3 ACCIDENT SEQUENCE ANALYSIS

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3 ACCIDENT SEQUENCE ANALYSIS

3.1 INTRODUCTION

The purpose of this section is to document the event trees and accident sequence analysis performed as part of the ESBWR PRA. This section includes the basis for the event trees modeled in the internal event analysis and a description of each event tree heading. These event trees also provide the baseline models for the external events analyses presented in later sections of this report.

The event trees developed for ESBWR are based on the initiating events included in Section 2. The event tree models include the set of systems needed to mitigate each initiating event. Each event tree provides a time independent, system-based response to each initiating event. The objective of these event tree analyses is to show which system combinations result in a safe, stable state, and which ones result in core damage.

The systems modeled, including both safety related and nonsafety systems, use the fault tree logic that is presented in Section 4. Support systems and operator actions are modeled explicitly within each system fault tree.

The accident sequence analysis core damage numerical results are presented in Section 7.

The event tree end states are grouped into plant damage states in order to simplify the containment analyses that are presented in Sections 8 and 21.

The event tree logic diagrams are shown at the end of this section in Appendix 3A.

3.2 ACCIDENT SEQUENCE METHODOLOGY

3.2.1 Acceptance Criteria

The acceptance criteria are the minimum requirements necessary for key safety functions to achieve safe, stable conditions i.e., to protect the fuel and prevent release of radionuclides to the environment. Safe conditions are determined by the ability to meet the following key safety function acceptance criteria. Stable conditions are determined by the ability to maintain each key safety function for long-term operation. For example, conditions may be considered safe during a given event, but not stable unless they can be maintained for at least 72 hours with the existing safety functions. In this case, a core damage end state is assumed. If there is no core damage until more than 72 hours from the initiating event, there is sufficient time to implement recovery actions, including repair of failed equipment.

Reactivity Control

The acceptance criterion is to achieve subcriticality and maintain the reactor in a subcritical state. The key functions in the PRA model are: RPS, FMCRD, SLC, FW Control, and ARI.

RPV Overpressure Protection

Maintaining pressure below 150 percent of the reactor coolant pressure boundary (Service Level C) pressure is the acceptance criterion for RPV overpressure protection. This limit is used to determine the number of Safety/Relief Valves (SRVs) that are required to operate following any event, including ATWS events. The key functions in the PRA model are actuation of ICS and opening of the SRVs at their pressure relief setpoints.

Core Cooling

A peak cladding temperature (PCT) of 2200°F (1477°K) is the criterion for establishing the adequacy of coolant inventory. This criterion defines the onset of core damage. In other words, core damage is defined as the point when a PCT of 2200°F is exceeded.

The key functions in the PRA model are: Feedwater Injection, CRD make-up, GDCS, FAPCS LPCI, and Dedicated LPCI Backup Pump.

Containment Heat Removal

For event sequences in which core cooling is successful utilizing passive systems, the containment cooling function acceptance criterion is to maintain the containment pressure below the ultimate containment pressure. If the containment fails under these conditions, the inventory of water available for the passive systems is depleted through the containment breach, and consequently core coverage would be lost without additional make-up from a source that is independent of the containment conditions, such as CRD or Dedicated LPCI Backup pump. The key functions in the PRA model are: PCCS, Vacuum Breakers, ICS, RWCU/SDC, Suppression Pool Cooling, and Containment Venting.

Core damage occurs directly from failure of the Core Cooling key safety function, and indirectly from the failure of Reactivity Control, RPV Overpressure Protection, or Containment Heat Removal.

3.2.2 Event Tree Development

Event trees are logical models that represent the postulated combinations of initiating events, mitigating system failures, and human errors that lead to either safe, stable conditions or core damage. They provide a framework for quantification of core damage frequencies. As shown in Table 3.2-1, each initiating event described in Section 2 is quantified by assigning it to an event tree. Credit is taken for safety related and nonsafety-related systems that are capable of responding to the event, as well as significant operator actions that are taken to mitigate the event.

In some cases, the mitigation responses of different initiating events are similar, so the same event tree model is applied to both. The following initiating events are represented in other event trees:

- Loss of PCS,
- Medium Liquid LOCA in RWCU,
- ISLOCA, and
- Loss of Air Systems.

Event trees are constructed for a core damage end state in the level 1 PRA model. Plant damage states, accident phenomena and containment systems responses are used in the level 2 analysis, and are described in Section 8. The initial node of each event tree is the occurrence of an initiating event. The final node is the end state, which is either a safe, stable core condition, or core damage. The other nodes in the tree represent outcomes of expected system or operator responses to the event. The upper branch of any node represents success of the function, and the lower branch represents a failure.

The accident conditions (phenomena) are implicitly addressed in the event tree structure. Most of the equipment in the containment (squib valves etc.) is designed to function during accident conditions (pressure, temperature etc). For instance, sequences include the need of an external low-pressure injection source when containment venting is successful to address potential NPSH issues and also the loss of inventory. However, the event trees conservatively did not credit external sources for low-pressure injection (Dedicated LPCI Backup) when failure of all decay heat removal systems, including containment vent, has occurred.

3.2.3 Success Criteria Identification

Success criteria are defined as the minimum numbers of systems, trains, or components that are required to operate in order to meet the acceptance criteria related to key safety functions. For example, the PCCS system has 6 heat exchangers, and its success criterion is the successful operation of four out of six heat exchangers to remove containment heat loads. This criterion is based on thermal-hydraulic analyses, which conclude that four heat exchangers are sufficient, in each potential accident scenario, to satisfy the containment heat removal key safety function. If three or less heat exchangers are available, then the PCCS function is assumed to be lost. Typically, credit is not taken for the benefits of partial functioning of safety functions in the PRA.

The ESBWR PRA success criteria are described in Section 3.3.4 and are summarized in Table 3.3-1. Each criterion is based on either a plant design parameter or a thermal-hydraulic calculation. When a success criterion is used to characterize a range of conditions, the limiting parameters are chosen to represent all cases. In addition, representative thermal-hydraulic analyses are run to validate the appropriateness of the success criteria.

The Modular Accident Analysis Program (MAAP) is used to develop success criteria not covered by design basis and to evaluate the plant response to accident initiation events. MAAP is an integral systems analysis computer code initially developed during the industry sponsored IDCOR Program. MAAP Version 4.0.6 is used in the ESBWR PRA and includes models for the important accident phenomena that might occur within the primary system, in the containment, and in the reactor building. MAAP calculates the progression of the postulated accident sequence, including the disposition of the fission products, from a set of initiating events to either a safe, stable state or to an impaired containment condition (by over-pressure or over-temperature) and the possible release of fission products to the environment.

MAAP also addresses the new and unique features, many of which are passive, included in the ESBWR design. These are:

- Passive heat removal system such as an in-containment isolation condenser,
- Gravity fed water injection systems,
- External heat removal from the containment,
- A generalized nodalization scheme for the containment to accommodate the ESBWR design, and
- The capability to analyze flow through large safety valves.

Since the beginning of the MAAP code development, the codes have represented all of the important safety systems such as emergency core cooling, containment sprays, residual heat removal, etc. MAAP allows operator interventions and incorporates these in a flexible manner, permitting the user to model the operator response and the availability of the various plant systems in a general way.

To establish that the MAAP code is capable of addressing the above purposes and uses, numerous benchmarks have been performed, both with respect to individual models and for the integral response of reactor systems. These benchmarks provide insights into the code performance and confidence in the capabilities of MAAP to represent individual phenomena as well as the integral response of reactor systems, including the influences of operator actions. These are documented in Volume III of the MAAP Users Manual.

The ESBWR MAAP results have been compared to those of TRACG. The comparison is described in EPRI Report 1011712. The comparison of results indicates that MAAP provides adequate and reasonable thermal hydraulic response for ESBWR specific passive containment systems.

3.2.4 End States of the Accident Sequences

The event trees presented in this section identify the potential sequences that can lead to core damage. Many of the sequences have common characteristics with respect to the challenge on the containment fission product barrier. These sequences are grouped into damage classes that are analyzed in the Level 2 portion of the PRA. The end states of the accident sequences developed for the ESBWR PRA are defined to facilitate the Level 2 Containment Performance Analysis and provide the link between the Level 1 and Level 2 analyses.

The core damage sequences are grouped together based upon the overall challenge to the containment barrier. They are defined as follows:

- OK: The core is successfully cooled and the containment is intact. There is no core damage in these events.
- CD I: The containment is intact when core damage occurs and the RPV is at low pressure.
- CD II: The containment is breached, either due to overpressurization or venting, while the core is successfully cooled. Core damage results because low pressure injection functions fail to maintain core cooling. This end state is divided into 2 classes due to their differing outcomes in the Level 2 analysis.
    - II-a: Containment Failure, Loss of Low Pressure Injection
    - II-b: Containment Vented, Loss of Low Pressure Injection
- CD III: The containment is intact when core damage occurs and there is high RPV pressure at the time of just prior to vessel failure.
- CD IV: Core damage results from an accident sequence with a failure of effective reactivity control (e.g., ATWS without SLCS). This has the potential to affect the containment in a more severe manner than the CD I and CD III because more energy is deposited into the containment prior to RPV failure. The analysis of this end state (Section 8, “Containment Performance”) demonstrates that in fact, all CD IV end states could be treated as CD I or CD III (depending on the RPV pressure) without affecting the results of the containment analysis. This end state has been retained in the Level 1 analysis to more easily allow for sensitivity analyses related to reactivity control.
- CD V: The containment is bypassed at the time of core damage.

The Level 2 analysis requires further discrimination between the end states to determine specific containment challenges. For example, in CD I sequences the water level in the lower drywell is required as input to the Level 2. These sub-classes cannot be determined solely from the sequence path definitions; rather the minimal cutsets must be reviewed for specific failures to determine the applicable plant state. Initial criteria is used to categorize the Level 1 results based on the expected lower drywell level. This information is presented in Section 7, (“PRA Quantification”) along with the results of the Level 1 quantification. Additional criteria is applied in the Level 2 model to provide more detailed results that are used to estimate the conditional containment failure probability.

3.2.5 Mission Time

The design of the ESBWR is such that the onsite inventory of cooling water available and plant battery capacity can keep the core covered using passive systems for more than 72 hours. However, the simplifying assumptions made in the PRA analysis are not always applicable for mission times longer than 24 hours. For example, the PRA assumes that once the initiator has occurred, no credit will be given for repair of failed equipment. This is a conservative assumption for a mission time of 24 hours; the results yields misleading insights for a 72 hour mission. Therefore, the mission time for the ESBWR PRA is 24 hours.

In cases where the core remains cooled during the short term (less than 24 hours) but conditions are not stable, a core damage end state will be assigned if there are no effective ways to stabilize the plant in the long term (i.e., from 24 to 72 hours).

3.2.6 Key Assumptions and Insights

The event tree model development process involves many assumptions. However, a single key assumption was identified and is used in the event tree models. The PRA assumes that if an automatic isolation failure occurs, then manual isolation of line breaks outside of containment is required for all BOC-RWCU sequences that have initial low pressure injection.

Other notable (non-key) assumptions are listed below:

(1) The PRA credits, for transient scenarios, continued injection for FW, CRD, or Dedicated LPCI Backup systems if these systems are operating or aligned early in the scenario, without consideration of possible containment failure (decay heat removal or venting not asked). The location of probable containment failures is not near equipment necessary for injection, and the containment fragility profile not likely to change in design phase. However, realignment of a system is not credited if automatic isolation occurs.

(2) The FAPCS LPCI function is assumed to provide make-up and remove enough decay heat. The heat exchanger is used to prevent containment pressurization and failure resulting in loss of inventory necessary to protect the core – the heat exchangers are included in LPCI fault tree.

(3) If high pressure injection fails, the operators will attempt to manually depressurize and align low pressure injection prior to depressurization with the DPVs.

(4) The feedwater system is isolated in LOCA scenarios where high drywell pressure exists. System realignment is not credited for these scenarios.

(5) The HPCRD system is isolated in LOCA scenarios where both high drywell pressure and high drywell lower water level exists. However, the HPCRD Isolation Bypass can be manually aligned, or it automatically aligns if GDCS injection failure is detected.

The insights are identified based on the potential to impact results. The following insights are identified based on the methods and results used in the event tree development task:

(1) Passive injection (GDCS) eventually fails due to loss of inventory when the containment fails or is vented. An external injection source must be available after containment venting to ensure RPV water level is maintained. The primary insight involves the need for

operations programs to identify the need, and means to line up external injection when containment is vented or failure is probable.

(2) The PRA uses conservative assumptions in the modeling for ATWS such as:

a. Failure of feedwater runback is assumed to result in core damage.

b. Failure to restart feedwater, or use CRD for power/level control is assumed to result in core damage.

c. Failure of ADS inhibit is assumed to result in core damage (boron dilution causes failure of reactivity control).

d. Failure of SLC is assumed to result in core damage.

(3) The PRA uses conservative assumptions in the modeling of containment pressure suppression failure. No credit is taken for alignment of any injection sources after failure of the DW/WW vacuum breakers to direct steam flow through suppression pool or to open after blowdown.

(4) The probability of SRVs failing to reclose is based upon the estimated number of SRVs that would open during a transient with high pressure conditions.

Table 3.2-1

Initiating Events Assigned to Event Trees

Initiating Event	Designator	Event Tree
Transients		
General Transient	%T-GEN	T-GEN
Transient with PCS Unavailable	%T-PCS	T-GEN
Loss of Feedwater	%T-FDW	T-FDW
IORV	%T-IORV	T-IORV
Loss of Preferred Power (LOPP)	%T-LOPP-PC %T-LOPP-SC %T-LOPP-GR %T-LOPP-WR	T-LOPP
LOCAs Inside Containment		
Large Steam LOCA	%LL-S	LL-S
Large Steam LOCA in FW Line A	%LL-S-FDWA	LL-S-FDWA
Large Steam LOCA in FW Line B	%LL-S-FDWB	LL-S-FDWB
Medium Liquid LOCA	%ML-L	ML-L
Medium/Small Steam LOCA	%SL-S	SL-S
Small Liquid LOCA	%SL-L	SL-L
Vessel Rupture	%RVR	RVR
LOCAs Outside Containment		
Main Steam Line	%BOC-MS	BOC-MS
Feedwater Line A	%BOC-FDWA	BOC-FDWA
Feedwater Line B	%BOC-FDWB	BOC-FDWB
RWCU Line	%BOC-RWCU	BOC-RWCU
IC Line	%BOC-IC	BOC-IC
ISLOCA	%ISLOCA	BOC-FDWA
Special Initiators		
Complete Loss of PSWS	%T-SW	T-SW
Complete Loss of Air Systems	%T-IA	T-FDW

Table 3.2-5

Event Tree Transfers

Figure	Event Tree	Description	Initiators Included	Transfers Out
1	T-GEN	General Transient	%T-GEN, %T-PCS	T-IORV, RVR, AT-T-GEN
2	T-FDW	Loss of Feedwater	%T-FDW, %T-IA	T-IORV, RVR, AT-T-FDW
3	T-LOPP	Loss of Preferred Power	%T-LOPP-PC %T-LOPP-SC %T-LOPP-GR %T-LOPP-WR	T-IORV, RVR, AT-T-LOPP
4	T-SW	Loss of PSWS	%T-SW	T-IORV, RVR, AT-T-SW
5	T-IORV	IORV	%T-IORV, %T-GEN, %T-PCS, %T-IA, %BOC-MS, %BOC-IC, %BOC-RWCU, %T-FDW, %T-SW, %T-LOPP-PC, %T-LOPP-SC, %T-LOPP-GR, %T-LOPP-WR	AT-T-IORV
6	LL-S	Large Steam LOCA	%LL-S	None
7	LL-S-FDWA	Large Steam LOCA in FW Line A	%LL-S-FDWA	None
8	LL-S-FDWB	Large Steam LOCA in FW Line B	%LL-S-FDWB	None
9	ML-L	Medium Liquid LOCA	%ML-L	None
10	SL-S	Medium/Small Steam LOCA	%SL-S	AT-LOCA
11	SL-L	Small Liquid LOCA	%SL-L	AT-LOCA, RVR
12	RVR	Vessel Rupture	%RVR	None
13	BOC-MS	Break in Main Steam Line	%BOC-MS	T-GEN
14	BOC-FDWA	Break in Feedwater Line A	%BOC-FDWA, %ISLOCA	RVR, AT-T-FDW
15	BOC-FDWB	Break in Feedwater Line	%BOC-FDWB	RVR, AT-T-FDW
16	BOC-RWCU	Break in RWCU Line	%BOC-RWCU	T-GEN
17	BOC-IC	Break in IC Line	%BOC-IC	T-GEN
18	AT-T-GEN	ATWS Transfer T-GEN	%T-GEN, %T-PCS, %T-IA,%BOC-MS, %BOC-IC, %BOC-RWCU	None
19	AT-T-FDW	ATWS Transfer T-FDW	%T-FDW, %BOC-FDWA, %BOC-	None

Table 3.2-5

Event Tree Transfers

Figure	Event Tree	Description	Initiators Included	Transfers Out
			FDWB	
20	AT-T-LOPP	ATWS Transfer T-LOPP	%T-LOPP-PC %T-LOPP-SC %T-LOPP-GR %T-LOPP-WR	None
21	AT-T-SW	ATWS Transfer T-SW	%T-SW	None
22	AT-T-IORV	ATWS Transfer T-IORV	%T-IORV, %T-GEN, %T-PCS, %T-IA, %BOC-MS, %BOC-IC, %BOC-RWCU, %T-FDW, %T-SW, %T-LOPP-PC, %T-LOPP-SC, %T-LOPP-GR, %T-LOPP-WR	None
23	AT-LOCA	ATWS Transfer LOCAs	%SL-S, %SL-L	None

3.3 FUNCTIONAL LOGIC AND SUCCESS CRITERIA

3.3.1 Introduction

The outcome of each event tree mitigating function (i.e., success or failure) is determined by success criteria. They define the failure modes for each mitigating system and functions that are included in the PRA model. Each event tree node and its respective mitigating function are designated as top events, and are identified as follows:

Event Tree Designator	Mitigating Function
CR	RPS, ARI, FMCRD
CF	FW Runback
CS	SLCS
DL	Vacuum Breakers Reclose
DS	Vacuum Breakers Open
IA	Isolate Feedwater Line A
IB	Isolate Feedwater Line B
IC	Isolate ICS Line
IS	Isolate MSIV Lines
IR	Isolate RWCU Line
IM	Isolate RWCU Line Manual
MA	Overpressure SRV ATWS
MS	Overpressure SRV
MW	Isolation Condenser
PA	SRV Reclose ATWS
PS	SRV Reclose Transients
PR	Multiple SRV Reclose Transients
QT	TPCS
UF	FW Injection
UD	CRD Injection
VI	GDCS Injection
VE	GDCS Equalize
VL	FAPCS LPCI
VM	Dedicated LPCI Backup
WP	PCCS
WS	Suppression Pool Cooling
WR	RWCU/SDC
WM	Long-Term PCC/IC Pool Make-up
WV	Containment Venting
XD	ADS
XI	ADS Inhibit
XM	Manual Depressurization

3.3.2 Functional Logic Affecting Reactivity Control

3.3.2.1 Top Event: (CR) Scram

The Reactor Protection System (RPS) and Control Rod Drive System (CRD) provide for rapid control rod insertion (scram) so that no fuel damage results from any anticipated operational occurrence. The hydraulic power required for scram is provided by high-pressure water stored in the individual hydraulic control units (HCU). The HCUs contain nitrogen-water accumulators, charged to high pressure, and the valves and components needed to scram the Fine-Motion Control Rod Drives (FMCRD).

Upon receipt of an RPS scram signal, the scram solenoid pilot valves de-energize, and the scram valve in the associated HCU opens to apply the hydraulic insert forces to its respective FMCRDs using high pressure water stored within the pre-charged accumulator. Once the hydraulic force is applied, a hollow piston inserts the control rod rapidly. The water displaced from the FMCRD is discharged into the reactor vessel (the need for a scram discharge volume has been eliminated from the ESBWR design.) Indication that the scram has been successfully completed (all rods full-in position) is displayed to the operator.

The alternate rod insertion (ARI) function of the CRD system provides a backup means of actuating a hydraulic scram that is diverse and independent from the RPS logic and components. Following receipt of an actuation signal, solenoid operated valves on the scram air header actuate to depressurize the header, allowing the HCU scram valves to open. The FMCRDs then insert the control rods hydraulically in the same manner as the RPS initiated scram. The same signals that initiate ARI simultaneously actuate the FMCRD motors to insert the control rods electrically.

Success criteria for CR are: RPS or ARI signal, and 3 out of 4 Control Rod Banks Fully Inserted.

Top event gate names: CR-TOPCR.

Dependencies: Failure of CR will transfer the sequence to an ATWS event tree. No operator actions are credited.

Assumptions: No credit is taken for manual RPS actuation by the operators during an initiating event.

3.3.2.2 Top Event: (CF) Feedwater Pump Run Back

A feedwater pump run-back occurs when the feedwater control system sends a zero-flow demand signal to the feed pump adjustable speed drives on identification of an ATWS condition. This is an automatic function that occurs on high RPV pressure and an "SRNM-Not-Downscale" signal. The feedwater pumps are run-back to zero flow to limit power production in the short term following the accident, in order to keep the pressure spike in the RPV within acceptable limits.

Top event gate names: CF-TOPRB

The Success Criterion: Both feedwater pumps run-back to zero-flow to reduce reactor power.

Dependencies: none

Assumptions: This action is automatic, and no manual recovery is credited in the ATWS sequences. Conservatively, the failure of this function is assumed to lead to core damage due to a failure to initially reduce reactor power during an ATWS condition.

3.3.2.3 Top Event: (CS) Standby Liquid Control System

The SLCS system contains two identical and separate trains. Each train provides 50% injection capacity. For ATWS events, the failure of control rods to insert in response to a valid trip demand is assumed. SLCS automatically initiates by "SRNM-Not-Downscale" and either high reactor dome pressure or low reactor water level persisting for at least 3 minutes.

The success criterion is successful injection of both trains.

Top event gate names: CS-TOP1

Dependencies: Boron dilution -The SLCS design incorporates sufficient margin to discount potential non-uniformities of the boron solution mixing process within the reactor. This result is then increased by an additional margin to discount potential dilution by the RWCU/SDC System in the shutdown cooling mode.

Assumptions: Conservatively, no back up or long term recovery of this function is considered. The failure of this function is assumed to lead to core damage due to failure to successfully control power. RWCU/SDC System Isolation valves are included in the SLC model.

3.3.3 Functional Logic Affecting RPV Overpressure Protection

3.3.3.1 Top Event: (MS) RPV Overpressure Protection

If the Power Conversion System and Isolation Condenser functions both fail, the pressure in the RPV will reach the pressure setpoints of the SRVs. The design basis is for one SRV to open to prevent exceeding the ASME overpressure limit during transients following successful scram.

Success criteria: One SRV opens to relief pressure

Top event gate names: MS-TOP18

Dependencies: none

Assumptions: Conservatively, an overpressurization of the RPV is assumed to result in a reactor vessel rupture (RVR) and a transfer to the RVR event tree. No credit is taken for operator action to open an SRV.

3.3.3.2 Top Event (MA) RPV Overpressure Protection During ATWS

During an ATWS, RPV pressure is challenged by the unmitigated reactor power. The success of this function is for 9 SRVs to open automatically.

Top event gate names: MA-TOP10

Dependencies: none

Assumptions: Conservatively, the failure of this function is assumed to lead to core damage due to RPV rupture and re-criticality at low RPV pressure.

3.3.3.3 Top Event (MW) Isolation Condensers

The design basis of the isolation condensers (ICs) is to remove post-reactor isolation decay heat with three out of four ICs operating and to reduce reactor pressure and temperature to safe shutdown conditions. Automatic initiation of this function occurs on either low RPV water level, closure of MSIVs, or high RPV pressure. In addition, each ICS train contains a condensate reservoir that provides sufficient water to the RPV following a loss of feedwater to ensure that Level 1 is not reached.

The success criterion of this function is the operation of at least three of four ICs.

Top event gate names: MW-TOPMW

Dependencies: The initiating event BOC-ICS, line break in an ICS line results in the need to isolate one ICS loop. Isolation of the ICS loop makes it unavailable for accident sequence mitigation.

Assumption: The PRA model does not take credit for partial functioning or reduced success criteria that are based on timing. Although MAAP analysis shows that only 2 ICs are needed to control reactor pressure after one hour in a transient initiating event, this is not credited.

3.3.4 Functional Logic Affecting Core Cooling

3.3.4.1 Top Events - Isolate Line Breaks Outside Containment:

- IA) Feedwater Line A
- (IB) Feedwater Line B
- (IC) ICS Line
- (IS)MSIV Line
- (IR) RWCU Line
- (IM) Manual Isolation of RWCU Line

This series of top events covers breaks that occur outside of containment that could lead to a loss of primary coolant. In each case, the top event requires the need for an isolation valve to close before RPV Level 1 is reached, so that ADS blowdown is prevented.

Success criterion: Automatic isolation occurs prior to RPV level reaching Level 1.

Top Event	Gate Name	Event Tree
IA	BC-TOPFWLA	BOC-FDWA
IB	BC-TOPFWLB	BOC-FDWB
IC	BC-TOPICS	BOC-IC
IS	BC-TOPMSL	BOC-MS
IR	BC-TOPRWCU	BOC-RWCU
IM	IM-TOPSDC	BOC-RWCU

Dependencies: Mitigating functions are not credited in BOC event trees if they are dependent on the initiating event. For example, no credit is taken for the failed isolation condenser in the BOC-ICS tree.

