x ____		x ____	=	____	Processing Failure Probability
Response:	10 E-3	x 2		x 1		x 5		x .7		x 1		x 1	=	+ .007	Response Failure Probability
														____	Task Failure Probability Without Formal Dependence

Multiply by .14 for moderate dependency with Unit Two Recovery

MKP-XHA-XA-CLGNI
MKP-XHA-XA-CLNIB
MKP-XHE-XA-RLGNI
MKP-XHE-XA-RLNIB

ASP HUMAN ERROR WORKSHEET (Page 1 of 2)

Plant:________ **Scenario:** ________________________ **Sequence Number:**_______

Task Error Description: Operator fails to align makeup system early- large leak, not isolated

1. Complexity, stress, and workload

		Processing	Response
high threat & stress	inadequate time	∞	∞
	adequate time	5	(5)
	expansive time	2	2
low threat & stress	inadequate time	∞	∞
	adequate time	1	1
	expansive time	1	1

2. Experience/training

		Processing	Response
low experience	poor training	10	10
	good training	1	(1)
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	(5)
	good procedures	1	1

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	3
	good ergonomics	0.7	(0.7)
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	(1)

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	(1)

Task Portion		Complexity, stress, and workload		Experience/training		Procedures		Ergonomics		Fitness for duty		Crew dynamics			
Processing:	10 E-2	x ____	x	____	x	____	x	____	x	____	x	____	=	____	Processing Failure Probability
Response:	10 E-3	x 5	x	1	x	5	x	.7	x	1	x	1	= +	.018	Response Failure Probability
														____	Task Failure Probability Without Formal Dependence

Multiply by .14 for moderate dependency for MKP-XHA-XA-CLGNI(.0025)
Recovery MKP-XHE-XA-RLGNI(.0025)

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) EPS-XHE-NOREC

Plant:________ **Scenario:** ______________________ **Sequence Number:**______

Task Error Description: Operator Fails to Recover Emergency Power

Factor	Branch	Sub-branch	Processing	Response
1. Complexity, stress, and workload	high threat & stress	inadequate time	∞	∞
		adequate time	5	5
		expansive time	2	2 (circled)
	low threat & stress	inadequate time	∞	∞
		adequate time	1	1
		expansive time	1	1
2. Experience/training	low experience	poor training	10	10
		good training	1	1 (circled)
	high experience	poor training	5	5
		good training	0.5	0.5
3. Procedures	procedures absent		10	10
	procedures present	poor procedures	5	5 (circled)
		good procedures	1	1
4. Ergonomics	old plant	poor ergonomics	5	5
		good ergonomics	1	1
	retrofit plant	poor ergonomics	3	3 (circled)
		good ergonomics	0.7	0.7
	new plant	poor ergonomics	2	2
		good ergonomics	0.4	0.4
5. Fitness for duty	unfit		25	25
	fit		1	1 (circled)
6. Crew dynamics	poor crew dynamics		10	10
	good crew dynamics		1	1 (circled)

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2	x ____		x ____		x ____		x ____		x ____		x ____	=	______ Processing Failure Probability
Response:	10 E-3	x 2		x 1		x 5		x 3		x 1		x 1	=	+ .03 Response Failure Probability
														______ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) GOPEN-XHE-XA-INT

Plant:________ **Scenario:** ______________________ **Sequence Number:**______

Task Error Description: Operator Fails to Open Gate, early

1. Complexity, stress, and workload

		Processing	Response
high threat & stress	inadequate time	∞	∞
	adequate time	5	5
	expansive time	2	2
low threat & stress	inadequate time	∞	∞
	adequate time	1	1
	expansive time	1	1

2. Experience/training

		Processing	Response
low experience	poor training	10	10
	good training	1	1
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	5
	good procedures	1	1

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	3
	good ergonomics	0.7	0.7
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	1

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	1

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2	x ______		x ______		x ______		x ______		x ______		x ______	=	______ Processing Failure Probability
Response:	10 E-3	x 2		x 1		x 5		x .7		x 1		x 1	=	+ .007 Response Failure Probability

______ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) LMKUP-XHE-XA-SFP

Plant:_________ **Scenario:** _______________________ **Sequence Number:**_______