Assumptions: none

3.3.4.2 Top Event: (PS) SRV Reclose

Following a transient with loss of PCS and ICS, RPV pressure rises, which causes one or more SRVs to lift at their pressure setpoint. It is necessary for all lifted SRVs to reclose to prevent an inadvertent loss of coolant through a stuck-open relief valve.

Success criterion: All SRVs that opened due to high reactor pressure are required to reclose.

Top event gate names: PS-TOPIORV

Dependencies: This top event is challenged after an MS event occurs.

Assumptions: The probability of SRVs failing to reclose is based upon the estimated number of SRVs that would open during a transient with high pressure conditions.

3.3.4.3 Top Event: (PR) 9 of 10 SRVs Reclose

Following a transient with loss of PCS and ICS, RPV pressure rises, which causes one or more SRVs to lift at their pressure setpoint. It is necessary for all lifted SRVs to reclose to prevent an inadvertent loss of coolant through a stuck-open relief valve. Top event PR is a conditional probability to account for more than one SRV failing to reclose.

Success criterion: 9 out of 10 SRVs are required to reclose.

Top event gate names: PS-TOPSLOCA

Dependencies: none

Assumptions: none

3.3.4.4 Top Event: (PA) SRV Reclose

During an ATWS with loss of PCS and ICS, RPV pressure rises, which causes one or more SRVs to lift at their pressure setpoint. It is necessary for all lifted SRVs to reclose to prevent an inadvertent loss of coolant through a stuck-open relief valve.

Success criterion: All SRVs that lifted have reclosed.

Top event gate names: PA-TOPCLOSE

Dependencies: This top event is challenged after an MA event occurs.

Assumptions: none

3.3.4.5 Top Event: (PB) All But 2 SRVs Reclose(Deleted)

3.3.4.6 Top Event: (QT) Power Conversion System

After a transient with reactivity insertion, the decay heat removal requirements can be accommodated by the minimum set of functions described below. This top event includes functional failures which fail both the steam pathway to the condenser and injection from the condensate and feedwater systems. The power conversion system (PCS) consists of the main condenser, turbine bypass valves, feedwater and condensate, and circulating water. PCS is the preferred method of heat transfer following a transient.

Success Criterion:

- 4 of 12 Turbine Bypass Valves open,
- 1 of 4 Main Steam Lines remain open,
- 1 of 4 Circulating Water Pumps function,
- 1 of 4 FW pumps function, and
- 1 of 4 Condensate pumps function.

Top event gate names: QT-TOPPCS

Dependencies: none

Assumptions: none

3.3.4.7 Top Event: (UF) FW Injection

Feedwater injection is successful if one of four Feedwater pumps and one of four Condensate pumps are available to supply water to the RPV during high or low pressure conditions. Suction is taken from the condensate storage tank. If UF fails to maintain RPV level above Level 2, then CRD injection (UD) is automatically initiated.

Success criterion: One of four Feedwater Pumps is successful.

Top event gate names:

- UF-TOP1
- UF-TOPATWS

Dependencies: UF is unavailable in loss of feedwater, loss of preferred power, loss of service water, LOCA, and feedwater line break initiating events. The event trees do not include feedwater injection in LOCA scenarios, since the Feedwater system is isolated when high drywell pressure conditions exist.

Assumptions: Operator actions for monitoring and controlling feedwater and condensate pumps are within the normal process for responding to a feedwater transient. Operator action for feedwater pump restart is necessary after feedwater runback (CF) under top UF-TOPATWS.

3.3.4.8 Top Event: (UD) CRD Injection

The CRD pumps supply high pressure makeup water to the reactor when the normal makeup supply (feedwater) is unable to prevent reactor water level from falling below the normal water range. To accomplish this function both CRD pumps are called upon to supply flow. Success is determined based on the initiating event. In the case of an ATWS event, both pumps are required to meet success. In all other transients that result in reactor water level falling below the normal water range, only one CRD pump is required. Regardless of cause, when a Level 2 signal is generated, both CRD pumps start and required flow path to reach the reactor is established with the majority of the other functions normally provided by the CRD system isolated from the flow path. The CRD system is isolated in LOCA scenarios where high drywell pressure, and high lower drywell water level conditions exist. However, the HPCRD Isolation Bypass logic and valves allow automatic injection by CRD if GDCS injection failure is detected.

Success criteria: 1 of 2 CRD pumps function during transient conditions (UD-TOPINJ), and

2 of 2 CRD pumps function during ATWS (UD-TOPINJ2).

Top event gate names:

- UD-TOPINJ
- UD-TOPINJ2 (ATWS)
- UD-TOPINJ_X
- UD-TOPINJ_MAN

Dependencies: UD is unavailable following a loss of preferred power or a loss of service water. UD is automatically initiated on low RPV water level, or GDCS injection signal if the GDCS pool level remains high 11 minutes after the GDCS initiation signal has been generated. Operator actions involve monitoring RPV water level, and manually bypassing HPCRD isolation if an external makeup source is needed.

Assumptions: For general transient scenarios, CRD injection is unaffected by containment overpressurization failure. This is an important assumption, based on the containment failure analysis, that supports the use of CRD in these sequences.

3.3.4.9 Top Event: (VI) GDCS Injection

GDCS provides emergency core cooling after any event that reduces the reactor coolant inventory. Once the reactor has been depressurized the GDCS is capable of injecting large volumes of water into the depressurized RPV to keep the core covered for at least 72 hours following LOCA. The GDCS injection function provides water from all three GDCS pools to the RPV via eight injection lines.

Success criteria: 2 of 8 injection lines and 1 of 3 GDCS pools functional (VI-TOPINJ), 4 of 8 injection lines and 3 of 3 pools (VI-TOPRUP), 8 of 8 injection lines and 3 of 3 pools (VI-TOPRVR).

Top event gate names:

- VI-TOPINJ
- VI-TOPRUP
- VI-TOPRVR

Dependencies: ADS (DPVs must open). GDCS requires PCCS, or SPC with an equalizing line open, to complete the inventory recirculation loop.

Assumptions: none

3.3.4.10 Top Event: (VE) GDCS Equalize

If the RPV level decreases to 1 m above the top of the active fuel, squib valves are actuated in each of four GDCS equalizing lines. The open equalizing lines leading from the suppression pool to the RPV make long-term coolant makeup possible. An equalization valve delay time ensures that the GDCS injection function from the GDCS pools has had time to drain to the RPV and that the initial RPV level collapse as a result of the blowdown does not open the equalizing line.

Success criterion: 1 of 4 equalize lines and 1 of 3 GDCS pools functional, or 2 of 3 GDCS pools.

Top event gate names: VE-TOPEQU

Dependencies: ADS (DPVs must open). GDCS requires PCCS, or SPC with an equalizing line open, to complete an inventory recirculation loop.

Assumptions: GDCS is not effective when the containment is vented or the containment has failed. External sources of injection are required to address loss of inventory when the containment is vented, or failed due to overpressure.

3.3.4.11 Top Event: (VL) LPCI

This mode may be initiated following an accident after the reactor has been depressurized to provide reactor makeup water for accident recovery. In this mode the FAPCS pump takes suction from the suppression pool, removes decay heat, and pumps it into the reactor vessel via RWCU/SDC loop B and then Feedwater loop A.

After successful RPV depressurization, the FAPCS can accomplish the core cooling function when configured in the RPV injection mode. It is manually actuated and it is necessary to inhibit containment isolation signals if any are present.

Success of this function is the effective operation of at least 1 train of FAPCS operating in RPV injection mode for the duration of the sequence. This function is manually actuated and it is also necessary to inhibit the isolation signals, RPV Level 2 and high drywell pressure that may be present in this case.

Success of this function is the success of at least 1 train of FAPCS operating in the RPV injection mode.

Top event gate names: VL-TOPINJ

Dependencies: RWCU line B and FDW line A. Operator must manually actuate FAPCS, align valves, and inhibit isolation signals.

Assumptions: none

3.3.4.12 Top Event: (VM) Dedicated LPCI Backup

Dedicated LPCI Backup provides reactor water inventory control through connection to FAPCS and feedwater injection line A. The motor driven pump and the piping to supply FAPCS are rated Seismic Category I and they remain functional following a safe shutdown earthquake. Dedicated LPCI is used as a backup RPV injection source to FAPCS. This pump is powered by the Ancillary Diesel Generators and takes suction from the Primary Fire Protection Tanks.

Successful Dedicated LPCI Backup requires success of the single motor driven pump and operator action.

Top event gate names: VM-TOPINJ

Dependencies: RWCU line B and FDW line A. Manual alignment, pump start, and level control.

Assumptions: none

3.3.4.13 Top Event: (XD) ADS

ADS consists of 10 SRVs and 8 DPVs. The SRVs are mounted on top of the main steamlines in the drywell and discharge through lines routed to quenchers in the suppression pool. Four DPVs are horizontally mounted on horizontal stub tubes connected to the RPV at about the elevation of the main steamlines. The other four DPVs are horizontally mounted on horizontal lines branching from each main steamline. ADS depressurizes the RPV so that gravity-driven flow from GDCS can inject.

Success criterion: 4 of 8 DPVs open

Top event gate names: XD-TOPDPV

Dependencies: Level 1 actuation signal

Assumptions: No credit for pressure reduction is taken for automatic SRVs opening if the DPVs have failed. In general, the model assumes that the DPVs are demanded after initial manual depressurization using SRV.

3.3.4.14 Top Event: (XI) ADS Inhibit

The ESBWR ATWS mitigation strategy is to maintain the reactor at high pressure until a controlled depressurization can be performed. To maintain the reactor at pressure, both the SSLC/ESF ADS inhibit signal, and DPS ADS inhibit signal are required. The SSLC/ESF ADS inhibit signal is provided on: (1) high RPV pressure; or, (2) RPV water Level 2 and APRM-not-down-scale signal. The DPS ADS inhibit signal is provided on: (1) high RPV pressure; or, (2) RPV water Level 2 and SRNM-not-down-scale signal raw signal. This avoids the potential consequences of boron dilution associated with reactor depressurization.

Success criterion: ADS is inhibited during ATWS sequences.

Top event gate names: XI-TOPINH

Dependencies: none

Assumptions: Conservatively, the failure of this function is assumed to lead to core damage due to failure to successfully control power.

3.3.4.15 Top Event: (XM) Manual Depressurization

If no high pressure injection systems are available, it is necessary to depressurize the RPV by opening SRVs to permit effective FACPS or Dedicated LPCI Backup injection to the RPV. Success of this function is the manually opening of at least five of the ten SRVs that can be opened by the operators. This allows for low-pressure injection using either the FAPCS LPCI mode or Dedicated LPCI makeup.

Success criterion: 5 of 10 SRVs open by Operator Action.

Top event gate names: XM-TOPXMAN

Dependencies: Support systems such as DC power, nitrogen and I&C are addressed in the fault trees.

3.3.5 Functional Logic Affecting containment Heat Removal

3.3.5.1 Top Event: (DS) Vacuum Breakers Open

The containment steam suppression function uses vacuum breakers that must be initially closed during the LOCA or ADS blowdown to force steam through vertical and horizontal vents and allow steam condensation in the pool. These vacuum breakers must also subsequently open if drywell pressure decreases relative to the wetwell pressure to avoid negative pressure failures. Vacuum breakers are provided between the drywell (DW) and wetwell (WW). The purpose of the DW-to-WW vacuum breaker system is to protect the integrity of the diaphragm floor slab and vent wall between the DW and the WW, and the DW structure and liner, and to prevent back-flooding of the suppression pool water into the DW.

Success criterion: At least one vacuum breaker to open after steam suppression to avoid containment failure due to negative pressure in the drywell.

Top event gate names: DS-TOPVB

Assumptions: Drywell depressurization following a LOCA is expected to produce the most severe negative pressure transient condition in the DW. The results of the Main Steam Line break analysis show that the containment does not reach negative pressure relative to the reactor building, and the maximum WW-DW differential pressure is within the design capability.

3.3.5.2 Top Event: (DL) Vacuum Breakers Reclose

The containment vacuum breakers open in case the pressure in the wetwell is greater than the pressure in the drywell. PCCS effectiveness in containment heat removal requires that a pressure differential exist between the drywell and wetwell. To this end, the vacuum breakers between the DW and WW must be leak tight to maintain this DW to WW pressure differential.

During a LOCA or ADS blowdown, the vacuum breakers open to allow the flow of gas from WW to DW to equalize the WW and DW pressure. Redundant vacuum breakers are provided to protect against a single failure of vacuum breaker, i.e., failure to open. Vacuum breaker isolation valves are provided to protect against failure to close when required.

Success criterion: All the vacuum breakers are closed or re-close following an actuation.

Top event gate name: DL-TOPVB

Dependencies: Support systems such power, and I&C are addressed in the fault trees.

Assumptions: none

3.3.5.3 Top Event: (WP) PCCS

Passive containment heat removal function is performed by PCCS during a LOCA or ADS actuation. It is effective when the drywell pressure is greater than the wetwell pressure, i.e., all of the vacuum breakers are closed and leak-tight. The PCCS loops receive a steam-gas mixture supply directly from the DW. The PCCS loops are initially driven by the pressure difference created between the containment DW and the suppression pool during a LOCA, or ADS actuation (DPVs), and then by gravity drainage of steam condensed in the tubes, so they require no sensing, control, logic or power-actuated devices to function. The PCCS loops are an extension of the safety related containment and do not have isolation valves. The system is always open to the containment atmosphere and has no valves that require opening. Failure of this function is the loss of effectiveness of the heat exchangers in removing the decay heat from containment atmosphere (e.g., tube plugging, loss of cooling water in pools located in the upper part of containment).

The success criterion for this function is the operation of at least 4 of 6 heat exchangers.

Top event gate name: WP-TOPDHR

Dependencies: Failure of vacuum breakers to reseat (DL) is handled in the event tree structure. In addition, the event trees also address failure to makeup to the PCCS/ICS pools.

Assumptions: none

3.3.5.4 Top Event: (WS) Suppression Pool Cooling

One of the FAPCS trains that is not operating in Spent Fuel Pool cooling mode is placed in the suppression pool cooling mode as necessary during normal plant operation. Water drawn from the suppression pool is cooled and cleaned and then returned to the suppression pool in this mode of operation. This mode may be manually initiated following an accident to cool the suppression pool for accident recovery. This mode is automatically initiated in response to a high suppression pool temperature signal.

Success criterion: 1 of 2 FAPCS loops function

Top event gate names: WS-TOPSPC, WS-TOPSPC-A (ATWS)

Dependencies: An equalizing line if PCCS fails, and RPV makeup comes from GDCS. AC power and component cooling are addressed in the fault trees.

Assumptions: none

3.3.5.5 Top Event: (WR) RWCU/SDC

The operation of the RWCU/SDC system at high reactor pressure reduces the plant reliance on the main condenser and ICS during normal reactor cooldowns. RWCU/SDC provides decay heat removal in response to transients. After an ATWS, RWCU may be manually restarted to supply shutdown cooling.

Success criterion: 1 of 2 RWCU loops function

Top event gate names: WR-TOPSDC, WR-TOPSDC-A (ATWS)

Dependencies: FDW Lines A and B. Operator actions to restart RWCU after an ATWS.

Assumptions: none

3.3.5.6 Top Event: (WM) PCC/IC Pool Make Up

PCCS and the Isolation Condensers can perform the long term containment heat removal function as long as water remains in the pools of the upper part of the containment. There is enough water present during operation to remove decay heat for at least 24 hours. A connection to the refueling well in the upper reactor building will automatically open to extend this inventory to at least 72 hours. This is backed up by the ability to make up water to the pools using various water systems. In the PRA, the source provided by FPS is credited because it is completely independent, including support systems, of GDCS and the PCCS automatic water makeup. FPS is used to refill the upper containment pools following boil-off of the cooling water during the passive heat removal process. Makeup to the upper containment pools is required in about 72 hours.

Success criterion: Automatic Pool Valves open on low pool level to connect Refuel Well to upper PCCS/ICS pools, or fire water makeup to the pools.

Top event gate names: WM-TOPINV

Dependencies: none

Assumptions: none

3.3.5.7 Top Event: (WV) Containment Venting

When no containment heat removal system is available, the pressure in the containment will rise. Containment venting is directed by procedure. The actuation of this function is required to avoid the failure of the containment boundary.

The success criterion for the system is manual opening of the vent line.

Top event gate names: WV-TOPVENT

Dependencies: Dedicated LPCI Backup is required after venting when GDCS is used, and PCCS fails. Support systems such instrument air, and local controls, are addressed in the fault trees.

Assumptions: An external low pressure injection source must be available after containment venting to ensure RPV water level is maintained. This dependency is captured within the event trees.

Table 3.3-1

Summary of Functional Logic and Success Criteria

EVENT TREE HEADING	FUNCTION	TOP GATE NAME	APPLICABLE TREES	SUCCESS CRITERIA	BASIS
CF	FW Pump Run-back	CR-TOPRB	AT-T-GEN, AT-T-SW, AT-T-IORV, AT-LOCA	Automatic Actuation	Design
CR	Reactor Protection System	CR-TOPCR	T-GEN, T-FDW, T-SW, T-LOPP, T-IORV, LL-S, LL-S-FDWA, LL-S-FDWB, SL-S, ML-L, SL-L, BOC-MS, BOC-FDWA, BOC-FDWB, BOC-IC, BOC-RWCU	3/4 CR Banks Insert	Design
CS	Standby Liquid Control System	CS-TOP1	AT-T-GEN, AT-T-FDW, AT-T-SW, AT-T-LOPP, , AT-T-IORV, AT-LOCA	2/2 SLCS Trains	Design
DL	Vapor Suppression System Close	DL-TOPVB	T-GEN, T-FDW, T-SW, T-LOPP, T-IORV, LL-S, LL-S-FDWA, LL-S-FDWB, ML-L, SL-S, SL-L, RVR, BOC-FDWA, BOC-FDWB, BOC-RWCU, BOC-MS, BOC-IC	All DW/WW Vacuum Breakers reclose after providing vacuum relief. MDS/ADS	Design
DS	Vapor Suppression System Open	DS-TOPVB	T-GEN, T-FDW, T-SW, T-LOPP, T-IORV, LL-S, LL-S-FDWA, LL-S-FDWB, ML-L, SL-S, SL-L, RVR, BOC-FDWA, BOC-FDWB, BOC-RWCU, BOC-MS, BOC-IC	1 of 3 vacuum breakers open to prevent excessive negative DW pressure	TRAC-G
IA	Isolation: FDW Line A	BC-TOPFWLA	BOC-FDWA	Isolation by 1 Valve or 1 check valve	Design
IB	Isolation: FDW Line B	BC-TOPFWLB	BOC-FDWB	Isolation by 1 Valve or 1 check valve	Design
IC	Isolation: IC Steam Line Broken	BC-TOPICS	BOC-IC	Isolation by 1/2 steam valves, and 1/2 condensate valves	Design
IS	Isolation: Main Steam Line Broken	BC-TOPMS	BOC-MS	Isolation by 1/2 MSIVs in each main steam line	Design
IR	Isolation: RWCU Line Broken	BC-TOPRWCU	BOC-RWCU	Isolation of both lines in operating train	Design
IM	Manual isolation RWCU	IM-TOPSDC	BOC-RWCU	Manual Selection	Design
MA	Overpressure Protection System	MA-TOP10	AT-T-GEN, AT-T-FDW, AT-T-SW, AT-T-LOPP, AT-T-IORV, AT-LOCA	9/18 SRV ATWS	MAAP
MS	Overpressure Protection System	MS-TOP18	T-GEN, T-FDW, T-SW, T-LOPP, SL-L, BOC-FDWA, BOC-FDWB,	1/18 SRV NO ATWS	Design
MW	Isolation Condensers	MW-TOPMW	T-GEN, T-FDW, T-SW, T-LOPP, AT-T-GEN, AT-T-FDW, AT-T-LOPP, AT-T-SW, SL-L, BOC-FDWA, BOC-FDWB,	3/4 IC Trains	Design
PA	SRV closure	PA-TOPCLOSE	AT-T-GEN, AT-T-FDW, AT-T-SW, AT-T-LOPP	All SRV reclose in ATWS	Design
PR	SRV closure	PS-TOPSLOCA	T-GEN, T-FDW, T-SW, T-LOPP,	9/10 SRVs reclose	Design
PS	SRV closure	PS-TOPIORV	T-GEN, T-FDW, T-SW, T-LOPP	All SRVs reclose	Design

Table 3.3-1

Summary of Functional Logic and Success Criteria

EVENT TREE HEADING	FUNCTION	TOP GATE NAME	APPLICABLE TREES	SUCCESS CRITERIA	BASIS
QT	Total Power Conversion System	QT-TOPPCS	T-GEN	4/12 TB Vlv, 1/4 Steam line open, 1/4 Circ Water Pmp, 1/4 FDW Pmp, 1/4 Cond Pmp	Design
UD	CRD for RPV injection	UD-TOPINJ	T-GEN, T-FDW, T-IORV, T-LOPP, LL-S, LL-S-FDWA, SL-S, SL-L, BOC-MS, BOC-FDWA, BOC-IC	1/2 CRD pumps	MAAP
UD	CRD for RPV injection - ATWS	UD-TOPINJ2	AT-T-GEN, AT-T-FDW, AT-T-LOPP, AT-T-IORV, AT-LOCA	2/2 CRD pumps	MAAP
UD	CRD Isolation Bypass for RPV injection	UD-TOPINJ_X	LL-S, LL-S-FDWA, SL-S, SL-L	1/2 CRD pumps	MAAP
UD	Manual CRD Isolation Bypass for RPV injection	UD-TOPINJ_MAN	LL-S-FDWA, SL-S, SL-L	1/2 CRD pumps	MAAP
UF	Feedwater Injection System	UF-TOP1	T-GEN, T-IORV, AT-T-GEN, AT-T-IORV, LL-S, SL-S, ML-L SL-L, BOC-MS, BOC-IC	1/4 FDW pumps	Design
VE	GDCS Equalize	VE-TOPEQU	T-GEN, T-FDW, T-SW, T-LOPP, T-IORV, LL-S, LL-S-FDWA, LL-S-FDWB, SL-S, ML-L, SL-L, RVR, BOC-MS, BOC-FDWA, BOC-FDWB, BOC-IC, BOC-RWCU	1/4 Equalize Lines	MAAP
VI	GDCS Injection	VI-TOPINJ	T-GEN, T-FDW, T-SW, T-LOPP, T-IORV, LL-S, LL-S-FDWA, LL-S-FDWB, SL-S, ML-L, SL-L, BOC-MS, BOC-FDWA, BOC-FDWB, BOC-IC	2/8 lines and 1/3 GDCS pools	MAAP
VI	GDCS Injection	VI-TOPRUP	BOC-RWCU	4/8 lines and 3/3 GDCS pools	MAAP
VI	GDCS Injection	VI-TOPRVR	RVR	8/8 lines and 3/3 GDCS pools	MAAP
VL	LPCI	VL-TOPINJ	T-GEN, T-FDW, T-LOPP, T-IORV, LL-S, LL-S-FDWB, SL-S, SL-L, RVR, BOC-MS, BOC-FDWB, BOC-IC, BOC-RWCU	1/2 FAPCS Trains	MAAP
VM	Dedicated LPCI Backup	VM-TOPINJ	T-GEN, T-FDW, T-SW, T-LOPP, T-IORV, LL-S, LL-S-FDWB, SL-S, ML-L, SL-L, BOC-MS, BOC-FDWB, BOC-IC, BOC-RWCU, RVR	1/1 Dedicated LPCI Backup RPV injection, Valves Open to FDWA line LPCI connection	MAAP
WM	Long-term Upper Pool Make-up	WM-TOPINV	T-GEN, T-FDW, T-SW, T-LOPP, T-IORV, AT-T-GEN, AT-T-FDW, AT-T-SW, LL-S, LL-S-FDWA, LL-S-FDWB, SL-S, ML-L, SL-L, RVR, BOC-FDWA, BOC-FDWB, BOC-RWCU, BOC-MS, BOC-IC	PCCS pools connected	MAAP
WP	Passive Containment Cooling System	WP-TOPDHR	T-GEN, T-FDW, T-SW, T-LOPP, T-IORV, LL-S, LL-S-FDWA, LL-S-FDWB, SL-S, ML-L, , SL-L, , RVR, BOC-FDWA, BOC-FDWB, BOC-RWCU, BOC-MS, BOC-IC	4/6 PCCS Trains	MAAP
WR	RWCU/SDC	WR-TOPSDC	T-GEN, T-FDW, T-LOPP, SL-L	1/2 RWCU/SDC RPV water level must be above Level 3	Design

Table 3.3-1

Summary of Functional Logic and Success Criteria

EVENT TREE HEADING	FUNCTION	TOP GATE NAME	APPLICABLE TREES	SUCCESS CRITERIA	BASIS
WR	RWCU/SDC after ATWS	WR-TOPSDC-A	AT-T-GEN, AT-T-FDW, AT-T-LOPP, AT-LOCA	1/2 RWCU/SDC in ATWS	Design
WS	Suppression Pool Cooling	WS-TOPSPC	T-GEN, T-FDW, T-LOPP, T-IORV, LL-S, LL-S-FDWA, LL-S-FDWB, SL-S, ML-L, SL-L, BOC-FDWA, BOC-FDWB, BOC-RWCU, BOC-MS, BOC-IC, RVR	1/2 FAPCS Suppression Pool cooling	MAAP
WS	Suppression Pool Cooling after ATWS	WS-TOPSPC-A	AT-T-GEN, AT-T-FDW, AT-T-LOPP, AT-T-IORV, AT-LOCA	1/2 FAPCS Suppression Pool cooling	MAAP
WV	Containment Venting	WV-TOPVENT	T-GEN, T-FDW, T-SW, T-LOPP, T-IORV, AT-LOCA, AT-T-GEN, AT-T-FDW, AT-T-LOPP, AT-T-IORV, LL-S, LL-S-FDWA, LL-S-FDWB, SL-S, SL-L, RVR, BOC-FDWB, BOC-RWCU, BOC-MS, BOC-IC	Vent path established	MAAP
XD	ADS	XD-TOPDPV	T-GEN, T-FDW, T-SW, T-LOPP, T-IORV, ML-L, SL-L, SL-S, BOC-MS, BOC-FDWA, BOC-FDWB, BOC-IC, BOC-RWCU, RVR	4/8 DPVs	MAAP
XI	ADS inhibit	XI-TOPINH	AT-T-GEN, AT-T-FDW, AT-T-LOPP, AT-T-SW, AT-T-IORV, AT-LOCA	Automatic Inhibition Actuation	Design
XM	Manual Depressurization	XM-TOPXMAN	T-GEN, T-FDW, T-SW, T-LOPP, T-IORV, SL-S, SL-L, BOC-MS, BOC-FDWB, BOC-IC	5/10 SRVs	MAAP

3.4 EVENT TREE SEQUENCE DESCRIPTIONS

3.4.1 General Transient Event Tree (T-GEN)

3.4.1.1 Sequence Description

Turbine or reactor trips are the most frequent initiating events at nuclear power plants. In these events, the Feedwater System and the Power Conversion System (PCS) are initially available.

Immediately following the trip, a scram signal is generated to initiate control rod insertion. The failure to insert control rods is transferred to an ATWS event tree.

If the PCS remains available, it provides both the short-term and long-term core cooling functions. In the case of PCS failure, the Isolation Condenser (IC) function is initiated by conditions such as high reactor pressure or low water level in the reactor pressure vessel (RPV). For cases that lead to low reactor water level, Main Steam Line Isolation Valve (MSIV) closure occurs. The IC function is sufficient to perform the short-term and long-term core cooling functions. Cooling water that is supplied by the upper pools for ICS and Passive Containment cooling System (PCCS) must be replenished in about 72 hours due to boil-off from the passive heat exchangers. The event trees assume that long-term makeup to the pools is always required since the time available is slightly less than 72 hours when ICS is used, and slightly greater than 72 hours whenever PCCS is used.

If the IC function fails, the pressure in the reactor rises until one or more Safety Relief Valves (SRV) open on their pressure setpoint. Steam is relieved to the suppression pool and makeup water is required to maintain level in the RPV. At this point in the sequence, the reactor pressure remains high and either Feedwater (FDW) or the Control Rod Drive (CRD) system in high pressure injection mode can provide adequate flow to the core. CRD initiates automatically on low water level. CRD Isolation Bypass initiates automatically if a GDCS actuation signal is received, but GDCS injection failure is detected. If either of these systems is successful, adequate core cooling is assured.

In the case of failure of at least one SRV to open and relieve high RPV pressure, the situation is assumed to be a Reactor Vessel Rupture (RVR), and it is transferred to the RVR event tree.

If the high pressure injection systems fail to maintain adequate water level in the RPV, depressurization of the RPV is required so that low pressure injection systems can operate. This can occur either manually using SRVs as directed by plant procedures, or automatically by the Automatic Depressurization System (ADS).

Manual depressurization is successful if at least 5 SRVs are opened to reduce RPV pressure enough to allow for injection from either the Fuel and Auxiliary Pool Cooling System (FAPCS) in the low pressure coolant injection (LPCI) mode, or the Dedicated LPCI Backup in the injection mode. Both have the capability to successfully perform the coolant makeup function for the short and long term. Condensate pumps could also be used to inject water to the vessel. However, because of their dependence with both PCS and Feedwater, which are already resolved as failed in these sequence paths, the condensate pumps are conservatively not credited as a separate low pressure injection source. If the operators fail to manually depressurize the RPV, it will automatically depressurize (ADS) on a low RPV water level signal.

Then, either Gravity Driven Cooling System (GDCS), LPCI or Dedicated LPCI Backup can provide inventory to the RPV.

When ADS is actuated, SRVs discharge to the suppression pool and DPVs open to relieve steam to the upper drywell, which is quenched in the suppression pool. The vacuum breakers open to equalize pressure between the wetwell airspace and the upper drywell to prevent containment damage. The vacuum breakers must, in turn, successfully close in order to maintain sufficient differential pressure for the PCCS venting function to occur. Failure of the opened vacuum breakers to reclose results in a failure of PCCS.

For the sequences in which LPCI or Dedicated LPCI Backup provide water injection, no further systems or actions are necessary to ensure long-term core cooling; however, long-term containment cooling (decay heat removal) is necessary to assure stable conditions. For the sequences where the water injection function is performed by GDCS, the core will remain covered for more than 24 hours, however to preserve the state indefinitely without recovery of any of the active systems, containment heat removal is necessary

The following methods satisfy the containment heat removal function:

- RWCU in shutdown cooling mode,
- PCCS,
- FAPCS in suppression pool cooling mode, and
- Containment venting.

It should be noted that venting the containment breaks the PCCS recirculation loop and continued injection by an external source is required.

3.4.1.2 Event Sequences

The General Transient event tree produces 21 sequences that end in a core damage end states or transfer to another event tree. Each core damage sequence is described below and is summarized in Table 3.4-1. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.1.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (T-GEN004a, T-GEN020, T- GEN021, T-GEN022, T-GEN051, T-GEN067)

A transient initiates each of these sequences. After a successful scram, the power conversion system fails either due to loss of the condenser, circulating water, condensate, feedwater, or turbine bypass capability. Vessel level decreases, which causes the MSIVs to close and the ICs to actuate. If ICS is initially successful (T-GEN004a), make-up to the ICS/PCCS pools or other long-term decay removal system is needed. If the long-term decay heat removal fails, containment fails an external source of injection is required. There is substantial time and systems available to mitigate core damage in this sequence, so CRD may be used to maintain RPV level after the failure of ICS long-term heat removal has occurred. However, if CRD fails, it is conservatively assumed that this sequence results in core damage. In the remaining sequences, the ICs fail to operate, which causes vessel pressure to further increase. The SRVs lift at their pressure setpoints to prevent vessel overpressure. High pressure injection using either the Feedwater pumps or Control Rod Drive pumps is also unsuccessful. The vessel is at high pressure and is losing inventory through the SRVs with no high pressure make-up available. ADS actuates on low RPV level to allow GDCS and LPCI injection.

If ADS is successful, four of these sequences differ by the combinations of GDCS and LPCI failures, and whether manual depressurization was previously successful prior to ADS actuation. Ultimately, each sequence results in a loss of low pressure injection, and core damage.

Sequence T-GEN022 has successful manual depressurization with subsequent failure of LPCI so that vessel level lowers to Level 1, which actuates ADS. However, ADS fails resulting in failure to lower the reactor pressure sufficiently to allow GDCS injection. The failure to inject with GDCS causes the level to decrease and leads to core damage.

3.4.1.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(T-GEN015, T-GEN017, T-GEN019, T-GEN027, T-GEN031, T-GEN035)

Similar to Class 1, the power conversion system is unavailable in all Class 2 sequences. Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. The Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures to prevent core damage. However, if only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

The sequences in this sub-class involve the failure of Isolation Condensers, which causes vessel pressure to increase and the SRVs to lift at their pressure setpoints to prevent vessel overpressure. Injection using Feedwater pumps or Control Rod Drive pumps is also unsuccessful. The vessel is at high pressure and is losing inventory through the SRVs with no high pressure make-up available.

RPV pressure is reduced by successful ADS actuation on Level 1 to allow low pressure injection. Finally, each of these sequences includes loss of decay heat removal by failure of:

- RWCU/Shutdown cooling,
- PCCS,
- Suppression pool cooling, and
- Containment venting.

It should be noted that RWCU/SDC is considered unavailable whenever the GDCS equalizing lines are open. When the GDCS equalizing lines are open, the RPV level settles below the RWCU/SDC suction line level.

The sequences differ in the timing and manner of low pressure injection, as described in the sub-groupings below:

(1) GDCS injection and equalizing are successful but injection by LPCI and Dedicated LPCI Backup fail. (T-GEN015, T-GEN017, T-GEN019)

(2) Manual depressurization fails, but ADS is successful. GDCS injection and equalizing are successful. (T-GEN027, T-GEN031, T-GEN035)

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(T-GEN026, T-GEN030, T-GEN034)

Similar to Class 2-a, the power conversion system is unavailable. The Isolation Condensers are demanded on high reactor pressure and they fail, which causes vessel pressure to further increase and the SRVs to lift at their pressure setpoints to prevent vessel overpressure. Injection using Feedwater pumps or Control Rod Drive pumps is also unsuccessful. The vessel is at high pressure and is losing inventory through the SRVs with no high pressure make-up available.

In sequences T-GEN026, T-GEN030, and T-GEN034, manual depressurization fails, but vessel pressure is reduced by ADS. GDCS injection and equalizing are initially successful in maintaining vessel level. Long-term decay heat removal is lost due to the failure of Suppression Pool Cooling, and PCCS. As noted earlier, RWCU/SDC is unavailable when the GDCS lines are opened. The loss of all DHR requires venting the containment to prevent its failure. The containment is successfully vented; however, GDCS eventually fails due to failure of the recirculation loop, and loss of inventory when the containment is open. Finally, a failure to initiate low pressure injection using Dedicated LPCI Backup results in loss of all low pressure injection and subsequent core damage.

3.4.1.2.3 High Pressure Core Damage with Containment Intact (Class III) End States: (T-GEN069)

A transient initiates each of these sequences. After a successful scram, the power conversion system fails either due to loss of the condenser, circulating water, condensate, feedwater, or turbine bypass failure. Vessel level decreases, which causes the MSIVs to close. This actuates the Isolation Condensers, and they fail to operate, which causes vessel pressure to further increase. The SRVs lift at their pressure setpoints to prevent vessel overpressure. Injection using Feedwater pumps or Control Rod Drive pumps is also unsuccessful. The vessel is at high pressure and is losing inventory through the SRVs with no high pressure make-up available.

Sequence T-GEN069 fails manual depressurization and ADS. The vessel level decreases due to loss of all injection, leading to core damage.

3.4.1.2.4 Core Damage with Containment Bypass (Class V) End State: (T-GEN068)

Sequence T-GEN068 results in a containment over-pressure failure. In this sequence, there is a loss of all high pressure injection, and the vacuum breakers fail to open after ADS. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is conservatively assumed to lead to core damage. The PRA model conservatively assumes that aligning or initiating injection after containment failure is not successful. However, if injection has been established prior to containment failure, injection is able to prevent core damage.

3.4.1.2.5 Initiating Event Transfers

Inadvertent Opening of a Relief Valve (IORV): (T-GEN070), T-GEN071

A transient-initiated sequence that challenges one, or more, SRVs with a failure to reseat. The behavior of these sequences follows the IORV event tree.

Reactor Vessel Rupture (RVR): (T-GEN072)

A transient-initiated sequence that requires over-pressure relief, but has a failure to open at least one SRV. This is assumed to lead the reactor vessel failure. The behavior of this sequence follows the RVR event tree.

Anticipated Transient Without Scram (ATWS): (T-GEN073)

A transient-initiated sequence that fails to scram, and is transferred to the AT-T-GEN event tree.

3.4.2 Loss of Feedwater Transient (T-FDW)

3.4.2.1 Sequence Description

A loss of Feedwater flow could occur from pump failures, operator errors, loss of instrument air or reactor system variables such as a high vessel water level trip signal. When Feedwater flow terminates, subcooling decreases, causing a reduction in core power level and pressure. As the core power level is reduced, the turbine steam flow starts to drop off because of the action of the pressure regulator in attempting to maintain pressure. Water level continues to drop, and the vessel level scram trip setpoint is reached. The reactor may have been scrammed previously if the initiating event involved a loss of the power generation buses. The vessel water level continues to drop to Level 2. At that time, ICS, CRD high pressure injection and closure of all MSIVs are actuated. In the case that CRD is unavailable for level control, the level can be maintained above the top of active fuel with the ICS as the primary success path.

The ICS design incorporates condensate reservoirs in each train. Upon ICS actuation, the reservoirs provide sufficient inventory to prevent RPV water level from reaching the ADS actuation setpoint after a loss of Feedwater.

If the water level is restored, the event tree proceeds in a similar manner to the general transient, except that PCS and FDW are not available. PCS is not available because the MSIVs close on water Level 2.

If ICS fails, then the ICS condensate reservoirs are not injected into the vessel, and the RPV water level reaches the ADS actuation setpoint.

If ADS successfully actuates, and the DW/WW vacuum breakers fail, the containment fails. However, CRD is able to keep the core covered since it was initiated prior to containment failure. If CRD fails, then core damage with containment bypass is assumed. If the DW/WW vacuum breakers are successful after ADS, and GDCS is successfully initiated the sequence proceeds the same as the general transient branch in which ADS is successful. If GDCS is not successfully initiated, CRD, FAPCS in LPCI, and Dedicated LPCI Backup can be used to provide low pressure injection.

If ADS does not successfully actuate, after ICS failure CRD is able to keep the core covered. FAPCS in LPCI mode or Dedicated LPCI Backup can provide core cooling if manual depressurization using SRVs is successful in reducing reactor pressure.

The major differences between loss of feedwater and general transient accident sequences are:

- No PCS,
- No Feedwater injection, and

ADS occurs earlier if ICS fails.

Each core damage sequence is described below and is summarized in Table 3.4-2. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.2.2 Event Sequences

The Loss of Feedwater event tree produces 16 sequences that end in core damage end states or transfers to other event trees. Each end state is described below.

3.4.2.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (T-FDW003a, T-FDW033, T-FDW050, T-FDW060)

A total and immediate loss of feedwater transient initiates each of these sequences. After a successful scram, the power conversion system is assumed to be failed due to the loss of feedwater. Vessel level decreases, which causes the MSIVs to close on Level 2. This actuates the Isolation Condensers. If ICS is initially successful (T-FDW003a), make-up to the ICS/PCCS pools or other long-term decay removal system is needed. If the long-term decay heat removal fails, containment fails an external source of injection is required. There is substantial time and systems available to mitigate core damage in this sequence, so CRD may be used to maintain RPV level after the failure of ICS long-term heat removal has occurred. However, if CRD fails, it is conservatively assumed that this sequence results in core damage. In the remaining sequences ICS fails to operate, which causes vessel pressure to further increase. The SRVs lift at their pressure setpoints to prevent vessel overpressure. Injection using Control Rod Drive pumps is unavailable, and the RPV reaches Level 1.

In sequences T-FDW033 and T-FDW050, ADS actuates on Level 1 to allow low pressure injection. In sequence T-FDW060, ADS fails to actuate, but manual depressurization is successful. At this point, these three sequences involve combinations of FAPCS LPCI and Dedicated LPCI Backup failures that result in a loss of low pressure injection, and core damage.

3.4.2.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(T-FDW008, T-FDW012, T-FDW016)

Similar to Class 1, the power conversion system is unavailable in all Class 2 sequences. Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. The Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures to prevent core damage. However, if only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

The remaining sequences in this sub-class involve the failure of Isolation Condensers, which causes vessel pressure to increase and the SRVs to lift at their pressure setpoints to prevent vessel overpressure. Although injection using Control Rod Drive pumps may be available, it is assumed that CRD injection flow rate is insufficient to prevent reaching Level 1.

The other 3 sequences in this sub-class reduce pressure by successful ADS actuation on Level 1 to allow successful GDCS injection. Finally, each of these sequences includes loss of decay heat removal by failure of:

(1) RWCU/Shutdown cooling,

(2) PCCS,

(3) Suppression pool cooling, and

(4) Containment venting.

It should be noted that RWCU/SDC is considered unavailable whenever the GDCS equalizing lines are open. When the GDCS equalizing lines are open, the RPV level settles below the RWCU/SDC suction line level.

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(T-FDW007, T-FDW011, T-FDW015)

This sub-class involves successful venting of the containment with loss of low pressure injection, and subsequent core damage.

Similar to Class 2-a, the power conversion system is unavailable. The Isolation Condensers are demanded on high reactor pressure and they fail, which causes vessel pressure to further increase and the SRVs to lift at their pressure setpoints to prevent vessel overpressure. Although injection using Control Rod Drive pumps may be available, it is assumed that CRD injection flow rate is insufficient to prevent reaching Level 1.

In sequences T-FDW007, T-FDW011, and T-FDW015, GDCS is successful after ADS; however, shutdown cooling is unavailable. RWCU is inoperable when RPV water level is controlled by the equalize mode of GDCS because it maintains water level below the upper RWCU suction line elevation. The additional loss of suppression pool cooling and active low pressure injection when containment vent is successful leads to core damage.

3.4.2.2.3 High Pressure Core Damage with Containment Intact (Class III) End State: (T-FDW061)

A total and immediate loss of feedwater transient initiates this sequence. After a successful scram, the power conversion system is assumed to be failed due to the loss of feedwater. Vessel level decreases, which causes the MSIVs to close on Level 2. This actuates the Isolation Condensers, and they fail to operate, which causes vessel pressure to further increase. The SRVs lift at their pressure setpoints to prevent vessel overpressure. ADS and manual depressurization fail to reduce pressure. The vessel level decreases due to loss of all injection, leading to core damage.

3.4.2.2.4 Core Damage with Containment Bypass (Class V) End State: (T-FDW052)

Sequence T-FDW052 results in a containment over-pressure failure. In this sequence, there is a loss of all high pressure injection, and the vacuum breakers fail after ADS. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is assumed to lead to core damage.

3.4.2.2.5 Initiating Event Transfers

Inadvertent Opening of a Relief Valve (IORV): (T-FDW062, T-FDW063)

A loss of feedwater transient-initiated sequence that challenges one, or more, SRVs with a failure to reseat. The behavior of these sequences follow the IORV event tree.

Reactor Vessel Rupture (RVR): (T-FDW064)

A loss of feedwater transient-initiated sequence that requires over-pressure relief, but has a failure to open at least one SRV. This is assumed to lead the reactor vessel failure. The behavior of this sequence follows the RVR event tree.

Anticipated Transient Without Scram (ATWS): (T-FDW065)

A loss of feedwater transient-initiated sequence that fails to scram, and is transferred to the AT-T-FDW event tree.

3.4.3 Loss of Preferred Power Transient (T-LOPP)

3.4.3.1 Sequence Description

The loss of the preferred power (T-LOPP) sequence of events is similar to the loss of feedwater. The discussion provided above relative to the loss of feedwater response remains applicable to the T-LOPP event tree. The modeling of the diesel generator is included in the AC power fault tree.

The event tree developed for the loss of feedwater is also valid for the loss of preferred power. After the initiating event, the sequences for T-LOPP are identical to the T-FDW sequences.

Each core damage sequence is described below and is summarized in Table 3.4-3. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.3.1.1 Station Blackout Events

Loss of preferred offsite power and diesel generators are modeled in detail under the AC Power fault tree. The postulated station blackout (SBO) scenario involves a total loss of offsite power (both normal and alternate) and the failure of both diesel generators.

The ESBWR has 72-hour safety related batteries. Under the SBO scenario, the safety related batteries still supply DC power to perform safety related functions. This is different from the existing BWR plant designs, which typically have concerns on battery depletion in SBO scenarios. The ESBWR nonsafety-related batteries are sized for two hours. The functions supported by the nonsafety-related batteries do not require continued DC power supply. These functions typically occur right at the beginning of the SBO scenario (e.g., circuit breakers transfer to their alternate alignment.)

The ESBWR passive design is significantly different from the previous BWR designs in that the reactor core is not uncovered in transients due to the additional inventory of coolant above the core. Therefore, even under the unlikely scenario that all the passive systems have failed, the time to core uncovery and time to core damage would be much longer than the traditional reactor designs. In addition, the 72-hour safety related batteries and the redundant passive systems would prevent the core uncovery.

3.4.3.2 Event Sequences

The Loss of Preferred Power event tree produces 16 sequences that end in a core damage end state or a transfer to another event tree. Each end state is described below.

3.4.3.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (T-LOPP003a, T-LOPP033, T-LOPP050, T-LOPP060)

A loss of preferred power initiates each of these sequences. The motor-driven feedwater pumps trip on loss of AC power. After a successful scram, the power conversion system is assumed to be failed due to the loss of feedwater. Vessel level decreases, which causes the MSIVs to close on Level 2. This actuates the Isolation Condensers. If ICS is initially successful (T-LOPP003a), make-up to the ICS/PCCS pools or other long-term decay removal system is needed. If the long-term decay heat removal fails, containment fails an external source of injection is required. There is substantial time and systems available to mitigate core damage in this sequence, so CRD may be used to maintain RPV level after the failure of ICS long-term heat removal has occurred. However, if CRD fails, it is conservatively assumed that this sequence results in core damage. In the remaining sequences ICS fails to operate, which causes vessel pressure to further increase. The SRVs lift at their pressure setpoints to prevent vessel overpressure. Injection using Control Rod Drive pumps is unavailable, and the RPV reaches Level 1.

In sequences T-LOPP033 and T-LOPP050, ADS actuates on Level 1 to allow low pressure injection. In sequence T-LOPP060, ADS fails to actuate, but manual depressurization is successful. At this point, these three sequences involve combinations of FAPCS LPCI and Dedicated LPCI Backup failures that result in a loss of low pressure injection, and core damage.

3.4.3.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(T-LOPP008, T-LOPP012, T-LOPP016)

Similar to Class 1, feedwater and the power conversion system are unavailable in all Class 2 sequences. Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. The Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures to prevent core damage. However, if only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

The remaining sequences in this sub-class involve the failure of Isolation Condensers, which causes vessel pressure to increase and the SRVs to lift at their pressure setpoints to prevent vessel overpressure. Although injection using Control Rod Drive pumps may be available, it is assumed that CRD injection flow rate is insufficient to prevent reaching Level 1.

The other 3 sequences in this sub-class reduce pressure by successful ADS actuation on Level 1 to allow successful GDCS injection. Finally, each of these sequences includes loss of decay heat removal by failure of:

- RWCU/Shutdown cooling,
- PCCS,
- Suppression pool cooling, and
- Containment venting.

It should be noted that RWCU/SDC is considered unavailable whenever the GDCS equalizing lines are open. When the GDCS equalizing lines are open, the RPV level settles below the RWCU/SDC suction line level.

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(T-LOPP007, T-LOPP011, T-LOPP015)

This sub-class involves successful venting of the containment with loss of low pressure injection, and subsequent core damage.

Similar to Class 2-a, feedwater and the power conversion system are unavailable. The Isolation Condensers are demanded on high reactor pressure and they fail, which causes vessel pressure to further increase and the SRVs to lift at their pressure setpoints to prevent vessel overpressure. Although injection using Control Rod Drive pumps may be available, it is assumed that CRD injection flow rate is insufficient to prevent reaching Level 1.

In sequences T-LOPP007, T-LOPP011, T-LOPP015, GDCS is successful after ADS; however, shutdown cooling is unavailable. RWCU is inoperable when RPV water level is controlled by the equalize mode of GDCS because it maintains water level below the upper RWCU suction line elevation. The additional loss of suppression pool cooling and active low pressure injection when containment vent is successful leads to core damage.

3.4.3.2.3 High Pressure Core Damage with Containment Intact (Class III) End State: (T-LOPP061)

A loss of preferred power initiates this sequence. The motor-driven feedwater pumps trip on loss of AC power. After a successful scram, the power conversion system is assumed to be failed due to the loss of feedwater. Vessel level decreases, which causes the MSIVs to close on Level 2. This actuates the Isolation Condensers, and they fail to operate, which causes vessel pressure to further increase. The SRVs lift at their pressure setpoints to prevent vessel overpressure. ADS and manual depressurization fail to reduce pressure. The vessel level decreases due to loss of all injection, leading to core damage.

3.4.3.2.4 Core Damage with Containment Bypass (Class V) End State: (T-LOPP052)

Sequence T-LOPP052 results in a containment over-pressure failure. In this sequence, there is a loss of all high pressure injection, and the vacuum breakers fail after ADS. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is assumed to lead to core damage.

3.4.3.2.5 Initiating Event Transfers

Inadvertent Opening of a Relief Valve (IORV): (T-LOPP062, T-LOPP063)

A loss of preferred power transient-initiated sequence that challenges one, or more, SRVs with a failure to reseat. The behaviors of these sequences follow the IORV event tree.

Reactor Vessel Rupture (RVR): (T-LOPP064)

A loss of preferred power transient-initiated sequence that requires over-pressure relief, but has a failure to open at least one SRV. This is assumed to lead the reactor vessel failure. The behavior of this sequence follows the RVR event tree.

Anticipated Transient Without Scram (ATWS): (T-LOPP065)

A loss of preferred power transient-initiated sequence that fails to scram. This sequence is transferred to the AT-T-LOPP event tree.