Task Error Description: Operator Fails to Align Makeup Systems, late

Factor	Branch	Sub-branch	Processing	Response
1. Complexity, stress, and workload	high threat & stress	inadequate time	∞	∞
		adequate time	5	(5)
		expansive time	2	2
	low threat & stress	inadequate time	∞	∞
		adequate time	1	1
		expansive time	1	1
2. Experience/training	low experience	poor training	10	10
		good training	1	(1)
	high experience	poor training	5	5
		good training	0.5	0.5
3. Procedures	procedures absent		10	10
	procedures present	poor procedures	5	(5)
		good procedures	1	1
4. Ergonomics	old plant	poor ergonomics	5	5
		good ergonomics	1	1
	retrofit plant	poor ergonomics	3	(3)
		good ergonomics	0.7	0.7
	new plant	poor ergonomics	2	2
		good ergonomics	0.4	0.4
5. Fitness for duty	unfit		25	25
	fit		1	(1)
6. Crew dynamics	poor crew dynamics		10	10
	good crew dynamics		1	(1)

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics			
Processing:	10 E-2	x ______		x ______		x ______		x ______		x ______		x ______	=	______	Processing Failure Probability
Response:	10 E-3	x 5		x 1		x 5		x 3		x 1		x 1	=	+ .075	Response Failure Probability
														______	Task Failure Probability Without Formal Dependence

Multiply by .14 for moderate dependency with Unit Two Recovery

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) MUES-XHE-XA-SFP

Plant:________ **Scenario:** ________________________ **Sequence Number:**______

Task Error Description: Operator Fails to Align Makeup or ECCS Systems, early

1. Complexity, stress, and workload

		Processing	Response
high threat & stress	inadequate time	∞	∞
	adequate time	5	5
	expansive time	2	(2)
low threat & stress	inadequate time	∞	∞
	adequate time	1	1
	expansive time	1	1

2. Experience/training

		Processing	Response
low experience	poor training	10	10
	good training	1	(1)
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	(5)
	good procedures	1	1

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	3
	good ergonomics	0.7	(0.7)
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	(1)

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	(1)

Task Portion		Complexity, stress, and workload	Experience/ training	Procedures	Ergonomics	Fitness for duty	Crew dynamics		
Processing:	10 E-2	x____	x____	x____	x____	x____	x____	=	______ Processing Failure Probability
Response:	10 E-3	x 2	x 1	x 5	x .7	x 1	x 1	=	+ .007 Response Failure Probability
									______ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) MUES-XHE-XA-LSFP

Plant:________ **Scenario:** ________________________ **Sequence Number:**_______

Task Error Description: Operator Fails to Align Makeup or ECCS Systems, late

Factor	Branch	Sub-branch	Processing	Response
1. Complexity, stress, and workload	high threat & stress	inadequate time	∞	∞
		adequate time	5	5
		expansive time	2	2
	low threat & stress	inadequate time	∞	∞
		adequate time	1	1
		expansive time	1	1
2. Experience/training	low experience	poor training	10	10
		good training	1	1
	high experience	poor training	5	5
		good training	0.5	0.5
3. Procedures	procedures absent		10	10
	procedures present	poor procedures	5	5
		good procedures	1	1
4. Ergonomics	old plant	poor ergonomics	5	5
		good ergonomics	1	1
	retrofit plant	poor ergonomics	3	3
		good ergonomics	0.7	0.7
	new plant	poor ergonomics	2	2
		good ergonomics	0.4	0.4
5. Fitness for duty	unfit		25	25
	fit		1	1
6. Crew dynamics	poor crew dynamics		10	10
	good crew dynamics		1	1

Task Portion		Complexity, stress, and workload		Experience/training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2	x ___	x	___	x	___	x	___	x	___	x	___	=	______ Processing Failure Probability
Response:	10 E-3	x 5	x	1	x	5	x	3	x	1	x	1	=	+ .075 Response Failure Probability
														______ Task Failure Probability Without Formal Dependence

Multiply by .14 for moderate dependency with Unit Two Recovery

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) SFP-XHE-XE-UC

Plant:________ **Scenario:** ____________________ **Sequence Number:**______

Task Error Description: Operator Fails to Restore SFP Cooling System Decision

Factor	Condition	Sub-condition	Processing	Response
1. Complexity, stress, and workload	high threat & stress	inadequate time	∞	∞
		adequate time	5	5
		expansive time	2	2
	low threat & stress	inadequate time	∞	∞
		adequate time	1	1
		expansive time	1	1
2. Experience/training	low experience	poor training	10	10
		good training	1	1
	high experience	poor training	5	5
		good training	0.5	0.5
3. Procedures	procedures absent		10	10
	procedures present	poor procedures	5	5
		good procedures	1	1
4. Ergonomics	old plant	poor ergonomics	5	5
		good ergonomics	1	1
	retrofit plant	poor ergonomics	3	3
		good ergonomics	0.7	0.7
	new plant	poor ergonomics	2	2
		good ergonomics	0.4	0.4
5. Fitness for duty	unfit		25	25
	fit		1	1
6. Crew dynamics	poor crew dynamics		10	10
	good crew dynamics		1	1

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2	x 1		x 1		x 5		x .7		x 1		x 1	=	.035 Processing Failure Probability
Response:	10 E-3	x ___		x ___		x ___		x ___		x ___		x ___	=	+ ___ Response Failure Probability
														___ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2)

SFP-XHE-XE-UR

Plant:________ **Scenario:** ____________________ **Sequence Number:**_______

Task Error Description: Operator Fails to Restore SFP Cooling System Decision

Factor	Branch	Sub-branch	Processing	Response
1. Complexity, stress, and workload	high threat & stress	inadequate time	∞	∞
		adequate time	5	5
		expansive time	2	2
	low threat & stress	inadequate time	∞	∞
		adequate time	1	1
		expansive time	(1)	1
2. Experience/training	low experience	poor training	10	10
		good training	(1)	1
	high experience	poor training	5	5
		good training	0.5	0.5
3. Procedures	procedures absent		10	10
	procedures present	poor procedures	5	(5)
		good procedures	1	1
4. Ergonomics	old plant	poor ergonomics	5	5
		good ergonomics	1	1
	retrofit plant	poor ergonomics	3	3
		good ergonomics	(0.7)	0.7
	new plant	poor ergonomics	2	2
		good ergonomics	0.4	0.4
5. Fitness for duty	unfit		25	25
	fit		(1)	1
6. Crew dynamics	poor crew dynamics		10	10
	good crew dynamics		(1)	1

Task Portion		Complexity, stress, and workload		Experience/training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2	x 1	x	1	x	5	x	.7	x	1	x	1	=	.035 Processing Failure Probability
Response:	10 E-3	x ___	x	___	x	___	x	___	x	___	x	___	=	+ ___ Response Failure Probability

________ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2)

SFP-XHE-XE-LP

Plant:________ **Scenario:** ________________________ **Sequence Number:**______

Task Error Description: Operator Fails to Restore SFP Cooling System, Decision

1. Complexity, stress, and workload

			Processing	Response
1. Complexity, stress, and workload	high threat & stress	inadequate time	∞	∞
		adequate time	5	5
		expansive time	(2)	2
	low threat & stress	inadequate time	∞	∞
		adequate time	1	1
		expansive time	1	1

			Processing	Response
2. Experience/training	low experience	poor training	10	10
		good training	(1)	1
	high experience	poor training	5	5
		good training	0.5	0.5

			Processing	Response
3. Procedures	procedures absent		10	10
	procedures present	poor procedures	(5)	5
		good procedures	1	1

			Processing	Response
4. Ergonomics	old plant	poor ergonomics	5	5
		good ergonomics	1	1
	retrofit plant	poor ergonomics	3	3
		good ergonomics	(0.7)	0.7
	new plant	poor ergonomics	2	2
		good ergonomics	0.4	0.4

		Processing	Response
5. Fitness for duty	unfit	25	25
	fit	1	(1)

		Processing	Response
6. Crew dynamics	poor crew dynamics	10	10
	good crew dynamics	(1)	1

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2	x 2	x	1	x	5	x	.7	x	1	x	1	=	.07 Processing Failure Probability
Response:	10 E-3	x ____	x	____	x	____	x	____	x	____	x	____	=	+ ______ Response Failure Probability
														______ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) SFP-XHE-XE-LINVR

Plant:________ **Scenario:** ____________________ **Sequence Number:**______

Task Error Description: Operator Fails to Restore SFP Cooling System

1. Complexity, stress, and workload

		Processing	Response
high threat & stress	inadequate time	∞	∞
	adequate time	5	5
	expansive time	2	2
low threat & stress	inadequate time	∞	∞
	adequate time	1	1
	expansive time	1	(1)

2. Experience/training

		Processing	Response
low experience	poor training	10	10
	good training	1	(1)
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	(5)
	good procedures	1	1

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	3
	good ergonomics	0.7	(0.7)
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	(1)

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	(1)

Task Portion		Complexity, stress, and workload		Experience/training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2	x ____	x	____	x	____	x	____	x	____	x	____	=	____ Processing Failure Probability
Response:	10 E-3	x 1	x	1	x	5	x	.7	x	1	x	1	=	+ .0035 Response Failure Probability
														____ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) SFP-XHE-XE-LINVC