3.4.4 Loss of Service Water (T-SW)

3.4.4.1 Sequence Description

This initiating event produces the failure of the Reactor Closed Cooling Water System (RCCWS) and Turbine Building Closed Cooling Water (TCCW) systems. The event is similar to a loss of the Feedwater system, except:

- The timing of the loss of RCCWS and TCCWS is not immediate because of the residual heat absorption available in these two systems.
- Feedwater is not lost immediately.
- Additional systems that fail following a loss of all service water are RWCU/SDC, FAPCS (LPCI and Suppression Pool Cooling), and CRD.

Each core damage sequence is described below and is summarized in Table 3.4-4. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.4.2 Event Sequences

The Loss of Service Water Transient event tree produces 21 sequences that end in a core damage end state, or transfer to another event tree. Each end state is described below.

3.4.4.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States (T-SW009, T-SW010, T-SW011, T-SW029, T-SW037)

A loss of Plant Service Water results in a transient due to loss of component cooling in the power conversion system. After a successful scram, vessel level decreases, which causes the MSIVs to close on Level 2. This actuates the Isolation Condensers, and they fail to operate, which causes vessel pressure to further increase. The SRVs lift at their pressure setpoints to prevent vessel overpressure. Feedwater pumps and Control Rod Drive pumps are not available for high pressure injection due to loss of cooling. The vessel is at high pressure and is losing inventory through the SRVs. ADS actuates on Level 1 to allow low pressure injection.

In sequences T-SW009 and T-SW010, reactor pressure is initially reduced by manual depressurization; however, the Dedicated LPCI Backup system fails and, ADS actuates when vessel level reaches Level 1. In this reduced pressure condition, a failure of the vacuum breakers to open would not result in containment failure. Finally, failure of either GDCS injection or GDCS equalization leads to core damage.

Sequence T-SW011 has successful manual depressurization with subsequent failure of the Dedicated LPCI Backup system so that vessel level lowers to Level 1, which actuates ADS. However, ADS fails and the vessel level decreases due to loss of all injection, leading to core damage.

In sequences T-SW029 and T-SW037, manual depressurization with SRV fails and, ADS actuates when vessel level reaches Level 1. Similar to the sequences above, failure of either

GDCS injection or GDCS equalization, and failure of Dedicated LPCI Backup injection lead to core damage.

3.4.4.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(T-SW002, T-SW006, T-SW007, T-SW008, T-SW015, T-SW018, T-SW021)

This sub-class involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. The Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures to prevent core damage. However, if only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

Similar to Class 1, a loss of Plant Service Water results in a transient due to loss of component cooling in the power conversion system. After a successful scram, vessel level decreases, which causes the MSIVs to close on Level 2.

Sequence T-SW002 has successful Isolation Condenser operation, with subsequent failure of PCCS due to loss of pool cooling makeup. Shutdown and suppression pool cooling are unavailable to remove long-term decay heat, which leads to core damage.

The remaining sequences in this sub-class involve the failure of Isolation Condensers, which causes vessel pressure to increase and the SRVs to lift at their pressure setpoints to prevent vessel overpressure. Feedwater pumps and Control Rod Drive pumps are not available for injection due to loss of cooling. The vessel is at high pressure and is losing inventory through the SRVs with no high pressure make-up available.

In sequences T-SW006, T-SW007, and T-SW008, manual depressurization is successful; however, Dedicated LPCI Backup injection fails, causing RPV water level to decrease to the ADS setpoint. After successful ADS, GDCS injection and equalize modes are successful. Long-term containment heat removal fails, leading to core damage.

In sequences T-SW015, T-SW018, and T-SW021 RPV pressure is reduced by successful ADS actuation to allow low pressure injection. GDCS injection and equalizing are initially successful in maintaining vessel level. Loss of service water causes failure of long-term decay heat removal Suppression Pool Cooling. RWCU/SDC is not available when the GDCS lines are opened, or when service water is lost. Finally, each of these sequences includes loss of decay heat removal by failure of PCCS and Containment venting. The complete loss of all DHR causes containment failure. GDCS eventually fails due to failure of the recirculation loop, and loss of inventory when the containment fails and core damage. The PRA model conservatively assumes that aligning or initiating injection after containment failure is not successful.

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(T-SW014, T-SW017, T-SW020)

This sub-class involves successful venting of the containment with loss of low pressure injection, and subsequence core damage.

Similar to Class 2-a, feedwater, CRD and the power conversion system are unavailable. The Isolation Condensers are demanded on high reactor pressure and they fail, which causes vessel pressure to further increase and the SRVs to lift at their pressure setpoints to prevent vessel overpressure. . Since high pressure injection sources are not available, the RPV level drops and reaches Level 1.

In sequences T-SW014, T-SW017, T-SW020, manual depressurization with the SRV fails, but GDCS is initially successful after ADS; however, shutdown cooling is unavailable when the GDCS equalizing lines open. RWCU and suppression pool cooling are inoperable due to loss of component cooling. The loss of all DHR requires venting the containment to prevent its failure. The containment is successfully vented; however, GDCS eventually fails due to failure of the recirculation loop, and loss of inventory when the containment is open. The additional loss of active low pressure injection (Dedicated LPCI Backup) when containment vent is successful leads core damage.

3.4.4.2.3 High Pressure Core Damage with Containment Intact (Class III) End State: (T-SW-039)

A loss of service water initiates each of this sequence. The motor-driven feedwater pumps, and the CRD pumps, trip on loss of pump cooling. After a successful scram, the power conversion system is assumed to be failed due to the loss of feedwater. Vessel level decreases, which causes the MSIVs to close on Level 2. This actuates the Isolation Condensers, and they fail to operate, which causes vessel pressure to further increase. The SRVs lift at their pressure setpoints to prevent vessel overpressure. ADS and manual depressurization fail to reduce pressure. The vessel level decreases due to loss of all injection, leading to core damage.

3.4.4.2.4 Core Damage with Containment Bypass (Class V) End State: (T-SW038)

After a successful scram, the power conversion system is unavailable. The Isolation Condensers have failed. The Control Rod Drive pumps are unavailable due to loss of component cooling. The vessel is at high pressure and is losing inventory through the SRVs with no high pressure make-up available. In this sequence, failure of the vacuum breakers to open following ADS is assumed to lead to core damage with a containment bypass.

3.4.4.2.5 Initiating Event Transfers:

Inadvertent Opening of a Relief Valve (IORV): (T-SW040, T-SW041)

A loss of service water transient-initiated sequence that challenges one, or more, SRVs with a failure to reseat. The behavior of these sequences follow the IORV event tree.

Reactor Vessel Rupture (RVR): (T-SW042)

A loss of service water transient-initiated sequence that requires over-pressure relief, but has a failure to open at least one SRV. This is assumed to lead the reactor vessel failure. The behavior of this sequence follows the RVR event tree.

Anticipated Transient Without Scram (ATWS): (T-SW043)

A loss of service water transient-initiated sequence that fails to scram. This sequence is transferred to the AT-T-SW event tree.

3.4.5 Inadvertent Opening of a Relief Valve Transient (T-IORV)

3.4.5.1 Sequence Description

The inadvertent opening of a relief valve at power produces the need for a reactor trip when the temperature in the suppression pool increases above the allowed limit. For this initiating event, the Power Conversion System (QT) and Isolation Condenser (MW) functions are unavailable and the MS function (SRV lift to prevent RPV overpressure) is not required.

The functions required to mitigate the events included in this group are the same as those following the General Transient, except that the QT, MW and MS top gates are removed from the event tree. Additionally, the XM heading (manual depressurization) only requires 4 SRVs in this case. For simplification, the same success criterion of 5 SRVs, as described in T-GEN, is used.

3.4.5.2 Event Sequences

The T-IORV event tree produces 17 sequences that end in a core damage end state or transfer to another event tree. Each core damage sequence is described below and is summarized in Table 3.4-5. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.5.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (T-IORV016, T-IORV017, T-IORV018, T-IORV047, T-IORV063, T-IORV065)

An inadvertent opening of a relief valve transient initiates each of these sequences. After a successful scram, the power conversion system is assumed to be unavailable. Vessel level decreases, which causes the MSIVs to close. In these sequences, it is assumed that the ICs fail to operate, which causes vessel pressure to further increase. High pressure injection using either the Feedwater pumps or Control Rod Drive pumps is also unsuccessful. The vessel is at high pressure and is losing inventory through the SRVs with no high pressure make-up available.

In sequences T-IORV016 and T-IORV017, manual depressurization is successful, but low pressure injection (FAPCS and Dedicated LPCI Backup) fails. ADS actuates on low RPV level to reduce pressure to allow low pressure injection by GDCS. However, GDCS early or late low pressure injection fails to provide adequate inventory, leading to core damage.

Sequence T-IORV018 has successful manual depressurization with subsequent failure of LPCI so that vessel level lowers to Level 1, which actuates ADS. However, ADS fails and the vessel level decreases due to loss of all injection, leading to core damage.

In sequences T-IORV047 and T-IORV063, ADS actuates on low RPV level because manual depressurization had previously failed. In combination with failure of all low pressure injection, the core eventually uncovers and leads to core damage.

An inadvertent opening of a relief valve transient initiates sequence T-IORV065. After a successful scram, the power conversion system and ICS are unavailable. Vessel level decreases, which causes the MSIVs to close. The SRVs lift at their pressure setpoints to prevent vessel overpressure. Injection using Feedwater pumps or Control Rod Drive pumps is also unsuccessful. The vessel is at high pressure and is losing inventory through the SRVs with no high pressure make-up available. Failure to depressurize the RPV by manual or automatic means leads to high pressure core damage. However, the RPV pressure is low at the time of vessel rupture as a result of the inadvertent opened relief valve.

3.4.5.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(T-IORV011, T-IORV013, T-IORV015, T-IORV023, T-IORV027, T-IORV031,)

Similar to Class 1, the power conversion system is unavailable in all Class 2 sequences. Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. The Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures to prevent core damage. However, if only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

The first 6 sequences in this sub-class reduce pressure by successful ADS actuation on Level 1 to allow low pressure injection. Finally, each of these sequences includes loss of decay heat removal by failure of:

- RWCU/Shutdown cooling,
- PCCS,
- Suppression pool cooling, and
- Containment venting with low pressure make-up source (e.g., Dedicated LPCI Backup).

It should be noted that RWCU/SDC is considered unavailable whenever the GDCS equalizing lines are open. When the GDCS equalizing lines are open, the RPV level settles below the RWCU/SDC suction line level.

The sequences differ in the timing and manner of low pressure injection, as described in the sub-groupings below:

(1) GDCS injection and equalizing are successful. Because the Dedicated LPCI Backup system has failed in these sequences, containment venting is not demanded. (T-IORV011, T-IORV013, T-IORV015)

(2) GDCS injection and equalizing are successful. While Dedicated LPCI Backup may be available in these sequences, core damage is assumed since decay heat removal including containment venting fails when demanded. T-IORV023, T-IORV027, T-IORV031)

These differences in the timing and amount of make-up inventory affect the timing of containment overpressurization and also the timing of core uncovery.

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(T-IORV022, T-IORV026, T-IORV030)

This sub-class involves successful venting of the containment with loss of low pressure injection, and subsequent core damage.

Similar to Class 2-a, the power conversion system is unavailable. Vessel pressure increases and the SRVs lift at their pressure setpoints to prevent vessel overpressure.

In sequences T-IORV022, T-IORV026, and T-IORV030, GDCS injection and equalize modes are successful after ADS; however, the additional loss of suppression pool cooling and active low pressure injection when containment vent is successful leads to core damage.

3.4.5.2.3 Core Damage with Containment Bypass (Class V) End State: (T-IORV064)

Sequence T-IORV064 also, results in a containment overpressure failure. In this sequence, there is a loss of all high pressure injection similar to the above sequences, and the vacuum breakers fail after ADS. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is assumed to lead to core damage.

3.4.5.2.4 Initiating Event Transfers

Anticipated Transient Without Scram (ATWS): (T-IORV066)

A transient, initiated by an inadvertent opening of a relief valve, with a failure to scram. This sequence is transferred to the AT-T-IORV event tree.

3.4.6 Large Steam LOCA (LL-S)

3.4.6.1 Sequence Description

A large steam LOCA is an event leading to a rapid loss of coolant, resulting in a rapid consequential depressurization, such that no emergency depressurization is required in order to permit the low pressure injection systems, including GDCS, to inject.

Immediately following the break, there is a drop in the RPV water level. The FDW system attempts to maintain the water level in the vessel, but the system automatically isolates on high drywell pressure. CRD automatically injects at RPV Level 2, but it isolates on high drywell pressure combined with high lower drywell water level. The GDCS automatically initiates on low RPV level with the vessel depressurized, and GDCS and the equalizing lines are sufficient to provide core cooling. If GDCS injection fails, the CRD Isolation Bypass logic automatically opens the bypass valves, and CRD can maintain the RPV level. If the CRD Isolation Bypass is unavailable, FAPCS or Dedicated LPCI Backup injection can be manually actuated after defeating automatic isolation.

Because the RPV is at low pressure, operability of the injection system components is not impaired, given the pump head and containment ultimate capability. When the core is cooled with GDCS, core cooling requires that the LOCA blowdown energy be dissipated by the condensation of the steam that passes through the vents to the suppression pool. If the vapor suppression function is successful, the decay heat removal is accomplished by PCCS, by natural convection and steam condensation. One FAPCS system train can also accomplish the long-term heat removal. Finally, if all other heat removal systems fail, the containment vent can be initiated to reduce the pressure in the containment. The Dedicated LPCI Backup system is required for makeup after venting when GDCS is used.

3.4.6.2 Event Sequences

The LL-S event tree produces 10 sequences that end with a core damage end state. No end states require a transfer to another event tree. Each core damage sequence is described below and summarized in Table 3.4-6. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.6.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (LL-S016, LL-S020)

A large LOCA initiates each of these sequences. The steam is quenched in the suppression pool, which requires the drywell to wetwell vacuum breakers to open and equalize pressure.

In sequence LL-S016, GDCS injection is successful, but GDCS equalizing, LPCI and Dedicated LPCI Backup fail to maintain RPV water level, leading to core damage.

In sequence LL-S020, GDCS injection fails, HPCRD Isolation Bypass, LPCI and Dedicated LPCI Backup fail to maintain RPV water level, leading to core damage.

Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(LL-S005, LL-S009, LL-S013)

Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. The Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures to prevent core damage. However, if only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

GDCS injection and equalize modes are successful; however, each of these sequences includes loss of decay heat removal by failure of long term suppression pool cooling and containment venting.

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(LL-S004, LL-S008, LL-S012)

This sub-class involves successful venting of the containment with loss of low pressure injection, and subsequent core damage. In sequences LL-S004, LL-S008, and LL-S012, GDCS injection and equalize modes are successful after ADS; however, shutdown cooling is unavailable. RWCU is inoperable when RPV water level is controlled by the equalize mode of GDCS because it maintains water level below the upper RWCU suction line elevation. In these sequences either the vacuum breakers fail to maintain a pressure differential between the drywell and wetwell or short or long term PCCS failures occur. The additional loss of suppression pool cooling and active low pressure injection, when containment vent is successful, leads to core damage.

3.4.6.2.2 Core Damage Due to ATWS Sequences (Class IV) End State: (LL-S022)

Sequence LL-S022 involves a LOCA and a failure to scram. This sequence is assumed to lead to core damage.

3.4.6.2.3 Core Damage with Containment Bypass (Class V) End State: (LL-S021)

Sequence LL-S021 results in a containment overpressure failure. In this sequence, there is a large steam LOCA, a successful scram, but the vacuum breakers fail. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is assumed to lead to core damage.

3.4.7 Large Steam LOCA in FDW Line A (LL-S-FDWA)

3.4.7.1 Sequence Description

The sequence of events subsequent to the initiating event is the similar as those described in large steam LOCAs (LL-S). Therefore, the event tree developed for large steam LOCAs is also valid for this initiating event, except that the functions that use the FAPCS line to FDW line A, i.e., Dedicated LPCI Backup (VM), LPCI (VL), and RWCU/SDC (WR) are removed due to the failure of FDW line A and manual CRD isolation bypass is used as an external makeup source for sequences where venting is successful. The FDW is assumed failed and/or isolated for a large break in either FDW line.

3.4.7.2 Event Sequences

The LL-S-FDWA event tree produces 10 sequences that end with a core damage end state. No end states require a transfer to another event tree. Each core damage sequence is described below and summarized in Table 3.4-7. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.7.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (LL-S-FDWA015, LL-S-FDWA017)

A large LOCA in feedwater line A initiates each of these sequences. The steam is quenched in the suppression pool, which requires the drywell to wetwell vacuum breakers to open and equalize pressure.

In sequence LL-FDWA015, GDCS injection is successful, but GDCS equalizing, and manual HPCRD Isolation Bypass fail to maintain RPV water level, leading to core damage.

In sequence LL-FDWA017, GDCS injection fails, and automatic HPCRD Isolation Bypass, fail to maintain RPV water level, leading to core damage.

3.4.7.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(LL-S-FDWA005, LL-S-FDWA009, LL-S-FDWA013)

Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. Although the Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures, it can not be credited since the break occurs in FDW Line A. However, if only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

GDCS injection and equalizing are successful; however, each of these sequences includes loss of decay heat removal by failure of:

- PCCS,
- Suppression pool cooling, and
- Containment venting.

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(LL-S-FDWA004, LL-S-FDWA008, LL-S-FDWA 012)

This sub-class involves successful venting of the containment with loss of low pressure injection, and subsequent core damage. In sequences LL-S-FDWA004, LL-S-FDWA008, and LL-S-FDWA 012, GDCS injection and equalize modes are successful after ADS; however, shutdown cooling is unavailable. RWCU is inoperable when RPV water level is controlled by the equalize mode of GDCS because it maintains water level below the upper RWCU suction line elevation. In these sequences either the vacuum breakers fail to maintain a pressure differential between the drywell and wetwell or short or long term PCCS failures occur. The additional loss of suppression pool cooling and active low pressure injection, when containment vent is successful, leads to core damage.

3.4.7.2.3 Core Damage Due to ATWS Sequences (Class IV) End State: (LL-S-FDWA019)

Sequence LL-S-FDWA019 involves a LOCA and a failure to scram. This sequence is assumed to lead directly to core damage.

3.4.7.2.4 Core Damage with Containment Bypass (Class V) End State: (LL-S-FDWA018)

Sequence LL-S-FDWA018 results in a containment overpressure failure. In this sequence, there is a large steam LOCA in feedwater line A, a successful scram, but the vacuum breakers and CRD injection fail. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is assumed to lead to core damage.

3.4.8 Large Steam LOCA in FDW Line B (LL-S-FDWB)

3.4.8.1 Sequence Description

The sequence of events after the initiating event is the same as described in large steam LOCAs (LL-S). Therefore, the event tree developed for large steam LOCAs is also valid for this initiating event, except that the UD headings are not applicable due to the failure of the line B of the FDW and the failure of CRD injection, which injects into FDW line B. The FDW is assumed failed and/or isolated for a large break in either FDW line.

3.4.8.2 Event Sequences

The LL-S-FDWB event tree produces 10 sequences that end with a core damage end state. No end states require a transfer to another event tree. Each core damage sequence is described below and summarized in Table 3.4-8. The table includes a listing of failed and successful top events to help illustrate each sequence of events

3.4.8.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (LL-S-FDWB029, LL-S-FDWB045)

A large LOCA initiates each of these sequences. The steam is quenched in the suppression pool, which requires the drywell to wetwell vacuum breakers to open and equalize pressure.

In sequences LL-S-FDWB029 and LL-SFDWB045, GDCS, FAPCS LPCI and Dedicated LPCI Backup fail to maintain RPV water level, leading to core damage.

3.4.8.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(LL-S-FDWB005, LL-S-FDWB009, LL-S-FDWB013)

Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. The Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures to prevent core damage. However, if only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

GDCS injection and equalize modes are successful; however, each of these sequences includes loss of decay heat removal by failure of PCCS, suppression pool cooling, and containment venting.

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(LL-S-FDWB004, LL-S-FDWB008, LL-S-FDWB012)

This sub-class involves successful venting of the containment with loss of low pressure injection, and subsequent core damage.

In sequences LL-S-FDWB004, LL-S-FDWB008, and LL-S-FDWB012, GDCS injection and equalize modes are successful after ADS; however, shutdown cooling is unavailable. RWCU is inoperable when RPV water level is controlled by the equalize mode of GDCS because it maintains water level below the upper RWCU suction line elevation. In these sequences either the vacuum breakers fail to maintain a pressure differential between the drywell and wetwell or short or long term PCCS failures occur. The additional loss of suppression pool cooling and active low pressure injection when containment vent is successful, leads to core damage.

3.4.8.2.3 Core Damage Due to ATWS Sequences (Class IV) End State: (LL-S-FDWB047)

Sequence LL-S-FDWB047 involves a LOCA and a failure to scram. This sequence is assumed to lead directly to core damage.

3.4.8.2.4 Core Damage with Containment Bypass (Class V) End State: (LL-S-FDWB046)

Sequence LL-S-FDWB046 results in a containment overpressure failure. In this sequence, there is a large steam LOCA in feedwater line B, a successful scram, but the vacuum breakers fail. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is assumed to lead to core damage.

3.4.9 Medium Liquid LOCA (ML-L)

3.4.9.1 Sequence Description

The flow rate at reactor pressure for a medium break liquid LOCA is greater than the CRD makeup capacity, and FDW is isolated due to high drywell pressure. Depressurization is needed for GDCS injection to prevent core uncovery. It is assumed that FAPCS in the LPCI injection mode, which takes suction from the suppression pool, is lost on suppression pool low water level, before the level of water outside the vessel can maintain the core covered. Therefore, FAPCS in the suppression pool cooling mode is not available in those cases. Due to water level in the vessel being below Level 3, the upper suction line to RWCU/SDC is not available. Therefore, it is assumed that shutdown cooling is not available.

3.4.9.2 Event Sequences

The ML-L event tree produces 12 sequences that end with a core damage end state. No end states require a transfer to another event tree. Each core damage sequence is described below and summarized in Table 3.4-9. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.9.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (ML-L015, ML-L017, ML-L019)

A medium liquid LOCA initiates each of these sequences. The steam is quenched in the suppression pool, which requires the drywell to wetwell vacuum breakers to open and equalize pressure. In sequences ML-L015 and ML-L017, ADS is successful; however, failure of GDCS and Dedicated LPCI Backup injection leads to core damage. In sequence ML-L019, automatic depressurization with the DPVs fails, manual depressurization using the SRVs is successful, but failure of the Dedicated LPCI Backup system leads to core damage.

3.4.9.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(ML-L005, ML-L009, ML-L013)

Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. The Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures to prevent core damage. However, if only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

GDCS injection and equalizing are successful; however, each of these sequences includes loss of decay heat removal by failure of:

- PCCS,
- Suppression pool cooling, and
- Containment venting

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(ML-L004, ML-L008, ML-L012)

This sub-class involves successful venting of the containment with loss of low pressure injection, and subsequent core damage.

In sequences ML-L004, ML-L008, and ML-L012, GDCS injection and equalize modes are successful after ADS; however, shutdown cooling is unavailable. RWCU is inoperable when RPV water level is controlled by the equalize mode of GDCS because it maintains water level below the upper RWCU suction line elevation. In these sequences either the vacuum breakers fail to maintain a pressure differential between the drywell and wetwell or short or long term PCCS failures occur. The additional loss of suppression pool cooling and active low pressure injection when containment vent is successful, leads to core damage.

3.4.9.2.3 High Pressure Core Damage with Containment Intact (Class III) End State: (ML-L020)

In this sequence, feedwater is isolated on high drywell pressure signal,CRD is isolated an not capable to makeup the inventory losses and the ADS setpoint is reached. ADS fails to actuate or the DPVs fail to open and manual depressurization using the SRV fails, so there low pressure injection is not available and core damage follows.

3.4.9.2.4 Core Damage Due to ATWS Sequences (Class IV) End State: (ML-L022)

Sequence ML-L022involves a medium LOCA and a failure to scram. This sequence is assumed to lead directly to core damage.

3.4.9.2.5 Core Damage with Containment Bypass (Class V) End State: (ML-L021)

After a successful scram, the vessel is at high pressure and is losing inventory through the break. In this sequence, failure of the vacuum breakers to open is assumed to lead to core damage with a containment bypass.

3.4.10 Small Steam LOCA (SL-S)

3.4.10.1 Sequence Description

A small steam LOCA is an event where RPV water level is decreasing while RPV pressure is reducing, but at a slower rate, such that depressurization is required in order to permit the low pressure injection systems to inject. This group includes both the medium and small LOCA group included in Section 2, "Initiating Events". These are combined because the mitigating responses are the same for both and can be managed in the same event tree.

3.4.10.2 Event Sequences

The SL-S event tree produces 12 sequences that end with a core damage end state. One end state requires a transfer to another event tree. Each core damage sequence is described below and summarized in Table 3.4-10. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.10.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (SL-S019, SL-S023, SL-S028)

A small break LOCA in a line above Level 3 initiates each of these sequences. After a successful scram, the power conversion system is assumed to be unavailable. Vessel level decreases, drywell pressure increases, and the MSIVs close. In these sequences, it is assumed that the ICs fail to operate. The Feedwater system isolates on high drywell pressure, CRD is unable to turn the RPV level before reaching the ADS setpoint.