Plant:________ **Scenario:** ____________________ **Sequence Number:**______

Task Error Description: Operator Fails to Restore SFP Cooling System

Factor	Branch	Sub-branch	Processing	Response
1. Complexity, stress, and workload	high threat & stress	inadequate time	∞	∞
		adequate time	5	5
		expansive time	2	2
	low threat & stress	inadequate time	∞	∞
		adequate time	1	1
		expansive time	1	1
2. Experience/training	low experience	poor training	10	10
		good training	1	1
	high experience	poor training	5	5
		good training	0.5	0.5
3. Procedures	procedures absent		10	10
	procedures present	poor procedures	5	5
		good procedures	1	1
4. Ergonomics	old plant	poor ergonomics	5	5
		good ergonomics	1	1
	retrofit plant	poor ergonomics	3	3
		good ergonomics	0.7	0.7
	new plant	poor ergonomics	2	2
		good ergonomics	0.4	0.4
5. Fitness for duty	unfit		25	25
	fit		1	1
6. Crew dynamics	poor crew dynamics		10	10
	good crew dynamics		1	1

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics			
Processing:	10 E-2	x 2		x 1		x 5		x .7		x 1		x 1	=	.07	Processing Failure Probability
Response:	10 E-3	x ___		x ___		x ___		x ___		x ___		x ___	=	+ ___	Response Failure Probability
														___	Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) SFP-XHE-XE-PLR

Plant:________ **Scenario:** ________________________ **Sequence Number:**______

Task Error Description: Operator Fails to Restore SFP Cooling System

Factor	Branch	Sub-branch	Processing	Response
1. Complexity, stress, and workload	high threat & stress	inadequate time	∞	∞
		adequate time	5	5
		expansive time	2	2
	low threat & stress	inadequate time	∞	∞
		adequate time	1	1
		expansive time	1	1 (circled)
2. Experience/training	low experience	poor training	10	10
		good training	1	1 (circled)
	high experience	poor training	5	5
		good training	0.5	0.5
3. Procedures	procedures absent		10	10
	procedures present	poor procedures	5	5 (circled)
		good procedures	1	1
4. Ergonomics	old plant	poor ergonomics	5	5
		good ergonomics	1	1
	retrofit plant	poor ergonomics	3	3
		good ergonomics	0.7	0.7 (circled)
	new plant	poor ergonomics	2	2
		good ergonomics	0.4	0.4
5. Fitness for duty	unfit		25	25
	fit		1	1 (circled)
6. Crew dynamics	poor crew dynamics		10	10
	good crew dynamics		1	1 (circled)

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2	x ____	x	____	x	____	x	____	x	____	x	____	=	______ Processing Failure Probability
Response:	10 E-3	x 1	x	1	x	5	x	.7	x	1	x	1	=	+ .0035 Response Failure Probability
														______ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) SFP-XHE-XE-PLC

Plant:________ **Scenario:** ____________________ **Sequence Number:**_______

Task Error Description: Operator Fails to Restore SFP Cooling System

Factor			Processing	Response
1. Complexity, stress, and workload	high threat & stress	inadequate time	∞	∞
		adequate time	5	5
		expansive time	(2)	2
	low threat & stress	inadequate time	∞	∞
		adequate time	1	1
		expansive time	1	1
2. Experience/training	low experience	poor training	10	10
		good training	(1)	1
	high experience	poor training	5	5
		good training	0.5	0.5
3. Procedures	procedures absent		10	10
	procedures present	poor procedures	(5)	5
		good procedures	1	1
4. Ergonomics	old plant	poor ergonomics	5	5
		good ergonomics	1	1
	retrofit plant	poor ergonomics	3	3
		good ergonomics	(0.7)	0.7
	new plant	poor ergonomics	2	2
		good ergonomics	0.4	0.4
5. Fitness for duty	unfit		25	25
	fit		(1)	1
6. Crew dynamics	poor crew dynamics		10	10
	good crew dynamics		(1)	1

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics			
Processing:	10 E-2	x 2		x 1		x 5		x .7		x 1		x 1	=	.07	Processing Failure Probability
Response:	10 E-3	x ___		x ___		x ___		x ___		x ___		x ___	=	+ ___	Response Failure Probability
														___	Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) R1-XHE-XM-RHR

Plant:________ **Scenario:** ____________________ **Sequence Number:**______

Task Error Description: Operator FAils to Initiate RHR Mode of SFP Cooling, early, uncomplicated

1. Complexity, stress, and workload

		Processing	Response
high threat & stress	inadequate time	∞	∞
	adequate time	5	5
	expansive time	2	2 (circled)
low threat & stress	inadequate time	∞	∞
	adequate time	1	1
	expansive time	1	1

2. Experience/training

		Processing	Response
low experience	poor training	10	10 (circled)
	good training	1	1
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	5 (circled)
	good procedures	1	1

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	3
	good ergonomics	0.7	0.7 (circled)
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	1 (circled)

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	1 (circled)

Task Portion		Complexity, stress, and workload		Experience/training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2	x ____	x	____	x	____	x	____	x	____	x	____	=	____ Processing Failure Probability
Response:	10 E-3	x 2	x	10	x	5	x	.7	x	1	x	1	=	+ .07 Response Failure Probability

______ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) R2-XHE-XM-RHR

Plant:________ **Scenario:** ______________________ **Sequence Number:**______

Task Error Description: Operator Fails to Initiate RHR Mode of SFP Cooling, early, uncomplicated

1. Complexity, stress, and workload

		Processing	Response
high threat & stress	inadequate time	∞	∞
	adequate time	5	5
	expansive time	2	**2**
low threat & stress	inadequate time	∞	∞
	adequate time	1	1
	expansive time	1	1

2. Experience/training

		Processing	Response
low experience	poor training	10	**10**
	good training	1	1
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	**5**
	good procedures	1	1

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	3
	good ergonomics	0.7	**0.7**
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	**1**

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	**1**

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics			
Processing:	10 E-2	x ____	x	____	x	____	x	____	x	____	x	____	=	____	Processing Failure Probability
Response:	10 E-3	x 2	x	10	x	5	x	.7	x	1	x	1	=	+ .07	Response Failure Probability
														____	Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) SFP-XHE-ISO-LK

Plant:________ **Scenario:** ______________________ **Sequence Number:**_______

Task Error Description: Operator Fails to Isolate Leak During Primary LOCA

1. Complexity, stress, and workload

		Processing	Response
high threat & stress	inadequate time	∞	∞
	adequate time	5	5
	expansive time	2	2
low threat & stress	inadequate time	∞	∞
	adequate time	1	1
	expansive time	1	1

2. Experience/training

		Processing	Response
low experience	poor training	10	10
	good training	1	1
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	5
	good procedures	1	1

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	3
	good ergonomics	0.7	0.7
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	1

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	1

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2 x	____	x	____	x	____	x	____	x	____	x	____	=	____ Processing Failure Probability
Response:	10 E-3 x	5	x	1	x	1	x	3	x	1	x	1	=	+ .045 Response Failure Probability

________ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2)

MISLSPHN
MISLSPCE

Plant:________ **Scenario:** ______________________ **Sequence Number:**______

Task Error Description: Operator Fails to Isolate SFP Boundary Leak Early- critical, refueling pipe leak

Factor			Processing	Response
1. Complexity, stress, and workload	high threat & stress	inadequate time	∞	∞
		adequate time	5	5
		expansive time	(2)	(2)
	low threat & stress	inadequate time	∞	∞
		adequate time	1	1
		expansive time	1	1
2. Experience/training	low experience	poor training	10	10
		good training	(1)	(1)
	high experience	poor training	5	5
		good training	0.5	0.5
3. Procedures	procedures absent		10	10
	procedures present	poor procedures	(5)	(5)
		good procedures	1	1
4. Ergonomics	old plant	poor ergonomics	5	5
		good ergonomics	1	1
	retrofit plant	poor ergonomics	3	3
		good ergonomics	(0.7)	(0.7)
	new plant	poor ergonomics	2	2
		good ergonomics	0.4	0.4
5. Fitness for duty	unfit		25	25
	fit		1	(1)
6. Crew dynamics	poor crew dynamics		10	10
	good crew dynamics		1	(1)

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics			
Processing:	10 E-2	x 2	x	1	x	5	x	.7	x	1	x	1	=	.07	Processing Failure Probability
Response:	10 E-3	x 2	x	1	x	5	x	.7	x	1	x	1	=	+ .007	Response Failure Probability
														.08	Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) MISLLGE

Plant:_________ **Scenario:** ________________________ **Sequence Number:**_______

Task Error Description: Operator Fails to Isolate SFP Boundary Leak Early, large seal leak

1. Complexity, stress, and workload

		Processing	Response
high threat & stress	inadequate time	∞	∞
	adequate time	5	(5)
	expansive time	2	2
low threat & stress	inadequate time	∞	∞
	adequate time	1	1
	expansive time	1	1

2. Experience/training

		Processing	Response
low experience	poor training	10	(10)
	good training	1	1
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	(5)
	good procedures	1	1

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	3
	good ergonomics	0.7	(0.7)
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	(1)

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	(1)

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics			
Processing:	10 E-2	x ____		x ____		x ____		x ____		x ____		x ____	=	____	Processing Failure Probability
Response:	10 E-3	x 5		x 10		x 5		x .7		x 1		x 1	=	+ .18	Response Failure Probability
														____	Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) MISLLGL

Plant:_________ **Scenario:** ________________________ **Sequence Number:**______

Task Error Description: Operator Fails to Isolate SFP Boundary Leak Late, large leak

1. Complexity, stress, and workload

		Processing	Response
high threat & stress	inadequate time	∞	∞
	adequate time	5	(5)
	expansive time	2	2
low threat & stress	inadequate time	∞	∞
	adequate time	1	1
	expansive time	1	1

2. Experience/training

		Processing	Response
low experience	poor training	10	(10)
	good training	1	1
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	(5)
	good procedures	1	1

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	(3)
	good ergonomics	0.7	0.7
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	(1)

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	(1)

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2	x ____		x ____		x ____		x ____		x ____		x ____	=	____ Processing Failure Probability
Response:	10 E-3	x 5		x 10		x 5		x 3		x 1		x 1	=	+ .8 Response Failure Probability
														____ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) SFP-XHE-MANISO-E

Plant:_________ **Scenario:** ________________________ **Sequence Number:**______

Task Error Description: Operator Fails to Isolate SFP Boundary Leak Early, small seal leak

1. Complexity, stress, and workload

			Processing	Response
high threat & stress	inadequate time		∞	∞
	adequate time		5	5
	expansive time		2	(2) circled
low threat & stress	inadequate time		∞	∞
	adequate time		1	1
	expansive time		1	1

2. Experience/training

		Processing	Response
low experience	poor training	10	10
	good training	1	(1) circled
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	(5) circled
	good procedures	1	1

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	3
	good ergonomics	0.7	(0.7) circled
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	(1) circled

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	(1) circled

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2	x ______		x ______		x ______		x ______		x ______		x ______	=	______ Processing Failure Probability
Response:	10 E-3	x 2		x 1		x 5		x .7		x 1		x 1	=	+ .007 Response Failure Probability
														______ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) SFP-XHE-MANISO-L

Plant:_________ **Scenario:** ________________________ **Sequence Number:**______

Task Error Description: Operator Fails to Isolate SFP Boundary Leak Late,small leak

1. Complexity, stress, and workload

		Processing	Response
high threat & stress	inadequate time	∞	∞
	adequate time	5	5
	expansive time	2	2
low threat & stress	inadequate time	∞	∞
	adequate time	1	1
	expansive time	1	1

2. Experience/training

		Processing	Response
low experience	poor training	10	10
	good training	1	1
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	5
	good procedures	1	1

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	3
	good ergonomics	0.7	0.7
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	1

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	1

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics		
Processing:	10 E-2	x ____	x	____	x	____	x	____	x	____	x	____	=	____ Processing Failure Probability
Response:	10 E-3	x 5	x	1	x	5	x	3	x	1	x	1	=	+ .08 Response Failure Probability
														____ Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2) SFP-XHE-XA-ECCS

Plant:________ **Scenario:** ____________________ **Sequence Number:**_______

Task Error Description: Operator Fails to Align ECCS Systems

1. Complexity, stress, and workload

		Processing	Response
high threat & stress	inadequate time	∞	∞
	adequate time	5	5
	expansive time	2	(2)
low threat & stress	inadequate time	∞	∞
	adequate time	1	1
	expansive time	1	1

2. Experience/training

		Processing	Response
low experience	poor training	10	10
	good training	1	(1)
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	5
	good procedures	1	(1)

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	3
	good ergonomics	0.7	(0.7)
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	(1)

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	(1)

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics			
Processing:	10 E-2	x ____	x	____	x	____	x	____	x	____	x	____	=	____	Processing Failure Probability
Response:	10 E-3	x 2	x	1	x	1	x	.7	x	1	x	1	=	+ .001	Response Failure Probability
														____	Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2)

SFP1-XHE-XM-SFP
SFP2-XHE-XM-SFP

Plant:________ Scenario: ____________________ Sequence Number:______

Task Error Description:____

1. Complexity, stress, and workload

		Processing	Response
high threat & stress	inadequate time	∞	∞
	adequate time	5	5
	expansive time	2	2
low threat & stress	inadequate time	∞	∞
	adequate time	1	1
	expansive time	1	1

2. Experience/training

		Processing	Response
low experience	poor training	10	10
	good training	1	1
high experience	poor training	5	5
	good training	0.5	0.5

3. Procedures

		Processing	Response
procedures absent		10	10
procedures present	poor procedures	5	5
	good procedures	1	1

4. Ergonomics

		Processing	Response
old plant	poor ergonomics	5	5
	good ergonomics	1	1
retrofit plant	poor ergonomics	3	3
	good ergonomics	0.7	0.7
new plant	poor ergonomics	2	2
	good ergonomics	0.4	0.4

5. Fitness for duty

	Processing	Response
unfit	25	25
fit	1	1

6. Crew dynamics

	Processing	Response
poor crew dynamics	10	10
good crew dynamics	1	1

Task Portion		Complexity, stress, and workload		Experience/training		Procedures		Ergonomics		Fitness for duty		Crew dynamics			
Processing:	10 E-2	x ____	x	____	x	____	x	____	x	____	x	____	=	____	Processing Failure Probability
Response:	10 E-3	x 2	x	1	x	5	x	.7	x	1	x	1	=	+ .007	Response Failure Probability
														____	Task Failure Probability Without Formal Dependence