In the following three sequences where ICS is assumed to be unavailable and not required to mitigate the pressure transient, but makeup is needed due to the small break LOCA. A low RPV level, or high drywell pressure condition is present, and either the DPVs open to reduce reactor pressure and allow low pressure injection by GDCS, or manual operation of the SRVs is required to allow injection by LPCI and Dedicated LPCI Backup.

In sequence SL-S019, GDCS injection is successful, but GDCS equalizing, LPCI and Dedicated LPCI Backup fail to maintain RPV water level, leading to core damage.

In sequence SL-S023, GDCS injection fails, HPCRD Isolation Bypass, LPCI and Dedicated LPCI Backup fail to maintain RPV water level, leading to core damage.

In Sequence SL-S028, ADS fails resulting in failure to lower the reactor pressure sufficiently to allow GDCS injection. Manual depressurization using the SRVs is successful, but HPCRD Isolation Bypass, LPCI and Dedicated LPCI Backup fail to maintain RPV water level, leading to core damage.

3.4.10.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(SL-S006, SL-S011, SL-S016)

Similar to Class 1, the power conversion system is unavailable in all Class 2 sequences. Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. The Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures to prevent core damage. However, if only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

The sequences in this sub-class reduce pressure by successful ADS actuation on Level 1 to allow low pressure injection. Finally, each of these sequences includes loss of decay heat removal by failure of:

- RWCU/Shutdown cooling,
- PCCS,
- Suppression pool cooling, and
- Containment venting

It should be noted that RWCU/SDC is considered unavailable whenever the GDCS equalizing lines are open. When the GDCS equalizing lines are open, the RPV level settles below the RWCU/SDC suction line level.

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(SL-S005, SL-S010, SL-S015)

This sub-class involves successful venting of the containment with loss of low pressure injection, and subsequent core damage. Similar to Class 2-a, the power conversion system is unavailable.

In sequences SL-S005, SL-S010, and SL-S015, GDCS injection and equalize modes are successful after ADS; however, shutdown cooling is unavailable. RWCU is inoperable when RPV water level is controlled by the equalize mode of GDCS because it maintains water level below the upper RWCU suction line elevation. In these sequences either the vacuum breakers fail to maintain a pressure differential between the drywell and wetwell or short or long term PCCS failures occur. The additional loss of suppression pool cooling and active low pressure injection, when containment vent is successful, leads to core damage

3.4.10.2.3 High Pressure Core Damage with Containment Intact (Class III) End State: (SL-S030)

A small break LOCA in a line above Level 3 initiates each of these sequences. After a successful scram, the power conversion system is assumed to be unavailable. Vessel level decreases, drywell pressure increases, and the MSIVs close. The Feedwater system isolates on high drywell pressure, and CRD is assumed to isolate after reaching the ADS setpoint.. The vessel is at high pressure and is losing inventory through the break with no high pressure make-up available. Failure to depressurize the RPV by manual or automatic means and failure of HPCRD Isolation Bypass after a GDCS signal leads to high pressure core damage.

3.4.10.2.4 Core Damage with Containment Bypass (Class V) End State: (SL-S024)

After a successful scram, the vessel is at high pressure and is losing inventory through the break. The Feedwater system isolates on high drywell pressure, and CRD is assumed to isolate after reaching the ADS setpoint. ADS is successful and the DPVs open. Failure of the vacuum breakers to open after ADS leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is assumed to lead to core damage with containment bypass.

3.4.10.2.5 Initiating Event Transfers

Anticipated Transient Without Scram (ATWS): (SL-S031)

A small steam LOCA, with a failure to scram transfers to the AT-T-LOCA event tree.

3.4.11 Small Liquid LOCA (SL-L)

3.4.11.1 Sequence Description

A small liquid LOCA is an event where RPV water level is decreasing while RPV pressure is reducing, but at a slower rate, such that depressurization is required in order to permit the low pressure injection systems to inject. In some cases, RPV pressure may still increase such that SRVs lift to prevent vessel overpressurization. All of the functions required to mitigate the events included in this group, except for the power conversion system, are the same as those following the General Transient. Because PCS is initially failed, top event QT is removed from the event tree. The small liquid LOCA results in isolation of Feedwater and CRD so RPV depressurization is required even if ICS mitigates the pressure transient and adds its limited inventory to the vessel.

3.4.11.2 Event Sequences

The SL-L event tree produces 24 sequences that end with a core damage end state. Two end states require a transfer to another event tree. Each core damage sequence is described below and summarized in Table 3.4-11. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.11.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (SL-L020, SL-L024, SL-L029, SL-L051, SL-L055, SL-L060)

A small break LOCA in a line below Level 3 initiates each of these sequences. After a successful scram, the power conversion system is assumed to be unavailable. Vessel level decreases, drywell pressure increases, and the MSIVs close. The small liquid LOCA results in isolation of Feedwater and CRD so RPV depressurization is required even if ICS mitigates the pressure transient and adds its limited inventory to the vessel. The vessel is at high pressure and is losing inventory through the break with no high-pressure make-up available.

In the following three sequences where ICS mitigates the pressure transient, but makeup is needed due to the small break LOCA. A low RPV level, or high drywell pressure condition is present, and either the DPVs open to reduce reactor pressure and allow low pressure injection by GDCS, or manual operation of the SRVs is required to allow injection by LPCI and Dedicated LPCI Backup.

In sequence SL-L020, GDCS injection is successful, but GDCS equalizing, FAPCS LPCI, Dedicated LPCI Backup, and Manual CRD Isolation Bypass fail to maintain RPV water level, leading to core damage.

In sequence SL-L024, GDCS injection fails, HPCRD Isolation Bypass, FAPCS LPCI and Dedicated LPCI Backup fail to maintain RPV water level, leading to core damage.

In Sequence SL-S029, ADS fails resulting in failure to lower the reactor pressure sufficiently to allow GDCS injection. Manual depressurization using the SRVs is successful, but HPCRD Isolation Bypass, FAPCS LPCI and Dedicated LPCI Backup fail to maintain RPV water level, leading to core damage.

In the following three sequences where ICS fails, but the SRVs are successful in controlling the pressure transient and makeup is needed due to the small break LOCA. A low RPV level, or high drywell pressure condition is present, and either the DPVs open to reduce reactor pressure and allow low pressure injection by GDCS, or manual operation of the SRVs is required to allow injection by LPCI and Dedicated LPCI Backup.

In sequence SL-L051, GDCS injection is successful, but GDCS equalizing, FAPCS LPCI, Dedicated LPCI Backup, and Manual CRD Isolation Bypass fail to maintain RPV water level, leading to core damage.

In sequence SL-L055, GDCS injection fails, HPCRD Isolation Bypass, FAPCS LPCI and Dedicated LPCI Backup fail to maintain RPV water level, leading to core damage.

In Sequence SL-L060, ADS fails resulting in failure to lower the reactor pressure sufficiently to allow GDCS injection. Manual depressurization using the SRVs is successful, but HPCRD Isolation Bypass, FAPCS LPCI and Dedicated LPCI Backup fail to maintain RPV water level, leading to core damage.

3.4.11.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(SL-L006, SL-L011, SL-L016, SL-L037, SL-L042, SL-L047)

Similar to Class 1, the power conversion system is unavailable in all Class 2 sequences. Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. The Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures to prevent core damage. However, if only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

The 6 sequences in this sub-class reduce pressure by successful ADS actuation on Level 1 to allow low pressure injection. Finally, each of these sequences includes loss of decay heat removal by failure of:

- RWCU/Shutdown cooling,
- PCCS,
- Suppression pool cooling, and
- Containment venting.

It should be noted that RWCU/SDC is considered unavailable whenever the GDCS equalizing lines are open. When the GDCS equalizing lines are open, the RPV level settles below the RWCU/SDC suction line level.

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(SL-L005, SL-L010, SL-L015, SL-L036, SL-L041, SL-L046)

This sub-class involves successful venting of the containment with loss of low pressure injection, and subsequent core damage. Similar to Class 2-a, the power conversion system is unavailable.

In these sequences, GDCS injection and equalize modes are successful after ADS; however, shutdown cooling is unavailable. RWCU is inoperable when RPV water level is controlled by the equalize mode of GDCS because it maintains water level below the upper RWCU suction line elevation. In these sequences either the vacuum breakers fail to maintain a pressure differential between the drywell and wetwell or short or long term PCCS failures occur. The additional loss of suppression pool cooling and active low pressure injection, or manual HPCRD Isolation Bypass, when containment vent is successful, leads to core damage.

3.4.11.2.3 *High Pressure Core Damage with Containment Intact (Class III) End State: (SL-L031, SL-L062)*

After a successful scram, the power conversion system is assumed to be unavailable. Vessel level decreases, drywell pressure increases, and the MSIVs close. The Feedwater system isolates on high drywell pressure, and CRD isolates on high drywell pressure combined with high lower drywell water level. The vessel is at high pressure and is losing inventory through the break with no high pressure make-up available. Failure to depressurize the RPV by manual or automatic means and failure of HPCRD Isolation Bypass after a GDCS signal leads to high pressure core damage.

3.4.11.2.4 *Core Damage with Containment Bypass (Class V) End State: (SL-L025, SL-L056)*

After a successful scram, the vessel is at high pressure and is losing inventory through the break. The Feedwater system isolates on high drywell pressure, and CRD isolates on high drywell pressure combined with high lower drywell water level. After reaching the ADS setpoint. ADS is successful and the DPVs open. Failure of the vacuum breakers to open after ADS leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. These sequences are assumed to lead to core damage with containment bypass.

3.4.11.2.5 *Initiating Event Transfers*

Anticipated Transient Without Scram (ATWS): (SL-L064)

A small steam LOCA with a failure to scram transfers to the AT-T-LOCA event tree.

Reactor Vessel Rupture (RVR): (SL-L063)

A small liquid LOCA sequence that requires over-pressure relief, but has a failure to open at least one SRV is assumed to lead the reactor vessel failure. The behavior of this sequence follows the RVR event tree.

3.4.12 Reactor Vessel Rupture (RVR)

3.4.12.1 Sequence Description

A Reactor Vessel Rupture (RVR) is postulated as an event leading to a rapid depressurization and a loss of coolant through a large break in the RPV.

For this initiating event, it is considered that no active high pressure or low pressure system is able to compensate for the inventory lost through the break and maintain the level in the reactor above RPV Level 1 before core damage. Only injection by the GDCS injection and equalize modes together can provide an amount of water quickly and with enough volume to allow the level of water outside the vessel to maintain the core covered.

3.4.12.2 Event Sequences

The RVR event tree produces 10 sequences that end with a core damage end state. No end states require a transfer to another event tree. Each core damage sequence is described below and summarized in Table 3.4-12. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.12.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (RVR-014, RVR-015)

A reactor vessel rupture initiates these sequences. The steam is quenched in the suppression pool, which requires the drywell to wetwell vacuum breakers to open and equalize pressure. In both sequences there is insufficient GDCS available to prevent core damage.

3.4.12.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(RVR005, RVR009, RVR013)

Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. The Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures to prevent core damage. However, if only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

GDCS injection and equalizing are successful; however, each of these sequences includes loss of decay heat removal by failure of:

- PCCS,
- Suppression pool cooling, and
- Containment venting.

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(RVR-004, RVR-008, RVR-012)

This sub-class involves successful venting of the containment with insufficient low pressure injection, and subsequent core damage.

3.4.12.2.3 Core Damage with Containment Bypass (Class V) End States: (RVR-016, RVR-017)

In sequence RVR-016, RPV rupture occurs, and the drywell to wetwell vacuum breakers fail to suppress containment pressure. This sequence is assumed to result in core damage with containment bypass.

In sequence RVR-017, RPV rupture occurs, and the control rods fail to insert. This sequence is assumed to result in core damage with containment bypass.

3.4.13 Break Outside Containment in Main Steam Line (BOC-MS)

3.4.13.1 Sequence Description

Immediately following a break in a Main Steam line, there is a drop in the RPV pressure and an isolation signal is sent to the MSIVs to close. In the case of successful isolation, the scenario develops into a general transient (T-GEN). If the isolation fails, this event behaves similar to an inadvertent opening of a relief valve, except that short-term core damage sequences are Class V, (containment bypass) sequences. Top event “I ML” is included for isolating the break, before the CR heading.

3.4.13.2 Event Sequences

The BOC-MS event tree produces 18 sequences that end in a core damage end state or a transfer to another event tree. Each core damage sequence is described below and is summarized in Table 3.4-13. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.13.2.1 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(BOC-MS011, BOC-MS014, BOC-MS017, BOC-MS026, BOC-MS030, BOC-MS034)

Similar to Class 1, the power conversion system is unavailable in all Class 2 sequences. Sub-class 2-a involves pressurization of the containment due to loss of long-term decay heat removal, with subsequent core damage. The Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures to prevent core damage. However, if only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

The 6 sequences in this sub-class reduce pressure by successful ADS actuation on Level 1 to allow low pressure injection. Finally, each of these sequences includes loss of decay heat removal by failure of:

- PCCS,
- Suppression pool cooling, and
- Containment venting with low pressure make-up source (e.g., Dedicated LPCI Backup).

The sequences differ in the timing and manner of low pressure injection, as described in the sub-groupings below:

(1) GDCS injection and equalizing are successful. Because Dedicated LPCI Backup is unavailable in these sequences, containment venting is not demanded. (BOC-MS011, BOC-MS014, BOC-MS017)

(2) GDCS injection and equalizing are successful. While Dedicated LPCI Backup may be available in these sequences, core damage is assumed since decay heat removal including containment venting fails when demanded. (BOC-MS026, BOC-MS030, BOC-MS034)

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(BOC-MS025, BOC-MS029, BOC-MS033)

This sub-class involves successful venting of the containment with loss of low pressure injection, and subsequent core damage. Similar to Class 2-a, the power conversion system is unavailable.

In sequences BOC-MS025, BOC-MS029, and BOC-MS033, GDCS injection and equalize modes are successful after ADS; however, shutdown cooling is unavailable. RWCU is inoperable when RPV water level is controlled by the equalize mode of GDCS because it maintains water level below the upper RWCU suction line elevation. The additional loss of suppression pool cooling and active low pressure injection, when containment vent is successful, leads to core damage.

3.4.13.2.2 Core Damage with Containment Bypass (Class V) End State: (BOC-MS067)

Sequence BOC-MS067 involves a failure to isolate the break and a failure of the control rods to insert. The combination of an ATWS with an unisolated break is assumed to lead to core damage. This sequences is classified as containment bypass since this scenario leads to unmitigated releases.

3.4.13.2.3 Core Damage with Containment Bypass (Class V) End State: (BOC-MS019, BOC-MS020, BOC-MS021, BOC-MS049, BOC-MS064, BOC-MS065, BOC-MS066)

Sequences BOC-MS019, BOC-MS020 and BOC-MS021 involve failure of high pressure injection, with successful depressurization. Core damage occurs due to failure of low pressure injection from GDCS, LPCI and Dedicated LPCI Backup. Failure to isolate the break results in containment bypass sequences.

In sequences BOC-MS049 and BOC-MS064, ADS actuates on low RPV level to reduce pressure to allow low pressure injection. However, low pressure injection fails to provide adequate inventory, leading to core damage. The break is not isolated, therefore, these are containment bypass sequences.

Sequence BOC-MS065 results in a containment overpressure failure. In this sequence, there is a loss of all high pressure injection, and the vacuum breakers fail after ADS. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is assumed to lead to core damage with a containment bypass.

In sequence BOC-MS066 there is a loss of high pressure injection and a failure to depressurize. Loss of RPV level leads to core damage at high pressure, with containment bypass.

3.4.13.2.4 Initiating Event Transfers

Transfer to General Transient (T-GEN): (BOC-MS001)

Upon successful MSIV closure, a transient induced by a Main Steam Line break outside of containment behaves like a generic transient.

3.4.14 Break Outside Containment in FDW Line A (BOC-FDWA)

3.4.14.1 Sequence Description

A line break outside containment in FDW Line A, or interfacing system LOCA could affect the functioning of RWCU and FAPCS lines that connect to the line. Therefore, it is assumed that RWCU shutdown cooling, FAPCS LPCI, and Dedicated LPCI Backup injection are not available. In addition, containment venting is assumed to be ineffective because low pressure injection from LPCI or Dedicated LPCI Backup are unavailable to maintain RPV water level. Short-term core damage sequences with isolation failure are considered to be Class V, (containment bypass) sequences. Top event “IA” is included for isolating the break, before the CR heading.

3.4.14.2 Event Sequences

The BOC-FDWA event tree produces 17 sequences that end in a core damage end state or a transfer to another event tree. Each core damage sequence is described below and is summarized in Table 3.4-14. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.14.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (BOC-FDWA020, BOC-FDWA027)

A Feedwater A Line break initiates each of these sequences. After a successful scram, and feedwater line isolation, the power conversion system is assumed to be unavailable. Vessel level decreases, drywell pressure increases, and the MSIVs close. In these sequences the ICs fail to operate. High pressure injection using Control Rod Drive pumps is also unsuccessful. The vessel is at high pressure and is losing inventory through the break with no high pressure make-up available.

In sequences BOC-FDWA020 and BOC-FDWA027, ADS actuates on low RPV level to reduce pressure to allow low pressure injection. However, low pressure injection fails to provide adequate inventory by GDCS, leading to core damage.

3.4.14.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(BOC-FDWA015, BOC-FDWA017, BOC-FDWA019, BOC-FDWA035, BOC-FDWA037, BOC-FDWA039, and BOC-FDWA001a)

Similar to Class 1, the power conversion system is unavailable in all Class 2 sequences. Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. . If only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

The 6 sequences in this sub-class reduce pressure by successful ADS actuation on Level 1 to allow low pressure injection. Finally, each of these sequences includes loss of decay heat removal by failure of PCCS and suppression pool cooling.

The sequences differ in the timing and manner of low pressure injection, as described in the sub-groupings below:

(1) FDW Line A is isolated and GDCS injection and equalizing are successful. Because Dedicated LPCI Backup is unavailable, containment venting is not demanded. (BOC-FDWA015, BOC-FDWA017, BOC-FDWA019)

(2) FDW Line A is not automatically isolated and GDCS injection and equalizing are successful. Because Dedicated LPCI Backup is unavailable, containment venting is not demanded. (BOC-FDWA035, BOC-FDWA037, BOC-FDWA039)

These differences in the timing and amount of make-up inventory affect the timing of containment overpressurization and also the timing of core uncovery.

In addition to the 6 sequences in this sub-class, BOC-FDWA001a is conservatively treated as Class IIa sequence. The break outside containment in the feedwater line is successfully isolated. ICS is initially successful, but make-up to the ICS/PCCS pools or other long-term decay removal system is needed. If the long-term decay heat removal fails, containment fails an external source of injection is required. There is substantial time and systems available to mitigate core damage in this sequence, so CRD may be used to maintain RPV level after the failure of ICS long-term heat removal has occurred. However, this sequence is not a dominant contributor to risk and CRD is not credited as a late injection recovery, and it is conservatively assumed that this sequence results in core damage.

3.4.14.2.3 High RPV Pressure at the time of Core Damage (Class III) End State: (BOC-FDWA029)

In this sequence, ICS and CRD injection fail. Although the line break is isolated, the failure of ADS to depressurize leads high pressure to core damage.

3.4.14.2.4 Core Damage with Containment Bypass (Class V) End State: (BOC-FDWA028, BOC-FDWA040, BOC-FDWA047, BOC-FDWA048, BOC-FDWA049, BOC-FDWA050)

In sequence BOC-FDWA028 the Feedwater line break is successfully isolated; however CRD injection is assumed to be unavailable. Upon successful ADS, the vacuum breakers fail to open, which leads to core damage with containment failure.

Sequences BOC-FDWA040 and BOC-FDWA047 involve failure of high pressure injection, with successful depressurization. Core damage occurs due to failure of low pressure injection from GDCS. Failure to isolate the break results in containment bypass sequences.

Sequence BOC-FDWA048 results in a containment overpressure failure. In this sequence, the line break is not isolated. There is a loss of all high pressure injection, and the vacuum breakers fail to open after ADS. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is assumed to lead to core damage with a containment bypass.

In sequence BOC-FDWA049 the line break is not isolated. There is a loss of high pressure injection and a failure to depressurize. Loss of RPV level leads to core damage at high pressure, with containment bypass.

Sequence BOC-FDWA050 involves a failure to isolate the break and a failure of the control rods to insert. The combination of an ATWS with an unisolated break is assumed to lead to core damage.

3.4.14.2.5 Initiating Event Transfers

Transfer Reactor Vessel Rupture (RVR): (BOC-FDWA030)

In this sequence, the line break is isolated. Failure of ICS and failure of at least one SRV to lift lead to RPV overpressurization.

Transfer to ATWS (AT-T-FDW): (BOC-FDWA031)

A transient initiated by line break that is successfully isolated leads to an ATWS due to failure of control rods to insert.

3.4.15 Break Outside Containment in FDW Line B (BOC-FDWB)

3.4.15.1 Sequence Description

A line break in FDW Line B is assumed to disable all FDW injection, and it also affects the functioning of CRD injection line that connects to the line. Therefore, it is assumed that CRD injection is not available. RWCU shutdown cooling is assumed to be unavailable due to the possibility that a steam break outside containment could cause an RWCU isolation. Short-term core damage sequences with isolation failure are considered to be Class V, (containment bypass) sequences. Top event "IB" is included for isolating the break, before the CR heading.

3.4.15.2 Event Sequences

The BOC-FDWB event tree produces 26 sequences that end with a core damage end state. Two end states require a transfer to another event tree. Each core damage sequence is described below and summarized in Table 3.4-15. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.15.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (BOC-FDWB019, BOC-FDWB021, BOC-FDWB020, BOC-FDWB036, BOC-FDWB053)

A break in feedwater line B initiates these sequences. After a successful scram, and feedwater line isolation, the power conversion system is assumed to be unavailable. The line break is successfully isolated. Vessel level decreases, drywell pressure increases, and the MSIVs close. In these sequences, the ICs fail to operate. There is no high pressure injection using the Control Rod Drive pumps in these sequences. The vessel is at high pressure and is losing inventory through the break. If ADS is successful, it actuates on low RPV level to reduce pressure to allow low pressure injection. However, in these sequences low pressure injection fails to provide adequate inventory, leading to core damage.

Sequence BOC-FDWB021 has successful manual depressurization with subsequent failure of LPCI so that vessel level lowers to Level 1, which actuates ADS. However, ADS fails resulting in failure to lower the reactor pressure sufficiently to allow GDCS injection. The failure to inject with GDCS causes the level to decrease and leads to core damage.

3.4.15.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(BOC-FDWB012, BOC-FDWB014, BOC-FDWB017, BOC-FDWB026, BOC-FDWB030, BOC-FDWB034, BOC-FDWB061, BOC-FDWB065, BOC-FDWB069 and BOC-FDWB001a)

Similar to Class 1, the power conversion system is unavailable in all Class 2 sequences. Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. The Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures to prevent core damage. However, if only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

The 9 sequences in this sub-class reduce pressure by successful ADS actuation to allow low pressure injection by GDCS, and loss of decay heat removal by failure of:

- PCCS,
- Suppression pool cooling, and
- Containment venting.

The sequences differ in the timing and manner of low pressure injection, as described in the sub-groupings below:

(1) The line break is successfully isolated, but FAPCS LPCI and Dedicated LPCI Backup fail. However, GDCS injection and equalizing are successful. Because Dedicated LPCI Backup is unavailable in these sequences, containment venting is not demanded. (BOC-FDWB012, BOC-FDWB014, BOC-FDWB017)

(2) The line break is successfully isolated, but SRV manual depressurization fails. However, GDCS injection and equalizing are successful. (BOC-FDWB026, BOC-FDWB030, BOC-FDWB034)

(3) The line break is not isolated, GDCS injection and equalizing are successful. (BOC-FDWB061, BOC-FDWB065, BOC-FDWB069)

These differences in the timing and amount of make-up inventory affect the timing of containment overpressurization and also the timing of core uncovery.

In addition to the 9 sequences in this sub-class, BOC-FDWB001a is conservatively treated as Class IIa sequence. The break outside containment in the feedwater line is successfully isolated. ICS is initially successful, but make-up to the ICS/PCCS pools or other long-term decay removal system is needed. If the long-term decay heat removal fails, containment fails an external source of injection is required. There is substantial time and systems available to mitigate core damage in this sequence, so CRD may be used to maintain RPV level after the failure of ICS long-term heat removal has occurred. However, this sequence is not a dominant contributor to risk and CRD is not credited as a late injection recovery, and it is conservatively assumed that this sequence results in core damage.

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(BOC-FDWB025, BOC-FDWB029, BOC-FDWB033, BOC-FDWB060, BOC-FDWB064, BOC-FDWB068)

This sub-class involves successful venting of the containment with loss of low pressure injection, and subsequent core damage. Similar to Class 2-a, the power conversion system is unavailable.

In sequences BOC-FDWB025, BOC-FDWB029, and BOC-FDWB033, the break is isolated, and GDCS injection and equalize modes are successful after ADS; however, shutdown cooling is unavailable. RWCU is inoperable when RPV water level is controlled by the equalize mode of GDCS because it maintains water level below the upper RWCU suction line elevation. The additional loss of suppression pool cooling and active low pressure injection, when containment vent is successful, leads to core damage.