ASP HUMAN ERROR WORKSHEET (Page 1 of 2)

SFP1-XHE-XM-LSFP
SFP2-XHE-XM-LSFP

Plant:________ **Scenario:** ____________________ **Sequence Number:**______

Task Error Description: Operator Fails to Initiate SFP Cooling after Late Recovery

Factor			Processing	Response
1. Complexity, stress, and workload	high threat & stress	inadequate time	∞	∞
		adequate time	5	(5)
		expansive time	2	2
	low threat & stress	inadequate time	∞	∞
		adequate time	1	1
		expansive time	1	1
2. Experience/training	low experience	poor training	10	10
		good training	1	(1)
	high experience	poor training	5	5
		good training	0.5	0.5
3. Procedures	procedures absent		10	10
	procedures present	poor procedures	5	(5)
		good procedures	1	1
4. Ergonomics	old plant	poor ergonomics	5	5
		good ergonomics	1	1
	retrofit plant	poor ergonomics	3	(3)
		good ergonomics	0.7	0.7
	new plant	poor ergonomics	2	2
		good ergonomics	0.4	0.4
5. Fitness for duty	unfit		25	25
	fit		1	(1)
6. Crew dynamics	poor crew dynamics		10	10
	good crew dynamics		1	(1)

Task Portion		Complexity, stress, and workload		Experience/ training		Procedures		Ergonomics		Fitness for duty		Crew dynamics			
Processing:	10 E-2	x ____	x	____	x	____	x	____	x	____	x	____	=	____	Processing Failure Probability
Response:	10 E-3	x 5	x	1	x	5	x	3	x	1	x	1	=	+ .075	Response Failure Probability
														____	Task Failure Probability Without Formal Dependence

C.5 References

C.1 H.S. Blackman and J.C. Byers, *ASP Human Reliability Methodology Development*, draft report prepared for the U.S. Department of Energy under DOE Idaho Operations Office Contract DE-AC07-94ID13223, Idaho National Engineering Laboratory, 1995.

C.2 A.D. Swain, *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*, NUREG/CR-1278, 1983.

APPENDIX D - KEY ASSUMPTIONS

D.1 General Assumptions

1) For those initiating events which affect more than the SFPC system (i.e., LOOP, seismic, PLOCA), if the plant recovery/stabilization is complicated, either there will be no early attempts to recover SFPC or such attempts will be ineffective. This assumes that the effective focus of the operators will be on safeguarding the core.

2) If there is no early attempt to restore cooling to the spent fuel pool, the RHR supplemental cooling assist mode cannot be used. This is based on the length of time necessary to initiate this cooling method (the pool will have already reached near boiling conditions in a late cooling restoration attempt), and the possibility of a harsh environment inhibiting any local actions.

3) If the operators' early attempts to restore cooling using the SFPC system fails, no late restoration of SFPC is modeled. This treats the possibility that the reason for the early failure still applies to later attempts.

4) During normal operation, two of the three SFPC pumps and two heat exchangers are operating.

5) If the pool cross-connect is open in a dual unit plant, the previously operating configuration of either units' SFPC system is adequate to prevent boiling in both units. For example, if Unit 1 loses SFPC with the pool cross-connect open, whatever combination of Unit 2 pump(s) that remained running will be adequate to prevent boiling in the Unit 1 pool. This assumption applies to Cases 1 and 2.

6) Once the spent fuel pool reaches near boiling conditions, the pool can not be cross-connected. This based on the possibility of a harsh environment prohibiting the action.

7) Top event ALT-C (alternate cooling) represents boiling/makeup cooling. In this case spent fuel is not assumed to be vulnerable but safety system(s) could be vulnerable.

8) A single pump RHR train in SFP cooling assist mode can provide cooling to both units if the pool cross-connect is open (in a dual unit plant).

10) If the pool cross-connect is closed, operators would first attempt to establish the cross connection prior to aligning RHR in the spent fuel pool cooling assist mode.

11) No cooling water systems can be cross-connected between the two units via piping connections, except Service Water. The only cross-connect of cooling systems is through the SFP cross-connect.

12) If restoration of cooling to the SFP is late (i.e., the pool is near boiling or already boiling), it is possible that reactor safety systems may be affected by the steam before cooling is restored.

13) Once reactor safety systems are affected by the effects of a boiling spent fuel pool, no chance of system restoration exists unless the steaming effects are first mitigated. This does not necessarily have to involve cooling the pool; redirection or venting of the steam from the reactor building is also possible.