In sequences BOC-FDWB060, BOC-FDWB064, and BOC-FDWB068, the break is not isolated. GDCS injection and equalize modes are successful after ADS; however, shutdown cooling is unavailable. RWCU is inoperable when RPV water level is controlled by the equalize mode of GDCS because it maintains water level below the upper RWCU suction line elevation. The additional loss of suppression pool cooling and active low pressure injection, when containment vent is successful, leads to core damage.

3.4.15.2.3 High RPV Pressure at the time of Core Damage (Class III) End State: (BOC-FDWB054)

The break is successfully isolated in this sequence. However, failure of ICS and depressurization leads to high pressure core damage.

3.4.15.2.4 Core Damage with Containment Bypass (Class V) End State: (BOC-FDW053a, BOC-FDWB086, BOC- FDWB103, BOC-FDWB104, BOC-FDWB105, BOC-FDWB106)

In sequence BOC-FDWB053a, the break is isolated. The RPV is depressurized; however, the vacuum breakers fail to reclose, which leads to containment failure and assumed core damage.

In sequence BOC-FDWB086 and BOC-FDWB103, the break is not isolated. Depressurization is successful; however, failure of adequate low pressure injection leads to core damage with a containment bypass.

In sequence BOC-FDWB104, the break is not isolated. The RPV is depressurized; however, the vacuum breakers fail to reclose, which leads to containment failure and assumed core damage.

In sequence BOC-FDWB105, RPV depressurization fails, which leads to core damage with containment bypass.

Sequence BOC-FDWB106 involves a failure to isolate the break and a failure of the control rods to insert. The combination of an ATWS with an unisolated break is assumed to lead to core damage.

3.4.15.2.5 Initiating Event Transfers

Transfer Reactor Vessel Rupture (RVR): (BOC-FDWB055)

In this sequence, the line break is isolated. Failure of ICS and failure of at least one SRV to lift lead to RPV overpressurization.

Transfer to ATWS (AT-T-FDW): (BOC-FDWB056)

A transient initiated by line break that is successfully isolated leads to an ATWS due to failure of control rods to insert.

3.4.16 Break Outside Containment in RWCU/SDC Line (BOC-RWCU)

3.4.16.1 Sequence Description

An isolation signal is sent to the RWCU/SDC valves to close, immediately following the line break. In the case of successful automatic isolation, this scenario develops to a General Transient with the WR function failed. Top event "IR" is included for automatic isolation of the break, before the CR heading, and top event IM is included for manual isolation of the break. In the cases when automatic isolation fails, depressurization is still required to allow for low pressure injection. Decay heat removal is still required to maintain containment integrity and prevent core damage. It is also assumed, that manual isolation is require for all sequences that have initial low pressure injection.

3.4.16.2 Event Sequences

The BOC-RWCU event tree produces 17 sequences that end in a core damage end state or a transfer to another event tree. Each core damage sequence is described below and is summarized in Table 3.4-16. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.16.2.1 *Containment Failure prior to Late Core Damage (Class II) End States*

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(BOC-RWCU 006, BOC-RWCU 010, BOC-RWCU 014)

Sub-class 2-a involves loss of long-term decay heat removal, with subsequent core damage. The RWCU line fails to automatically isolate, but is successfully isolated manually. The Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures to prevent core damage. However, if only GDCS is available DHR (PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

The sequences in this sub-class reduce pressure by successful ADS actuation on Level 1 to allow successful GDCS injection and equalize modes. Finally, each of these sequences includes loss of decay heat removal by failure of:

- PCCS,
- Suppression pool cooling, and
- Containment venting.

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(BOC-RWCU005, BOC-RWCU009, BOC-RWCU013)

This sub-class involves successful venting of the containment with loss of low pressure injection, and subsequent core damage. The RWCU line fails to automatically isolate but, is successfully isolated manually. In sequences BOC-RWCU005, BOC-RWCU009, and BOC-RWCU013, GDCS injection and equalize modes are successful after ADS; however, shutdown cooling is unavailable. The additional loss of suppression pool cooling and active low pressure injection, when containment vent is successful, leads to long-term containment failure.

3.4.16.2.2 *Core Damage with Containment Bypass (Class V) End State: (BOC-RWCU015, BOC-RWCU029, BOC-RWCU031, BOC-RWCU032, BOC-RWCU046, BOC-RWCU048, BOC-RWCU049, BOC-RWCU050, BOC-RWCU051, BOC-RWCU 052)*

Sequences BOC-RWCU015, BOC-RWCU029 and BOC-RWCU031 assume failure of high pressure injection, with successful depressurization. Low pressure injection is initially available. However, failure to isolate the break manually results in core damage and containment bypass sequences.

In sequence BOC-RWCU032, the line is not isolated and GDCS injection is successful after depressurization. However, subsequent failure of GDCS equalize, LPCI, and Dedicated LPCI Backup lead to core damage with a bypassed containment.

In sequences BOC-RWCU046, and BOC-RWCU048, ADS actuates on low RPV level to reduce pressure to allow low pressure injection. GDCS low pressure injection fails, but LPCI or Dedicated LPCI Backup is initially available to provide adequate inventory. However, failure to manually isolate the break is assumed to lead to core damage and containment bypass.

In sequence BOC-RWCU049, the line is not isolated and GDCS injection fails after depressurization. Subsequent failure LPCI, and Dedicated LPCI Backup lead to core damage with a bypassed containment.

Sequence BOC-RWCU050 results in a containment overpressure failure. In this sequence, there is a loss of all high pressure injection, and the vacuum breakers fail after ADS. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is assumed to lead to core damage with a containment bypass.

In sequence BOC-RWCU051 there is a loss of high pressure injection and a failure to depressurize. Loss of RPV level leads to core damage at high pressure, with containment bypass.

Sequence BOC-RWCU052 involves a failure to isolate the break and a failure of the control rods to insert. The combination of an ATWS with an unisolated break is assumed to lead to core damage.

3.4.16.2.3 *Initiating Event Transfers*

Transfer to General Transient (T-GEN): (BOC-RWCU001)

Upon successful isolation valve closure, a transient induced by an RWCU line break outside of containment behaves like a generic transient.

3.4.17 Break Outside Containment in IC Line (BOC-IC)

3.4.17.1 Sequence Description

RPV pressure drops immediately following the break and an isolation signal is sent to the IC valves to close. In the case of successful isolation of the affected line, the scenario develops to a general transient with one IC train unavailable. If the isolation function fails, the containment is open and the sequence of events following this initiating event is similar to Main Steam line break sequences.

3.4.17.2 Event Sequences

The BOC-IC event tree produces 17 sequences that end with a core damage end state. One end state requires a transfer to another event tree. Each core damage sequence is described below and summarized in Table 3.4-17. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.17.2.1 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(BOC-IC012, BOC-IC014, BOC-IC016, BOC-IC024, BOC-IC028, BOC-IC032)

The power conversion system is unavailable in all Class 2 sequences. Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. The Dedicated LPCI Backup system has been designed to allow injection at higher containment pressures to prevent core damage. However, if only GDCS is available DHR

(PCCS or SPC) is also required. If all the decay heat removal systems fail, the containment pressure increases until the containment fails, and core damage is assumed to occur.

In these sequences, the line break fails to automatically isolate, and high pressure injection is unavailable. Successful ADS actuation on Level 1 allows low pressure injection. Finally, each of these sequences includes loss of decay heat removal by failure of:

- PCCS,
- Suppression pool cooling, and
- Containment venting.

The sequences differ in the timing and manner of low pressure injection, as described in the sub-groupings below:

(1) GDCS injection and equalizing are successful. Because Dedicated LPCI Backup is unavailable in these sequences, containment venting is not demanded. (BOC-IC012, BOC-IC014, BOC-IC016)

(2) GDCS injection and equalizing are successful. While Dedicated LPCI Backup may be available in these sequences, core damage is assumed since decay heat removal including containment venting fails when demanded. (BOC-IC024, BOC-IC028, BOC-IC032)

These differences in the timing and amount of make-up inventory affect the timing of containment overpressurization and also the timing of core uncovery.

Class 2-b: Containment Vented with Loss of Low Pressure Injection

(BOC-IC023, BOC-IC027, BOC-IC031)

In sequences BOC-IC023, BOC-IC0279, and BOC-IC031, GDCS injection and equalize modes are successful after ADS; however, shutdown cooling is unavailable. The additional loss of suppression pool cooling and active low pressure injection, when containment vent is successful, core damage.

3.4.17.2.2 Core Damage with Containment Bypass (Class V) End State: (BOC-IC017, BOC-IC018, BOC-IC019, BOC-IC047, BOC-IC062, BOC-IC063, BOC-IC064, BOC-IC065)

In sequences BOC-IC017 and BOC-IC018, the break is not isolated and high pressure injection fails. Depressurization is successful; however, failure of adequate low pressure injection leads to core damage with a containment bypass.

In sequences BOC-IC047 and BOC-IC062, the break is not isolated and high pressure injection fails. Manual depressurization fails, however, ADS is successful. Failure of adequate low pressure injection leads to core damage with a containment bypass.

In sequence BOC-IC063, the break is not isolated. The RPV is depressurized; however, either the vacuum breakers leak initially during blowdown or subsequently fail to open for vacuum relief, which leads to containment failure and assumed core damage.

In sequence BOC-IC019 and BOC-IC064, RPV depressurization fails, which leads to core damage with containment bypass.

Sequence BOC-IC065 involves a failure to isolate the break and a failure of the control rods to insert. The combination of an ATWS with an unisolated break is assumed to lead to core damage

3.4.17.2.3 Initiating Event Transfers

Transfer General Transient (T-GEN): (BOC-IC001)

A break in an ICS line outside of containment that successfully isolates is treated like a general transient.

3.4.18 ATWS Event Tree (AT-T-GEN)

3.4.18.1 Sequence Description

ATWS sequences are initiated by an event in which there is a failure of either the hydraulic or electrical control rod insertion functions. To mitigate an ATWS condition, sodium pentaborate, in sufficient quantity to achieve subcriticality, is injected into the reactor core region by the Standby Liquid Control System (SLCS). SLCS is activated automatically on high RPV pressure or an RPV Level 2 signal in combination with a Source Range Neutron Monitoring permissive (SRNM) not downscale signal lasting for 3 minutes.

In addition to SLCS injection, Feedwater runback and ADS inhibit functions are used to control reactivity. FDW runback reduces the power by affecting natural circulation. ADS inhibit allows adequate reactor pressure to maintain RPV water level control. The ADS inhibit signal is sealed in. Under these conditions, power generation is reduced within the cooling capability of IC and/or CRD until SLCS injection is completed.

ADS inhibit also prevents uncontrolled reactor depressurization and the subsequent GDCS injection which could lead to boron washing out of the RPV. It is assumed that without ADS inhibit the resulting boron dilution causes recriticality.

Following an ATWS with the PCS remaining available, RPV overpressure protection is provided by the actuation of three possible systems: SRV, turbine bypass (Power Conversion System), or ICS.

With successful SLCS injection, core cooling can be performed: (1) by ICS if all the valves that are open also close correctly, (2) by the FDW or CRD with the heat removal by the FAPCS in the cooling mode; or, (3) by RWCU/SDC if isolation signals are inhibited and the filters are bypassed. In case of failure of high pressure systems, core damage is assumed because the reactor is depressurized, and reactivity control is not credited in preventing core damage because of the potential for boron dilution.

The long term heat removal function is similar to that for transients except that no credit is taken for PCCS, because ATWS mitigation is not carried out at low pressure, as discussed earlier. The preferred source for residual heat removal is FAPCS, because in ATWS situations the RWCU/SDC is automatically isolated. Nevertheless, if FAPCS fails, the isolation signal can be overridden and the filters bypassed to provide shutdown cooling.

It should be noted that in the transient event trees, successful injection with a high pressure makeup system is considered a stable safe state. For ATWS scenarios the PRA model assumes that high pressure injection is necessary to prevent core damage. However, since ATWS scenarios involve higher initial energies that may threaten containment integrity, the model assumes that decay heat removal systems, excluding PCCS, are required when high pressure injection is successful.

3.4.18.2 Event Sequences

The AT-T-GEN event tree produces 11 sequences that end with a core damage end state. No end states require a transfer to another event tree. Each core damage sequence is described below and summarized in Table 3.4-18. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.18.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (AT-T-GEN003a, AT-T-GEN021)

A transient initiates each of these sequences. Reactor scram fails but feedwater runback and SLC, and ADS inhibit are successful. Vessel level decreases, which causes the MSIVs to close and the ICs to actuate. If ICS is initially successful (AT-T-GEN003a), make-up to the ICS/PCCS pools or other long-term decay removal system is needed. If the long-term decay heat removal fails, containment fails an external source of injection is required. There is substantial time and systems available to mitigate core damage in this sequence, so CRD may be used to maintain RPV level after the failure of ICS long-term heat removal has occurred. However, if CRD fails, it is conservatively assumed that this sequence results in core damage.

In sequence AT-T-GEN021, feedwater and CRD injection fail. There is no high pressure injection available for power/level control and core damage follows. However, since this sequence involves failure to reclose a SRV, the reactor pressure decreases significantly prior to RPV failure.

3.4.18.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(AT-T-GEN007, AT-T-GEN011, AT-T-GEN016, AT-T-GEN020)

Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. Feedwater runback is successful in reducing core power level. ADS is successfully inhibited, and SLCS injection is successful. As discussed earlier, a high pressure system, and a decay heat removal system are required for ATWS scenarios.

Each of these sequences includes loss of decay heat removal by failure of:

- RWCU Shutdown cooling,
- Suppression pool cooling, and
- Containment venting.

The sequences differ in the timing and manner of RPV water level control by ICS, Feedwater, and CRD injection.

3.4.18.2.3 High Pressure Core Damage with Containment Intact (Class III) End State: (AT-T-GEN012)

In this sequence, feedwater and CRD injection fail. There is no high pressure injection available for power/level control and core damage follows.

3.4.18.2.4 Core Damage Due to ATWS Sequences (Class IV) End State: (AT-T-GEN023, AT-T-GEN024, AT-T-GEN025, AT-T-GEN026)

Sequence AT-T-GEN023 involves failure of SLCS. This sequence is assumed to lead to core damage.

Sequence AT-T-GEN024 involves a failure to inhibit ADS. It is assumed that the RPV is depressurized by ADS when ADS inhibit fails, and the vacuum breakers are successful. This sequence is assumed to lead to core damage.

Sequence AT-T-GEN025 involves an RPV overpressurization due to an insufficient number of SRVs lifting. This sequence is assumed to lead to core damage.

Sequence AT-T-GEN026 involves failure of the Feedwater runback function. This sequence is assumed to lead to core damage.

3.4.18.2.5 Core Damage with Containment Bypass (Class V)End State: (AT-T-GEN024a)

Sequence AT-T-GEN024a results in a containment over-pressure failure. In this sequence, there is failure to inhibit ADS, and the vacuum breakers fail to open after ADS. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is conservatively assumed to lead to core damage with containment bypass.

3.4.19 ATWS Transfer from Loss of FDW Transient Event Tree (AT-T-FDW)

3.4.19.1 Sequence Description

ATWS sequences are initiated by an event in which there is a failure of either the hydraulic or electrical control rod insertion functions. To mitigate an ATWS condition, sodium pentaborate, in sufficient quantity to achieve subcriticality, is injected into the reactor core region by the Standby Liquid Control System (SLCS). SLCS is activated automatically on high RPV pressure or an RPV Level 2 signal in combination with a Source Range Neutron Monitoring permissive (SRNM) not downscale signal lasting for 3 minutes.

In addition to SLCS injection, Feedwater runback and ADS inhibit functions are used to control reactivity. However, in a loss of feedwater transient, automatic FDW runback is not necessary. ADS inhibit allows adequate reactor pressure to maintain RPV water level control. The ADS inhibit signal is sealed in. Under these conditions, power generation is reduced within the cooling capability of IC and/or CRD until SLCS injection is completed.

It should be noted that in the transient event trees, successful injection with a high pressure makeup system is considered a stable safe state. For ATWS scenarios the PRA model assumes that high pressure injection is necessary to prevent core damage. However, since ATWS scenarios involve higher initial energies that may threaten containment integrity, the model assumes that decay heat removal systems, excluding PCCS, are required when high pressure injection is successful.

3.4.19.2 Event Sequences

The AT-T-FDW event tree produces 8 sequences that end with a core damage end state. No end states require a transfer to another event tree. Each core damage sequence is described below and summarized in Table 3.4-19. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.19.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (AT-T-FDW003a, AT-T-FDW013)

A loss of feedwater transient initiates each of these sequences. Reactor scram fails, but SLC and ADS inhibit are successful. Vessel level decreases, which causes the MSIVs to close and the ICs to actuate. If ICS is initially successful (AT-T-FDW003a), make-up to the ICS/PCCS pools or other long-term decay removal system is needed. If the long-term decay heat removal fails, containment fails an external source of injection is required. There is substantial time and systems available to mitigate core damage in this sequence, so CRD may be used to maintain RPV level after the failure of ICS long-term heat removal has occurred. However, if CRD fails, it is conservatively assumed that this sequence results in core damage.

In sequence AT-T-FDW013, CRD injection fails. There is no high pressure injection available for power/level control and core damage follows. However, since this sequence involves failure to reclose a SRV, the reactor pressure decreases significantly prior to RPV failure.

3.4.19.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection

(AT-T-FDW007, AT-T-FDW012)

Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. ADS is successfully inhibited, and SLCS injection is successful. As discussed earlier, a high pressure system, and a decay heat removal system are required for ATWS scenarios.

Each of these sequences includes loss of decay heat removal by failure of:

- RWCU Shutdown cooling,
- Suppression pool cooling, and
- Containment venting.

The sequences differ in the timing and manner of RPV water level control by ICS and CRD injection.

3.4.19.2.3 High Pressure Core Damage with Containment Intact (Class III) End State: (AT-T-FDW008)

In this sequence CRD injection fails. There is no injection available and core damage follows.

3.4.19.2.4 Core Damage Due to ATWS Sequences (Class IV) End State: (AT-T-FDW015,

AT-T-FDW016, AT-T-FDW017)

Sequence AT-T-FDW015 involves failure of SLCS. This sequence is assumed to lead to core damage.

Sequence AT-T-FDW016 involves a failure to inhibit ADS. It is assumed that the RPV is depressurized by ADS when ADS inhibit fails, and the vacuum breakers are successful. This sequence is assumed to lead to core damage.

Sequence AT-T-FDW017 involves an RPV overpressurization due to an insufficient number of SRVs lifting. This sequence is assumed to lead to core damage.

3.4.19.2.5 Core Damage with Containment Bypass (Class V) End State: (AT-T-FDW016a)

Sequence AT-T-FDW016a results in a containment over-pressure failure. In this sequence, there is failure to inhibit ADS, and the vacuum breakers fail to open after ADS. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is conservatively assumed to lead to core damage with containment bypass.

3.4.20 ATWS Transfer from Loss of Preferred Power Event Tree (AT-T-LOPP)

3.4.20.1 Sequence Description

ATWS sequences are initiated by an event in which there is a failure of either the hydraulic or electrical control rod insertion functions. To mitigate an ATWS condition, sodium pentaborate, in sufficient quantity to achieve subcriticality, is injected into the reactor core region by the Standby Liquid Control System (SLCS). SLCS is activated automatically on high RPV pressure or an RPV Level 2 signal in combination with a Source Range Neutron Monitoring permissive (SRNM) not downscale signal lasting for 3 minutes.

In addition to SLCS injection, Feedwater runback and ADS inhibit functions are used to control reactivity. However, in a loss of preferred power transient, feedwater pumps trip, and thus, automatic FDW runback is not necessary. ADS inhibit allows adequate reactor pressure to maintain RPV water level control. The ADS inhibit signal is sealed in. Under these conditions, power generation is reduced within the cooling capability of IC and/or CRD until SLCS injection is completed.

It should be noted that in the transient event trees, successful injection with a high pressure makeup system is considered a stable safe state. For ATWS scenarios the PRA model assumes that high pressure injection is necessary to prevent core damage. However, since ATWS scenarios involve higher initial energies that may threaten containment integrity, the model assumes that decay heat removal systems, excluding PCCS, are required when high pressure injection is successful.

3.4.20.2 Event Sequences

The AT-T-LOPP event tree produces 8 sequences that end with a core damage end state. No end states require a transfer to another event tree. Each core damage sequence is described below and summarized in Table 3.4-20. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.20.2.1 Low Pressure Core Damage with Containment Intact (Class I) End States: (AT-T-LOPP003a, AT-T-LOPP013)

A loss of preferred power transient initiates each of these sequences. Reactor scram fails, but SLC and ADS inhibit are successful. Vessel level decreases, which causes the MSIVs to close and the ICs to actuate. If ICS is initially successful (AT-T-LOPP003a), make-up to the ICS/PCCS pools or other long-term decay removal system is needed. If the long-term decay heat removal fails, containment fails an external source of injection is required. There is substantial time and systems available to mitigate core damage in this sequence, so CRD may be used to maintain RPV level after the failure of ICS long-term heat removal has occurred. However, if CRD fails, it is conservatively assumed that this sequence results in core damage.

In sequence AT-T-LOPP013, CRD injection fails. There is no high pressure injection available for power/level control and core damage follows. However, since this sequence involves failure to reclose a SRV, the reactor pressure decreases significantly prior to RPV failure.

3.4.20.2.2 Containment Failure prior to Late Core Damage (Class II) End States Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection (AT-T-LOPP003, AT-T-LOPP007, AT-T-LOPP012)

Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. ADS is successfully inhibited, and SLCS injection is successful. As discussed earlier, a high pressure system, and a decay heat removal system are required for ATWS scenarios.

Each of these sequences includes loss of decay heat removal by failure of:

- RWCU Shutdown cooling,
- Suppression pool cooling, and
- Containment venting.

The sequences differ in the timing and manner of RPV water level control by ICS and CRD injection.

3.4.20.2.3 High Pressure Core Damage with Containment Intact (Class III) End State: (AT-T-LOPP008)

In this sequence CRD injection fails. There is no injection available and core damage follows.

3.4.20.2.4 Core Damage Due to ATWS Sequences (Class IV) End State: (AT-T-LOPP015, AT-T-LOPP016, AT-T-LOPP017)

Sequence AT-T-LOPP015 involves failure of SLCS. This sequence is assumed to lead to core damage.

Sequence AT-T-LOPP016 involves a failure to inhibit ADS. It is assumed that RPV is depressurized by ADS when ADS inhibit fails, and the vacuum breakers are successful. This sequence is assumed to lead to core damage.

Sequence AT-T-LOPP017 involves an RPV overpressurization due to an insufficient number of SRVs lifting. This sequence is assumed to lead to core damage.

3.4.20.2.5 Core Damage with Containment Bypass (Class V) End State: (AT-T-LOPP016a)

Sequence AT-T-LOPP016a results in a containment over-pressure failure. In this sequence, there is failure to inhibit ADS, and the vacuum breakers fail to open after ADS. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is conservatively assumed to lead to core damage with containment bypass.

3.4.21 ATWS Transfer from Loss of Service Water Event Tree (AT-T-SW)

3.4.21.1 Sequence Description

ATWS sequences are initiated by an event in which there is a failure of either the hydraulic or electrical control rod insertion functions. To mitigate an ATWS condition, sodium pentaborate, in sufficient quantity to achieve subcriticality, is injected into the reactor core region by the Standby Liquid Control System (SLCS). SLCS is activated automatically on high RPV pressure or an RPV Level 2 signal in combination with a Source Range Neutron Monitoring permissive (SRNM) not downscale signal lasting for 3 minutes.

In addition to SLCS injection, Feedwater runback and ADS inhibit functions are used to control reactivity. However, in a loss of service water transient, the feedwater pumps trip and thus, automatic FDW runback is not necessary. ADS inhibit allows adequate reactor pressure to maintain RPV water level control. The ADS inhibit signal is sealed in. Under these conditions, power generation is reduced within the cooling capability of IC and/or CRD until SLCS injection is completed. For loss of SW ATWS scenarios, only IC is modeled for makeup and heat removal since feedwater, CRD, and decay heat removal systems are assumed to fail due to loss of component cooling.

It should be noted that in the transient event trees, successful injection with a high pressure makeup system is considered a stable safe state. For ATWS scenarios the PRA model assumes that high pressure injection is necessary to prevent core damage. However, since ATWS scenarios involve higher initial energies that may threaten containment integrity, the model assumes that decay heat removal systems, excluding PCCS, are required when high pressure injection is successful.

3.4.21.2 Event Sequences

The AT-T-SW event tree produces 8 sequences that end with a core damage end state. No end states require a transfer to another event tree. Each core damage sequence is described below and summarized in Table 3.4-21. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.21.2.1 Low Pressure Core Damage with Containment Intact (Class I) End State: (AT-T-SW004)

In this sequence, SLCS is successful; however, SRVs that had lifted to relieve RPV pressure have failed to reseat, leading to core damage.

3.4.21.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection (AT-T-SW002)

Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. In this sequence, SLCS is successful. Containment heat removal fails due to failure to provide long-term makeup to the PCCS pools.

3.4.21.2.3 High Pressure Core Damage with Containment Intact (Class III) End State: (AT-T-SW003)

In this sequence SLCS is successful; however, ICS fails, and core damage follows.

3.4.21.2.4 Core Damage Due to ATWS Sequences (Class IV) End State: (AT-T-SW006, AT-T-SW007, AT-T-SW008, AT-T-SW009)

Sequence AT-T-SW006 involves failure of SLCS. This sequence is assumed to lead to core damage.