14) In the case of reactor scram concurrent with loss of the SFPC system, the RHR train is modeled to be available for SFP cooling only if the operator establishes alternate shutdown cooling mode using a core spray injection system. No RHR train can be aligned in the spent fuel pool cooling assist mode if it is being used in the normal shutdown cooling mode.

15) Since there are several direct and indirect alarms and indications when boiling initiates, the unavailability of these alarms and indicators is not modeled.

16) The probability of direct core damage (i.e., core damage not caused by spent fuel pool steaming or flooding) is assumed to be negligible in the case of an uncomplicated recovery.

17) The SFPC system is powered from a non-safety bus. It will automatically trip on LOOP or on an engineered safeguards feature (ESF) actuation signal.

D.2 Loss of SFPC (LOSFP) Modeling Assumptions

1) The loss of the SFPC system does not cause a plant transient or reactor scram.

2) For Cases 1 and 2, one RHR train (two pumps) is assumed to be unavailable for use in spent fuel pool cooling.

D.3 Loss of Offsite Power (LOOP) Modeling Assumptions

1) The pool cross-connect cannot be opened without offsite power. (The overhead crane necessary for gate removal is powered from non-diesel backed buses.)

2) Two-unit plants can cross-connect vital power sources and share emergency diesel generator (EDG) power.

3) Unless all EDGs are available or offsite power is recovered within 4 hours, neither unit's RHR system is modeled on the basis that recovery would be complicated.

4) Availability of only a partial set of EDGs causes operator distraction and will inhibit early restoration of SFPC.

5) SFPC systems which are powered from non-diesel backed buses cannot be powered without offsite power. In other words, credit is not taken for any ability to cross-tie vital and non-vital buses.

6) Loss of all EDGs (SBO) followed by an early recovery of offsite power is assumed to be a complicated recovery.

7) Early recovery of power is assumed to mean recovery of power within 4 hrs. After that, if all EDGs fail, the core cannot be cooled (DC power will last only for 4 hours).

8) Late recovery of power is assumed to mean recovery of power within 20 hrs. After that, the pool coolant will be near boiling in many cases.

D.4 Loss of Coolant Accident in Primary System (PLOCA) Modeling Assumptions

1) Upon a PLOCA, the SFPC system pumps trip on ESF actuation.

2) RHR is not available for spent fuel pool cooling assist mode for Case 1. This assumes that both trains of RHR are needed to cool the primary system.

3) The transfer gate between the reactor cavity and the spent fuel pool is always assumed to be open during refueling.

4) While in refueling mode, the operator must isolate the break and must establish the level using the ECCS prior to restoring spent fuel pool cooling.

5) In Cases 2 and 3, the transfer gate cannot be put back in place once a PLOCA event has been initiated.

6) While in Case 1, the operator will establish cooling on the primary side before restoring the spent fuel pool cooling.

7) Failure to isolate the break is assumed to result in a boiloff. Makeup systems are assumed not to be able to keep up with the loss from the break.

D.5 Loss of Spent Fuel Pool Inventory Modeling Assumptions

1) Two leak sites are modeled: the SFPC system (e.g., pipe break) and the spent fuel pool boundary.

2) Only leaks in the SFPC system with flow rates greater than the normal makeup rate are analyzed.

3) If a siphon breaker fails to isolate a leak in the SFPC system, the operator must isolate the break manually, otherwise leakage is assumed to continue until the level in the spent fuel

pool drops below the end of the inlet piping and automatic siphon breaking ("isolation") occurs.

4) Failure to isolate a spent fuel pool boundary leak is assumed to result eventually in pool boiling (the leak rate greatly exceeds the makeup rate). Also, the boiloff timing is not affected by the makeup rate.

5) If the operator fails to respond relatively early to a spent fuel pool boundary leak, late recovery is not possible.

6) Early isolation of a leak is assumed to lead to a non-consequential flooding event.

D.6 Seismic Event Modeling Assumptions

1) Three levels of peak ground acceleration are considered. These ranges are as follows:

$PGA < 0.2g$
$0.2g \leq PGA \leq 0.6g$
$PGA > 0.6g$

Earthquakes with PGA < 0.1g are assumed to result in a recoverable loss of offsite power and negligible component/structural damage. In this study, their effects are assumed to be included in the LOOP analysis. Earthquakes with PGA > 0.6g are assumed to cause failure of the spent fuel pool structure. (The high confidence of low probability of failure capacity — HCLPF — for spent fuel pool structural damage was estimated to be 0.5g for a representative BWR and 0.65g for a representative PWR [2,19].)

2) If the spent fuel pool structure is damaged by an earthquake (i.e., PGA > 0.6g), pool boiloff (of the remaining inventory) is assumed.