Sequence AT-T-SW007 involves a failure to inhibit ADS. It assumed that the RPV is depressurized by ADS when ADS inhibit fails, and the vacuum breakers are successful. This sequence is assumed to lead to core damage.

Sequence AT-T-SW008 involves an RPV overpressurization due to an insufficient number of SRVs lifting. This sequence is assumed to lead to core damage.

Sequence AT-T-SW009 involves failure of the Feedwater runback function. This sequence is assumed to lead to core damage. It should be noted that feedwater is eventually loss due to component cooling. However, the Feedwater runback function is assumed to be required at the beginning of the accident scenario.

3.4.21.2.5 Core Damage with Containment Bypass (Class V) End State: (AT-T-SW007a)

Sequence AT-T-SW007a results in a containment over-pressure failure. In this sequence, there is failure to inhibit ADS, and the vacuum breakers fail to open after ADS. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is conservatively assumed to lead to core damage with containment bypass.

3.4.22 ATWS Transfer from Inadvertent Opening of a Relief Valve (AT-T-IORV)

3.4.22.1 Sequence Description

ATWS sequences are initiated by an event in which there is a failure of either the hydraulic or electrical control rod insertion functions. To mitigate an ATWS condition, sodium pentaborate, in sufficient quantity to achieve subcriticality, is injected into the reactor core region by the Standby Liquid Control System (SLCS). These sequences involve a failure to scram and originate as an IORV transient. Feedwater and CRD are available for high pressure injection to maintain RPV water level. Failure to control water level is assumed to lead to core damage. For IORV ATWS scenarios, the IC system is not credited for makeup or decay heat removal.

It should be noted that in the transient event trees, successful injection with a high pressure makeup system is considered a stable safe state. For ATWS scenarios the PRA model assumes that high pressure injection is necessary to prevent core damage. However, since ATWS scenarios involve higher energies that may threaten containment integrity, the model also requires the availability of a decay heat removal systems, excluding PCCS, when high pressure injection is successful.

3.4.22.2 Event Sequences

The AT-T-IORV event tree produces 8 sequences that end with a core damage end state. No end states require a transfer to another event tree. Each core damage sequence is described below and summarized in Table 3.4-22. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.22.2.1 Low Pressure Core Damage with Containment Intact (Class I) End State: (AT-T-IORV009)

In this sequence, ADS inhibit and SLCS injection are successful. However, failure of feedwater and CRD injection results in failure to control RPV water level. This is assumed to lead to core damage.

3.4.22.2.2 Containment Failure prior to Late Core Damage (Class II) End States

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection (AT-T-IORV004, AT-T-IORV008)

Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. In these sequences, SLCS and ADS inhibit, and feedwater or CRD are successful. Containment heat removal fails due to loss of suppression pool cooling, shutdown cooling, and failure to vent.

3.4.22.2.3 Core Damage Due to ATWS Sequences (Class IV) End State: (AT-T-IORV011, AT-T-IORV012, AT-T-IORV013, AT-T-IORV014)

Sequence AT-T-IORV011 involves failure of SLCS. This sequence is assumed to lead to core damage.

Sequence AT-T-IORV012 involves a failure to inhibit ADS, which results in failure to control RPV water level. It is assumed that RPV is depressurized by ADS when ADS inhibit fails, and the vacuum breakers are successful. This sequence is assumed to lead to core damage.

Sequence AT-T-IORV013 involves an RPV overpressurization due to an insufficient number of SRVs lifting. This sequence is assumed to lead to core damage.

Sequence AT-T-IOR014 involves failure of the Feedwater runback function. This sequence is assumed to lead to core damage.

3.4.22.2.4 Core Damage with Containment Bypass (Class V) End State: (AT-T-IORV012a)

Sequence AT-T-IORV012a results in a containment over-pressure failure. In this sequence, there is failure to inhibit ADS, and the vacuum breakers fail to open after ADS. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is conservatively assumed to lead to core damage with containment bypass.

3.4.23 ATWS Transfer from LOCA Event Tree (AT-LOCA)

3.4.23.1 Sequence Description

ATWS sequences are initiated by an event in which there is a failure of either the hydraulic or electrical control rod insertion functions. To mitigate an ATWS condition, sodium pentaborate, in sufficient quantity to achieve subcriticality, is injected into the reactor core region by the Standby Liquid Control System (SLCS). These sequences involve a failure to scram following a LOCA. Feedwater and CRD are available for high pressure injection to maintain RPV water level. Failure to control water level is assumed to lead to core damage.

It should be noted that in the transient event trees, successful injection with a high pressure makeup system is considered a stable safe state. For ATWS scenarios the PRA model assumes that high pressure injection is necessary to prevent core damage. However, since ATWS scenarios involve higher energies that may threaten containment integrity, the model also requires the availability of a decay heat removal systems, excluding PCCS, when high pressure injection is successful.

3.4.23.2 Event Sequences

The AT-LOCA event tree produces 8 sequences that end with a core damage end state. No end states require a transfer to another event tree. Each core damage sequence is described below and summarized in Table 3.4-23. The table includes a listing of failed and successful top events to help illustrate each sequence of events.

3.4.23.2.1 Containment Failure prior to Late Core Damage (Class II) End State:

Class 2-a: Loss of Decay Heat Removal with Failure of Low Pressure Injection (AT-LOCA001d, AT -LOCA004)

Sub-class 2-a involves pressurization of the containment due to loss of decay heat removal, with subsequent core damage. In these sequences, SLCS, ADS inhibit, and either Feedwater or CRD injection are successful. However, long-term containment heat removal fails, which leads to containment failure and core damage.

3.4.23.2.2 High Pressure Core Damage with Containment Intact (Class III) End State: (AT-LOCA005)

In this sequence, SLCS and ADS inhibit are successful; however, loss of Feedwater and CRD injection results in failure to control water level, leading to core damage.

3.4.23.2.3 Core Damage Due to ATWS Sequences (Class IV) End State: (AT -LOCA012, AT-LOCA013, AT -LOCA014, AT -LOCA015)

Sequence AT -LOCA012 involves failure of SLCS. This sequence is assumed to lead to core damage.

Sequence AT -LOCA013 involves a failure to inhibit ADS, which results in failure to control RPV water level. It is assumed that the RPV is depressurized by ADS when ADS inhibit fails, and the vacuum breakers are successful. This sequence is assumed to lead to core damage.

Sequence AT -LOCA014 involves an RPV overpressurization due to an insufficient number of SRVs lifting. This sequence is assumed to lead to core damage.

Sequence AT -LOCA015 involves failure of the Feedwater runback function. This sequence is assumed to lead to core damage.

3.4.23.2.4 Core Damage with Containment Bypass (Class V) End State: (AT- LOCA013a)

Sequence AT-T-LOCA013a results in a containment over-pressure failure. In this sequence, there is failure to inhibit ADS, and the vacuum breakers fail to open after ADS. This leads to containment failure due to excessive pressure differential between the drywell and the wetwell airspace. This sequence is conservatively assumed to lead to core damage with containment bypass.

Table 3.4-1

General Transient Event Paths

Sequence	Class	Failures	Successes
T-GEN004A	cdi	T-GEN, QT, WR, WM, UD	CR, MW
T-GEN015	cdii-a	T-GEN, QT, MW, UF, UD, VL, VM, WM, WS	CR, MS, PS, XM, XD, VI, VE, DL, WP
T-GEN017	cdii-a	T-GEN, QT, MW, UF, UD, VL, VM, WP, WS	CR, MS, PS, XM, XD, VI, VE, DL
T-GEN019	cdii-a	T-GEN, QT, MW, UF, UD, VL, VM, DL, WS	CR, MS, PS, XM, XD, VI, VE
T-GEN020	cdi	T-GEN, QT, MW, UF, UD, VL, VM, VE	CR, MS, PS, XM, XD, VI
T-GEN021	cdi	T-GEN, QT, MW, UF, UD, VL, VM, VI	CR, MS, PS, XM, XD
T-GEN022	cdi	T-GEN, QT, MW, UF, UD, VL, VM, XD	CR, MS, PS, XM
T-GEN026	cdii-b	T-GEN, QT, MW, UF, UD, XM, WM, WS, VM	CR, MS, PS, XD, DS, VI, VE, DL, WP, WV
T-GEN027	cdii-a	T-GEN, QT, MW, UF, UD, XM, WM, WS, WV	CR, MS, PS, XD, DS, VI, VE, DL, WP
T-GEN030	cdii-b	T-GEN, QT, MW, UF, UD, XM, WP, WS, VM	CR, MS, PS, XD, DS, VI, VE, DL, WV
T-GEN031	cdii-a	T-GEN, QT, MW, UF, UD, XM, WP, WS, WV	CR, MS, PS, XD, DS, VI, VE, DL
T-GEN034	cdii-b	T-GEN, QT, MW, UF, UD, XM, DL, WS, VM	CR, MS, PS, XD, DS, VI, VE, WV
T-GEN035	cdii-a	T-GEN, QT, MW, UF, UD, XM, DL, WS, WV	CR, MS, PS, XD, DS, VI, VE
T-GEN051	cdi	T-GEN, QT, MW, UF, UD, XM, VE, VL, VM	CR, MS, PS, XD, DS, VI
T-GEN067	cdi	T-GEN, QT, MW, UF, UD, XM, VI, VL, VM	CR, MS, PS, XD, DS
T-GEN068	cdv	T-GEN, QT, MW, UF, UD, XM, DS	CR, MS, PS, XD
T-GEN069	cdiii	T-GEN, QT, MW, UF, UD, XM, XD	CR, MS, PS
T-GEN070	IORV	T-GEN, QT, MW, PS	CR, MS, PR
T-GEN071	IORV	T-GEN, QT, MW, PS, PR	CR, MS
T-GEN072	RVR	T-GEN, QT, MW, MS	CR
T-GEN073	ATWS	T-GEN, CR	

Table 3.4-2

Loss of Feedwater Transient Event Paths

Sequence	Class	Failures	Successes
T-FDW003A	cdi	T-FDW, WR, WM, UD	CR, MW
T-FDW007	cdii-b	T-FDW, MW, WM, WS, VM	CR, MS, PS, XD, DS, VI, VE, DL, WP, WV
T-FDW008	cdii-a	T-FDW, MW, WM, WS, WV	CR, MS, PS, XD, DS, VI, VE, DL, WP
T-FDW011	cdii-b	T-FDW, MW, WP, WS, VM	CR, MS, PS, XD, DS, VI, VE, DL, WV
T-FDW012	cdii-a	T-FDW, MW, WP, WS, WV	CR, MS, PS, XD, DS, VI, VE, DL
T-FDW015	cdii-b	T-FDW, MW, DL, WS, VM	CR, MS, PS, XD, DS, VI, VE, WV
T-FDW016	cdii-a	T-FDW, MW, DL, WS, WV	CR, MS, PS, XD, DS, VI, VE
T-FDW033	cdi	T-FDW, MW, VE, UD, VL, VM	CR, MS, PS, XD, DS, VI
T-FDW050	cdi	T-FDW, MW, VI, UD, VL, VM	CR, MS, PS, XD, DS
T-FDW052	cdv	T-FDW, MW, DS, UD	CR, MS, PS, XD
T-FDW060	cdi	T-FDW, MW, XD, UD, VL, VM	CR, MS, PS, XM
T-FDW061	cdiii	T-FDW, MW, XD, UD, XM	CR, MS, PS
T-FDW062	IORV	T-FDW, MW, PS	CR, MS, PR
T-FDW063	IORV	T-FDW, MW, PS, PR	CR, MS
T-FDW064	RVR	T-FDW, MW, MS	CR
T-FDW065	ATWS	T-FDW, CR	

Table 3.4-3

Loss of Preferred Power Transient Event Paths

Sequence	Class	Failures	Successes
T-LOPP003A	cdi	T-LOPP, WR, WM, UD	CR, MW
T-LOPP007	cdii-b	T-LOPP, MW, WM, WS, VM	CR, MS, PS, XD, DS, VI, VE, DL, WP, WV
T-LOPP008	cdii-a	T-LOPP, MW, WM, WS, WV	CR, MS, PS, XD, DS, VI, VE, DL, WP
T-LOPP011	cdii-b	T-LOPP, MW, WP, WS, VM	CR, MS, PS, XD, DS, VI, VE, DL, WV
T-LOPP012	cdii-a	T-LOPP, MW, WP, WS, WV	CR, MS, PS, XD, DS, VI, VE, DL
T-LOPP015	cdii-b	T-LOPP, MW, DL, WS, VM	CR, MS, PS, XD, DS, VI, VE, WV
T-LOPP016	cdii-a	T-LOPP, MW, DL, WS, WV	CR, MS, PS, XD, DS, VI, VE
T-LOPP033	cdi	T-LOPP, MW, VE, UD, VL, VM	CR, MS, PS, XD, DS, VI
T-LOPP050	cdi	T-LOPP, MW, VI, UD, VL, VM	CR, MS, PS, XD, DS
T-LOPP052	cdv	T-LOPP, MW, DS, UD	CR, MS, PS, XD
T-LOPP060	cdi	T-LOPP, MW, XD, UD, VL, VM	CR, MS, PS, XM
T-LOPP061	cdiii	T-LOPP, MW, XD, UD, XM	CR, MS, PS
T-LOPP062	IORV	T-LOPP, MW, PS	CR, MS, PR
T-LOPP063	IORV	T-LOPP, MW, PS, PR	CR, MS
T-LOPP064	RVR	T-LOPP, MW, MS	CR
T-LOPP065	ATWS	T-LOPP, CR	

Table 3.4-4

Loss of Service Water Transient Event Paths

Sequence	Class	Failures	Successes
T-SW002	cdii-a	%T-SW, WM	CR, MW
T-SW006	cdii-a	%T-SW, MW, VM, WM	CR, MS, PS, XM, XD, VI, VE, DL, WP
T-SW007	cdii-a	%T-SW, MW, VM, WP	CR, MS, PS, XM, XD, VI, VE, DL
T-SW008	cdii-a	%T-SW, MW, VM, DL	CR, MS, PS, XM, XD, VI, VE
T-SW009	cdi	%T-SW, MW, VM, VE	CR, MS, PS, XM, XD, VI
T-SW010	cdi	%T-SW, MW, VM, VI	CR, MS, PS, XM, XD
T-SW011	cdi	%T-SW, MW, VM, XD	CR, MS, PS, XM
T-SW014	cdii-b	%T-SW, MW, XM, WM, VM	CR, MS, PS, XD, DS, VI, VE, DL, WP, WV
T-SW015	cdii-a	%T-SW, MW, XM, WM, WV	CR, MS, PS, XD, DS, VI, VE, DL, WP
T-SW017	cdii-b	%T-SW, MW, XM, WP, VM	CR, MS, PS, XD, DS, VI, VE, DL, WV
T-SW018	cdii-a	%T-SW, MW, XM, WP, WV	CR, MS, PS, XD, DS, VI, VE, DL
T-SW020	cdii-b	%T-SW, MW, XM, DL, VM	CR, MS, PS, XD, DS, VI, VE, WV
T-SW021	cdii-a	%T-SW, MW, XM, DL, WV	CR, MS, PS, XD, DS, VI, VE
T-SW029	cdi	%T-SW, MW, XM, VE, VM	CR, MS, PS, XD, DS, VI
T-SW037	cdi	%T-SW, MW, XM, VI, VM	CR, MS, PS, XD, DS
T-SW038	cdv	%T-SW, MW, XM, DS	CR, MS, PS, XD
T-SW039	cdiii	%T-SW, MW, XM, XD	CR, MS, PS
T-SW040	IORV	%T-SW, MW, PS	CR, MS, PR
T-SW041	IORV	%T-SW, MW, PS, PR	CR, MS
T-SW042	RVR	%T-SW, MW, MS	CR
T-SW043	ATWS	%T-SW, CR	

Table 3.4-5

Inadvertent Opening of Relief Valve Transient Event Paths

Sequence	Class	Failures	Successes
T-IORV011	cdii-a	MS-T-IORV, UF, UD, VL, VM, WM, WS	CR, XM, XD, VI, VE, DL, WP
T-IORV013	cdii-a	MS-T-IORV, UF, UD, VL, VM, WP, WS	CR, XM, XD, VI, VE, DL
T-IORV015	cdii-a	MS-T-IORV, UF, UD, VL, VM, DL, WS	CR, XM, XD, VI, VE
T-IORV016	cdi	MS-T-IORV, UF, UD, VL, VM, VE	CR, XM, XD, VI
T-IORV017	cdi	MS-T-IORV, UF, UD, VL, VM, VI	CR, XM, XD
T-IORV018	cdi	MS-T-IORV, UF, UD, VL, VM, XD	CR, XM
T-IORV022	cdii-b	MS-T-IORV, UF, UD, XM, WM, WS, VM	CR, XD, DS, VI, VE, DL, WP, WV
T-IORV023	cdii-a	MS-T-IORV, UF, UD, XM, WM, WS, WV	CR, XD, DS, VI, VE, DL, WP
T-IORV026	cdii-b	MS-T-IORV, UF, UD, XM, WP, WS, VM	CR, XD, DS, VI, VE, DL, WV
T-IORV027	cdii-a	MS-T-IORV, UF, UD, XM, WP, WS, WV	CR, XD, DS, VI, VE, DL
T-IORV030	cdii-b	MS-T-IORV, UF, UD, XM, DL, WS, VM	CR, XD, DS, VI, VE, WV
T-IORV031	cdii-a	MS-T-IORV, UF, UD, XM, DL, WS, WV	CR, XD, DS, VI, VE
T-IORV047	cdi	MS-T-IORV, UF, UD, XM, VE, VL, VM	CR, XD, DS, VI
T-IORV063	cdi	MS-T-IORV, UF, UD, XM, VI, VL, VM	CR, XD, DS
T-IORV064	cdv	MS-T-IORV, UF, UD, XM, DS	CR, XD
T-IORV065	cdi	MS-T-IORV, UF, UD, XM, XD	CR
T-IORV066	ATWS	MS-T-IORV, CR	

Table 3.4-6

Large Steam LOCA Event Paths

Sequence	Class	Failures	Successes
LL-S004	cdii-b	LL-S, WM, WS, VM	CR, DS, VI, VE, DL, WP, WV
LL-S005	cdii-a	LL-S, WM, WS, WV	CR, DS, VI, VE, DL, WP
LL-S008	cdii-b	LL-S, WP, WS, VM	CR, DS, VI, VE, DL, WV
LL-S009	cdii-a	LL-S, WP, WS, WV	CR, DS, VI, VE, DL
LL-S012	cdii-b	LL-S, DL, WS, VM	CR, DS, VI, VE, WV
LL-S013	cdii-a	LL-S, DL, WS, WV	CR, DS, VI, VE
LL-S016	cdi	LL-S, VE, VL, VM	CR, DS, VI
LL-S020	cdi	LL-S, UD, VI, VL, VM	CR, DS
LL-S021	cdv	LL-S, DS	CR
LL-S022	cdiv	LL-S, CR	

Table 3.4-7

LOCA in FDW Line A Event Paths

Sequence	Class	Failures	Successes
LL-S-FDWA004	cdii-b	%LL-S-FDWA, WM, WS, UD	CR, DS, VI, VE, DL, WP, WV
LL-S-FDWA005	cdii-a	%LL-S-FDWA, WM, WS, WV	CR, DS, VI, VE, DL, WP
LL-S-FDWA008	cdii-b	%LL-S-FDWA, WP, WS, UD	CR, DS, VI, VE, DL, WV
LL-S-FDWA009	cdii-a	%LL-S-FDWA, WP, WS, WV	CR, DS, VI, VE, DL
LL-S-FDWA012	cdii-b	%LL-S-FDWA, DL, WS, UD	CR, DS, VI, VE, WV
LL-S-FDWA013	cdii-a	%LL-S-FDWA, DL, WS, WV	CR, DS, VI, VE
LL-S-FDWA015	cdi	%LL-S-FDWA, VE, UD	CR, DS, VI
LL-S-FDWA017	cdi	%LL-S-FDWA, VI, UD	CR, DS
LL-S-FDWA018	cdv	%LL-S-FDWA, DS	CR
LL-S-FDWA019	cdiv	%LL-S-FDWA, CR	

Table 3.4-8

LOCA in FDW Line B Event Paths

Sequence	Class	Failures	Successes
LL-S-FDWB004	cdii-b	%LL-S-FDWB, WM, WS, VM	CR, DS, VI, VE, DL, WP, WV
LL-S-FDWB005	cdii-a	%LL-S-FDWB, WM, WS, WV	CR, DS, VI, VE, DL, WP
LL-S-FDWB008	cdii-b	%LL-S-FDWB, WP, WS, VM	CR, DS, VI, VE, DL, WV
LL-S-FDWB009	cdii-a	%LL-S-FDWB, WP, WS, WV	CR, DS, VI, VE, DL
LL-S-FDWB012	cdii-b	%LL-S-FDWB, DL, WS, VM	CR, DS, VI, VE, WV
LL-S-FDWB013	cdii-a	%LL-S-FDWB, DL, WS, WV	CR, DS, VI, VE
LL-S-FDWB029	cdi	%LL-S-FDWB, VE, VL, VM	CR, DS, VI
LL-S-FDWB045	cdi	%LL-S-FDWB, VI, VL, VM	CR, DS
LL-S-FDWB046	cdv	%LL-S-FDWB, DS	CR
LL-S-FDWB047	cdiv	%LL-S-FDWB, CR	

Table 3.4-9

Medium Liquid LOCA Event Paths Event Paths

Sequence	Class	Failures	Successes
ML-L004	cdii-b	%ML-L, WM, WS, VM	CR, DS, XD, VI, VE, DL, WP, WV
ML-L005	cdii-a	%ML-L, WM, WS, WV	CR, DS, XD, VI, VE, DL, WP
ML-L008	cdii-b	%ML-L, WP, WS, VM	CR, DS, XD, VI, VE, DL, WV
ML-L009	cdii-a	%ML-L, WP, WS, WV	CR, DS, XD, VI, VE, DL
ML-L012	cdii-b	%ML-L, DL, WS, VM	CR, DS, XD, VI, VE, WV
ML-L013	cdii-a	%ML-L, DL, WS, WV	CR, DS, XD, VI, VE
ML-L015	cdi	%ML-L, VE, VM	CR, DS, XD, VI
ML-L017	cdi	%ML-L, VI, VM	CR, DS, XD
ML-L019	cdi	%ML-L, XD, VM	CR, DS, XM
ML-L020	cdiii	%ML-L, XD, XM	CR, DS
ML-L021	cdv	%ML-L, DS	CR
ML-L022	cdiv	%ML-L, CR	

Table 3.4-10

Small Steam LOCA Event Paths

Sequence	Class	Failures	Successes
SL-S005	cdii-b	SL-S, WM, WS, VM, UD	CR, XD, DS, VI, VE, DL, WP, WV
SL-S006	cdii-a	SL-S, WM, WS, WV	CR, XD, DS, VI, VE, DL, WP
SL-S010	cdii-b	SL-S, WP, WS, VM, UD	CR, XD, DS, VI, VE, DL, WV
SL-S011	cdii-a	SL-S, WP, WS, WV	CR, XD, DS, VI, VE, DL
SL-S015	cdii-b	SL-S, DL, WS, VM, UD	CR, XD, DS, VI, VE, WV
SL-S016	cdii-a	SL-S, DL, WS, WV	CR, XD, DS, VI, VE
SL-S019	cdi	SL-S, VE, VL, VM	CR, XD, DS, VI
SL-S023	cdi	SL-S, VI, UD, VL, VM	CR, XD, DS
SL-S024	cdv	SL-S, DS	CR, XD
SL-S028	cdi	SL-S, XD, UD, VL, VM	CR, XM
SL-S030	cdiii	SL-S, XD, XM, UD	CR
SL-S031	ATWS	SL-S, CR	

Table 3.4-11

Small Liquid LOCA Event Paths

Sequence	Class	Failures	Successes
SL-L005	cdii-b	%SL-L, WM, WS, VM, UD	CR, MW, XD, DS, VI, VE, DL, WP, WV
SL-L006	cdii-a	%SL-L, WM, WS, WV	CR, MW, XD, DS, VI, VE, DL, WP
SL-L010	cdii-b	%SL-L, WP, WS, VM, UD	CR, MW, XD, DS, VI, VE, DL, WV
SL-L011	cdii-a	%SL-L, WP, WS, WV	CR, MW, XD, DS, VI, VE, DL
SL-L015	cdii-b	%SL-L, DL, WS, VM, UD	CR, MW, XD, DS, VI, VE, WV
SL-L016	cdii-a	%SL-L, DL, WS, WV	CR, MW, XD, DS, VI, VE
SL-L020	cdi	%SL-L, VE, VL, VM, UD	CR, MW, XD, DS, VI
SL-L024	cdi	%SL-L, VI, UD, VL, VM	CR, MW, XD, DS
SL-L025	cdv	%SL-L, DS	CR, MW, XD
SL-L029	cdi	%SL-L, XD, UD, VL, VM	CR, MW, XM
SL-L031	cdiii	%SL-L, XD, XM, UD	CR, MW
SL-L036	cdii-b	%SL-L, MW, WM, WS, VM, UD	CR, MS, XD, DS, VI, VE, DL, WP, WV
SL-L037	cdii-a	%SL-L, MW, WM, WS, WV	CR, MS, XD, DS, VI, VE, DL, WP
SL-L041	cdii-b	%SL-L, MW, WP, WS, VM, UD	CR, MS, XD, DS, VI, VE, DL, WV
SL-L042	cdii-a	%SL-L, MW, WP, WS, WV	CR, MS, XD, DS, VI, VE, DL
SL-L046	cdii-b	%SL-L, MW, DL, WS, VM, UD	CR, MS, XD, DS, VI, VE, WV
SL-L047	cdii-a	%SL-L, MW, DL, WS, WV	CR, MS, XD, DS, VI, VE
SL-L051	cdi	%SL-L, MW, VE, VL, VM, UD	CR, MS, XD, DS, VI
SL-L055	cdi	%SL-L, MW, VI, UD, VL, VM	CR, MS, XD, DS
SL-L056	cdv	%SL-L, MW, DS	CR, MS, XD
SL-L060	cdi	%SL-L, MW, XD, UD, VL, VM	CR, MS, XM
SL-L062	cdiii	%SL-L, MW, XD, XM, UD	CR, MS
SL-L063	RVR	%SL-L, MW, MS	CR
SL-L064	ATWS	%SL-L, CR	

Table 3.4-12

Reactor Vessel Rupture Event Paths

Sequence	Class	Failures	Successes
RVR-004	cdii-b	T-RVR, WM, WS, VM	CR, DS, XD, VI, DL, WP, WV
RVR-005	cdii-a	T-RVR, WM, WS, WV	CR, DS, XD, VI, DL, WP
RVR-008	cdii-b	T-RVR, WP, WS, VM	CR, DS, XD, VI, DL, WV
RVR-009	cdii-a	T-RVR, WP, WS, WV	CR, DS, XD, VI, DL
RVR-012	cdii-b	T-RVR, DL, WS, VM	CR, DS, XD, VI, WV
RVR-013	cdii-a	T-RVR, DL, WS, WV	CR, DS, XD, VI
RVR-014	cdi	T-RVR, VI	CR, DS, XD
RVR-015	cdi	T-RVR, XD	CR, DS
RVR-016	cdv	T-RVR, DS	CR
RVR-017	cdv	T-RVR, CR	

Table 3.4-13

Break Outside Containment in MS Line Event Paths

Sequence	Class	Failures	Successes
BOC-MS001	T-GEN	%BOC-MS	IS
BOC-MS011	cdii-a	%BOC-MS, IS, UF, UD, VL, VM, WM, WS	CR, XM, XD, VI, VE, DL, WP
BOC-MS014	cdii-a	%BOC-MS, IS, UF, UD, VL, VM, WP, WS	CR, XM, XD, VI, VE, DL
BOC-MS017	cdii-a	%BOC-MS, IS, UF, UD, VL, VM, DL, WS	CR, XM, XD, VI, VE
BOC-MS019	cdv	%BOC-MS, IS, UF, UD, VL, VM, VE	CR, XM, XD, VI
BOC-MS020	cdv	%BOC-MS, IS, UF, UD, VL, VM, VI	CR, XM, XD
BOC-MS021	cdv	%BOC-MS, IS, UF, UD, VL, VM, XD	CR, XM
BOC-MS025	cdii-b	%BOC-MS, IS, UF, UD, XM, WM, WS, VM	CR, XD, DS, VI, VE, DL, WP, WV
BOC-MS026	cdii-a	%BOC-MS, IS, UF, UD, XM, WM, WS, WV	CR, XD, DS, VI, VE, DL, WP
BOC-MS029	cdii-b	%BOC-MS, IS, UF, UD, XM, WP, WS, VM	CR, XD, DS, VI, VE, DL, WV
BOC-MS030	cdii-a	%BOC-MS, IS, UF, UD, XM, WP, WS, WV	CR, XD, DS, VI, VE, DL
BOC-MS033	cdii-b	%BOC-MS, IS, UF, UD, XM, DL, WS, VM	CR, XD, DS, VI, VE, WV
BOC-MS034	cdii-a	%BOC-MS, IS, UF, UD, XM, DL, WS, WV	CR, XD, DS, VI, VE
BOC-MS049	cdv	%BOC-MS, IS, UF, UD, XM, VE, VL, VM	CR, XD, DS, VI
BOC-MS064	cdv	%BOC-MS, IS, UF, UD, XM, VI, VL, VM	CR, XD, DS
BOC-MS065	cdv	%BOC-MS, IS, UF, UD, XM, DS	CR, XD
BOC-MS066	cdv	%BOC-MS, IS, UF, UD, XM, XD	CR
BOC-MS067	cdv	%BOC-MS, IS, CR	

Table 3.4-14

Break Outside Containment in FDW Line A Event Paths

Sequence	**Class**	**Failures**	**Successes**
BOC-FDWA001A	cdii-a	BOC-FDWA, WM	IA, CR, MW
BOC-FDWA015	cdii-a	BOC-FDWA, MW, UD, WM, WS	IA, CR, MS, XD, DS, VI, VE, DL, WP
BOC-FDWA017	cdii-a	BOC-FDWA, MW, UD, WP, WS	IA, CR, MS, XD, DS, VI, VE, DL
BOC-FDWA019	cdii-a	BOC-FDWA, MW, UD, DL, WS	IA, CR, MS, XD, DS, VI, VE
BOC-FDWA020	cdi	BOC-FDWA, MW, UD, VE	IA, CR, MS, XD, DS, VI
BOC-FDWA027	cdi	BOC-FDWA, MW, UD, VI	IA, CR, MS, XD, DS
BOC-FDWA028	cdv	BOC-FDWA, MW, UD, DS	IA, CR, MS, XD
BOC-FDWA029	cdiii	BOC-FDWA, MW, UD, XD	IA, CR, MS
BOC-FDWA030	RVR	BOC-FDWA, MW, MS	IA, CR
BOC-FDWA031	ATWS	BOC-FDWA, CR	IA
BOC-FDWA035	cdii-a	BOC-FDWA, IA, UD, WM, WS	CR, XD, DS, VI, VE, DL, WP
BOC-FDWA037	cdii-a	BOC-FDWA, IA, UD, WP, WS	CR, XD, DS, VI, VE, DL
BOC-FDWA039	cdii-a	BOC-FDWA, IA, UD, DL, WS	CR, XD, DS, VI, VE
BOC-FDWA040	cdv	BOC-FDWA, IA, UD, VE	CR, XD, DS, VI
BOC-FDWA047	cdv	BOC-FDWA, IA, UD, VI	CR, XD, DS
BOC-FDWA048	cdv	BOC-FDWA, IA, UD, DS	CR, XD
BOC-FDWA049	cdv	BOC-FDWA, IA, UD, XD	CR
BOC-FDWA050	cdv	BOC-FDWA, IA, CR	

Table 3.4-15

Break Outside Containment in FDW Line B Event Paths

Sequence	Class	Failures	Successes
BOC-FDWB001A	cdii-a	%BOC-FDWB, WM	IB, CR, MW
BOC-FDWB012	cdii-a	%BOC-FDWB, MW, VL, VM, WM, WS	IB, CR, MS, XM, XD, VI, VE, DL, WP
BOC-FDWB014	cdii-a	%BOC-FDWB, MW, VL, VM, WP, WS	IB, CR, MS, XM, XD, VI, VE, DL
BOC-FDWB017	cdii-a	%BOC-FDWB, MW, VL, VM, DL, WS	IB, CR, MS, XM, XD, VI, VE
BOC-FDWB019	cdi	%BOC-FDWB, MW, VL, VM, VE	IB, CR, MS, XM, XD, VI
BOC-FDWB020	cdi	%BOC-FDWB, MW, VL, VM, VI	IB, CR, MS, XM, XD
BOC-FDWB021	cdi	%BOC-FDWB, MW, VL, VM, XD	IB, CR, MS, XM
BOC-FDWB025	cdii-b	%BOC-FDWB, MW, XM, WM, WS, VM	IB, CR, MS, XD, DS, VI, VE, DL, WP, WV
BOC-FDWB026	cdii-a	%BOC-FDWB, MW, XM, WM, WS, WV	IB, CR, MS, XD, DS, VI, VE, DL, WP
BOC-FDWB029	cdii-b	%BOC-FDWB, MW, XM, WP, WS, VM	IB, CR, MS, XD, DS, VI, VE, DL, WV
BOC-FDWB030	cdii-a	%BOC-FDWB, MW, XM, WP, WS, WV	IB, CR, MS, XD, DS, VI, VE, DL
BOC-FDWB033	cdii-b	%BOC-FDWB, MW, XM, DL, WS, VM	IB, CR, MS, XD, DS, VI, VE, WV
BOC-FDWB034	cdii-a	%BOC-FDWB, MW, XM, DL, WS, WV	IB, CR, MS, XD, DS, VI, VE
BOC-FDWB036	cdi	%BOC-FDWB, MW, XM, VE, VL, VM	IB, CR, MS, XD, DS, VI
BOC-FDWB053	cdi	%BOC-FDWB, MW, XM, VI, VL, VM	IB, CR, MS, XD, DS
BOC-FDWB053A	cdv	%BOC-FDWB, MW, XM, DS	IB, CR, MS, XD
BOC-FDWB054	cdiii	%BOC-FDWB, MW, XM, XD	IB, CR, MS
BOC-FDWB055	RVR	%BOC-FDWB, MW, MS	IB, CR
BOC-FDWB056	ATWS	%BOC-FDWB, CR	IB
BOC-FDWB060	cdii-b	%BOC-FDWB, IB, WM, WS, VM	CR, XD, DS, VI, VE, DL, WP, WV
BOC-FDWB061	cdii-a	%BOC-FDWB, IB, WM, WS, WV	CR, XD, DS, VI, VE, DL, WP
BOC-FDWB064	cdii-b	%BOC-FDWB, IB, WP, WS, VM	CR, XD, DS, VI, VE, DL, WV
BOC-FDWB065	cdii-a	%BOC-FDWB, IB, WP, WS, WV	CR, XD, DS, VI, VE, DL
BOC-FDWB068	cdii-b	%BOC-FDWB, IB, DL, WS, VM	CR, XD, DS, VI, VE, WV
BOC-FDWB069	cdii-a	%BOC-FDWB, IB, DL, WS, WV	CR, XD, DS, VI, VE

Table 3.4-15

Break Outside Containment in FDW Line B Event Paths

Sequence	Class	Failures	Successes
BOC-FDWB086	cdv	%BOC-FDWB, IB, VE, VL, VM	CR, XD, DS, VI
BOC-FDWB103	cdv	%BOC-FDWB, IB, VI, VL, VM	CR, XD, DS
BOC-FDWB104	cdv	%BOC-FDWB, IB, DS	CR, XD
BOC-FDWB105	cdv	%BOC-FDWB, IB, XD	CR
BOC-FDWB106	cdv	%BOC-FDWB, IB, CR	

Table 3.4-16

Break Outside Containment in RWCU/SDC Line

Sequence	Class	Failures	Successes
BOC-RWCU001	T-GEN	%BOC-RWCU	IR
BOC-RWCU005	cdii-b	%BOC-RWCU, IR, WM, WS, VM	CR, XD, DS, VI, VE, IM, DL, WP, WV
BOC-RWCU006	cdii-a	%BOC-RWCU, IR, WM, WS, WV	CR, XD, DS, VI, VE, IM, DL, WP
BOC-RWCU009	cdii-b	%BOC-RWCU, IR, WP, WS, VM	CR, XD, DS, VI, VE, IM, DL, WV
BOC-RWCU010	cdii-a	%BOC-RWCU, IR, WP, WS, WV	CR, XD, DS, VI, VE, IM, DL
BOC-RWCU013	cdii-b	%BOC-RWCU, IR, DL, WS, VM	CR, XD, DS, VI, VE, IM, WV
BOC-RWCU014	cdii-a	%BOC-RWCU, IR, DL, WS, WV	CR, XD, DS, VI, VE, IM
BOC-RWCU015	cdv	%BOC-RWCU, IR, IM	CR, XD, DS, VI, VE
BOC-RWCU029	cdv	%BOC-RWCU, IR, VE, IM	CR, XD, DS, VI, VL
BOC-RWCU031	cdv	%BOC-RWCU, IR, VE, VL, IM	CR, XD, DS, VI, VM
BOC-RWCU032	cdv	%BOC-RWCU, IR, VE, VL, VM	CR, XD, DS, VI
BOC-RWCU046	cdv	%BOC-RWCU, IR, VI, IM	CR, XD, DS, VL
BOC-RWCU048	cdv	%BOC-RWCU, IR, VI, VL, IM	CR, XD, DS, VM
BOC-RWCU049	cdv	%BOC-RWCU, IR, VI, VL, VM	CR, XD, DS
BOC-RWCU050	cdv	%BOC-RWCU, IR, DS	CR, XD
BOC-RWCU051	cdv	%BOC-RWCU, IR, XD	CR
BOC-RWCU052	cdv	%BOC-RWCU, IR, CR	

Table 3.4-17

Break Outside Containment in ICS Event Paths

Sequence	Class	Failures	Successes
BOC-IC001	T-GEN	%BOC-IC	IC
BOC-IC012	cdii-a	%BOC-IC, IC, UF, UD, VL, VM, WM, WS	CR, XM, XD, VI, VE, DL, WP
BOC-IC014	cdii-a	%BOC-IC, IC, UF, UD, VL, VM, WP, WS	CR, XM, XD, VI, VE, DL
BOC-IC016	cdii-a	%BOC-IC, IC, UF, UD, VL, VM, DL, WS	CR, XM, XD, VI, VE
BOC-IC017	cdv	%BOC-IC, IC, UF, UD, VL, VM, VE	CR, XM, XD, VI
BOC-IC018	cdv	%BOC-IC, IC, UF, UD, VL, VM, VI	CR, XM, XD
BOC-IC019	cdv	%BOC-IC, IC, UF, UD, VL, VM, XD	CR, XM
BOC-IC023	cdii-b	%BOC-IC, IC, UF, UD, XM, WM, WS, VM	CR, XD, DS, VI, VE, DL, WP, WV
BOC-IC024	cdii-a	%BOC-IC, IC, UF, UD, XM, WM, WS, WV	CR, XD, DS, VI, VE, DL, WP
BOC-IC027	cdii-b	%BOC-IC, IC, UF, UD, XM, WP, WS, VM	CR, XD, DS, VI, VE, DL, WV
BOC-IC028	cdii-a	%BOC-IC, IC, UF, UD, XM, WP, WS, WV	CR, XD, DS, VI, VE, DL
BOC-IC031	cdii-b	%BOC-IC, IC, UF, UD, XM, DL, WS, VM	CR, XD, DS, VI, VE, WV
BOC-IC032	cdii-a	%BOC-IC, IC, UF, UD, XM, DL, WS, WV	CR, XD, DS, VI, VE
BOC-IC047	cdv	%BOC-IC, IC, UF, UD, XM, VE, VL, VM	CR, XD, DS, VI
BOC-IC062	cdv	%BOC-IC, IC, UF, UD, XM, VI, VL, VM	CR, XD, DS
BOC-IC063	cdv	%BOC-IC, IC, UF, UD, XM, DS	CR, XD
BOC-IC064	cdv	%BOC-IC, IC, UF, UD, XM, XD	CR
BOC-IC065	cdv	%BOC-IC, IC, CR	

Table 3.4-18

ATWS Transfer from T-GEN Event Paths

Sequence	Class	Failures	Successes
AT-T-GEN003A	cdi	AT-T-GEN, WR, WM, UD	CF, MA, XI, CS, PA, MW
AT-T-GEN007	cdii-a	AT-T-GEN, MW, WS, WR, WV	CF, MA, XI, CS, PA, UF
AT-T-GEN011	cdii-a	AT-T-GEN, MW, UF, WS, WR, WV	CF, MA, XI, CS, PA, UD
AT-T-GEN012	cdiii	AT-T-GEN, MW, UF, UD	CF, MA, XI, CS, PA
AT-T-GEN016	cdii-a	AT-T-GEN, PA, WS, WR, WV	CF, MA, XI, CS, UF
AT-T-GEN020	cdii-a	AT-T-GEN, PA, UF, WS, WR, WV	CF, MA, XI, CS, UD
AT-T-GEN021	cdi	AT-T-GEN, PA, UF, UD	CF, MA, XI, CS
AT-T-GEN023	cdiv	AT-T-GEN, CS	CF, MA, XI
AT-T-GEN024	cdiv	AT-T-GEN, XI	CF, MA, DS
AT-T-GEN024A	cdv	AT-T-GEN, XI, DS	CF, MA
AT-T-GEN025	cdiv	AT-T-GEN, MA	CF
AT-T-GEN026	cdiv	AT-T-GEN, CF	

Table 3.4-19

ATWS Transfer from T-FDW Event Paths

Sequence	Class	Failures	Successes
AT-T-FDW003A	cdi	AT-T-FDW, WR, WM, UD	MA, XI, CS, PA, MW
AT-T-FDW007	cdii-a	AT-T-FDW, MW, WS, WR, WV	MA, XI, CS, PA, UD
AT-T-FDW008	cdiii	AT-T-FDW, MW, UD	MA, XI, CS, PA
AT-T-FDW012	cdii-a	AT-T-FDW, PA, WS, WR, WV	MA, XI, CS, UD
AT-T-FDW013	cdi	AT-T-FDW, PA, UD	MA, XI, CS
AT-T-FDW015	cdiv	AT-T-FDW, CS	MA, XI
AT-T-FDW016	cdiv	AT-T-FDW, XI	MA, DS
AT-T-FDW016A	cdv	AT-T-FDW, XI, DS	MA
AT-T-FDW017	cdiv	AT-T-FDW, MA	

Table 3.4-20

ATWS Transfer from T-LOPP Event Paths

Sequence	**Class**	**Failures**	**Successes**
AT-T-LOPP003A	cdi	AT-T-LOPP, WR, WM, UD	MA, XI, CS, PA, MW
AT-T-LOPP007	cdii-a	AT-T-LOPP, MW, WS, WR, WV	MA, XI, CS, PA, UD
AT-T-LOPP008	cdiii	AT-T-LOPP, MW, UD	MA, XI, CS, PA
AT-T-LOPP012	cdii-a	AT-T-LOPP, PA, WS, WR, WV	MA, XI, CS, UD
AT-T-LOPP013	cdi	AT-T-LOPP, PA, UD	MA, XI, CS
AT-T-LOPP015	cdiv	AT-T-LOPP, CS	MA, XI
AT-T-LOPP016	cdiv	AT-T-LOPP, XI	MA, DS
AT-T-LOPP016A	cdv	AT-T-LOPP, XI, DS	MA
AT-T-LOPP017	cdiv	AT-T-LOPP, MA	

Table 3.4-21

ATWS Transfer from T-SW Event Paths

Sequence	Class	Failures	Successes
AT-T-SW002	cdii-a	AT-T-SW, WM	CF, MA, XI, CS, PA, MW
AT-T-SW003	cdiii	AT-T-SW, MW	CF, MA, XI, CS, PA
AT-T-SW004	cdi	AT-T-SW, PA	CF, MA, XI, CS
AT-T-SW006	cdiv	AT-T-SW, CS	CF, MA, XI
AT-T-SW007	cdiv	AT-T-SW, XI	CF, MA, DS
AT-T-SW007A	cdv	AT-T-SW, XI, DS	CF, MA
AT-T-SW008	cdiv	AT-T-SW, MA	CF
AT-T-SW009	cdiv	AT-T-SW, CF	

Table 3.4-22

ATWS Transfer from T-IORV Event Paths

Sequence	**Class**	**Failures**	**Successes**
AT-T-IORV004	cdii-a	AT-T-IORV, WS, WR, WV	CF, MA, XI, CS, UF
AT-T-IORV008	cdii-a	AT-T-IORV, UF, WS, WR, WV	CF, MA, XI, CS, UD
AT-T-IORV009	cdi	AT-T-IORV, UF, UD	CF, MA, XI, CS
AT-T-IORV011	cdiv	AT-T-IORV, CS	CF, MA, XI
AT-T-IORV012	cdiv	AT-T-IORV, XI	CF, MA, DS
AT-T-IORV012A	cdv	AT-T-IORV, XI, DS	CF, MA
AT-T-IORV013	cdiv	AT-T-IORV, MA	CF
AT-T-IORV014	cdiv	AT-T-IORV, CF	

Table 3.4-23

ATWS Transfer fromT-LOCA Event Paths

Sequence	Class	Failures	Successes
AT-LOCA001D	cdii-a	AT-LOCA, WS, WR, WV	CF, MA, XI, CS, UF
AT-LOCA004	cdii-a	AT-LOCA, UF, WS, WR, WV	CF, MA, XI, CS, UD
AT-LOCA005	cdiii	AT-LOCA, UF, UD	CF, MA, XI, CS
AT-LOCA012	cdiv	AT-LOCA, CS	CF, MA, XI
AT-LOCA013	cdiv	AT-LOCA, XI	CF, MA, DS
AT-LOCA013A	cdv	AT-LOCA, XI, DS	CF, MA
AT-LOCA014	cdiv	AT-LOCA, MA	CF
AT-LOCA015	cdiv	AT-LOCA, CF	

3.5 REFERENCES

3-1 ESBWR DCD Tier 2, Chapter 6, Engineering Safety Features, 26A6642AT

3-2 ESBWR DCD Tier 2, Chapter 15, Safety Analysis, 26A6642BP3.3 MAAP 4.0.6 ESBWR Application and Comparison to TRACG Benchmarks; *MAAP Support of ESBWR Design Certification Document*, EPRI, Palo Alto, CA and General Electric Co.; 2005 1011712

APPENDIX 3A FIGURES

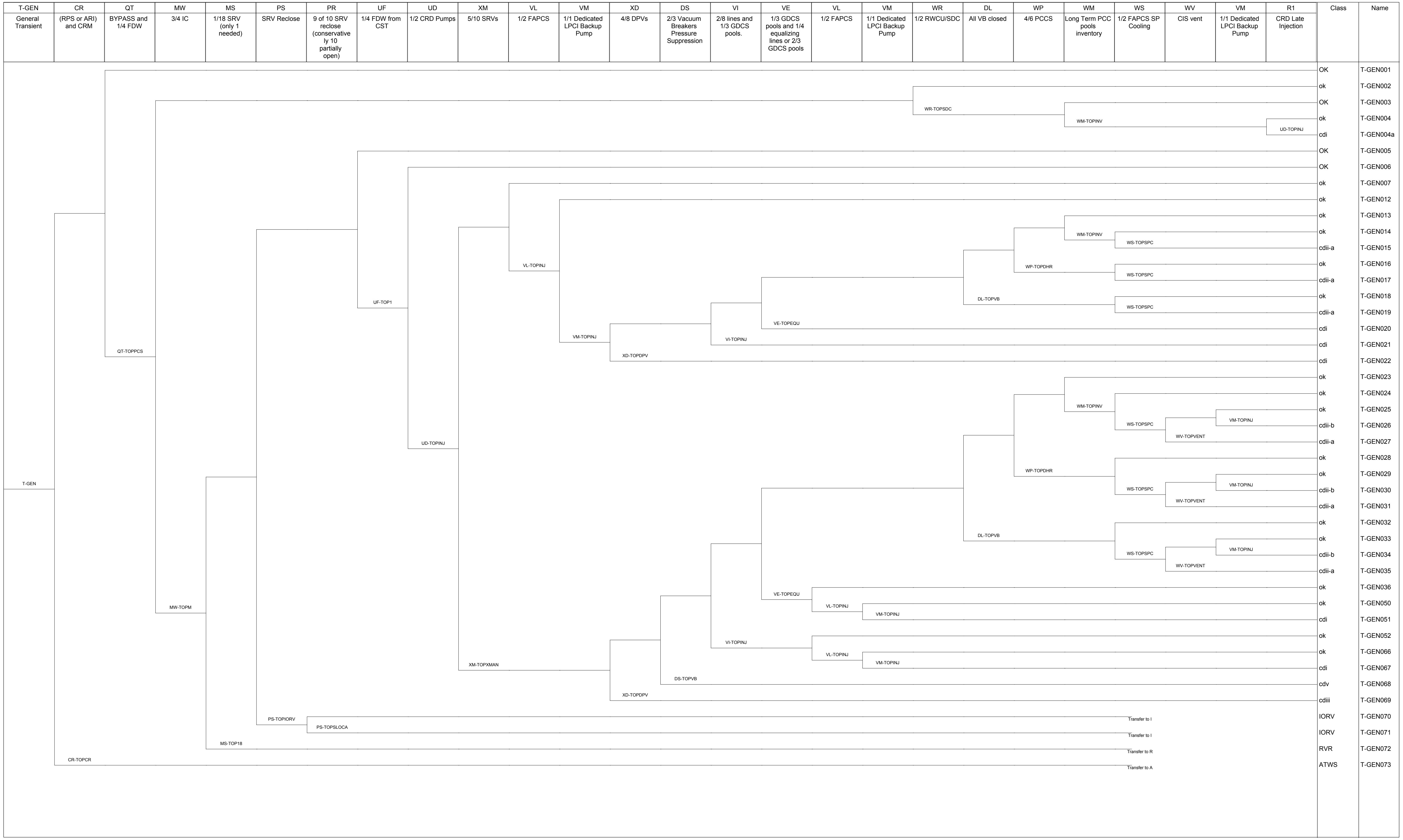

Figure 3A-1. General Transient

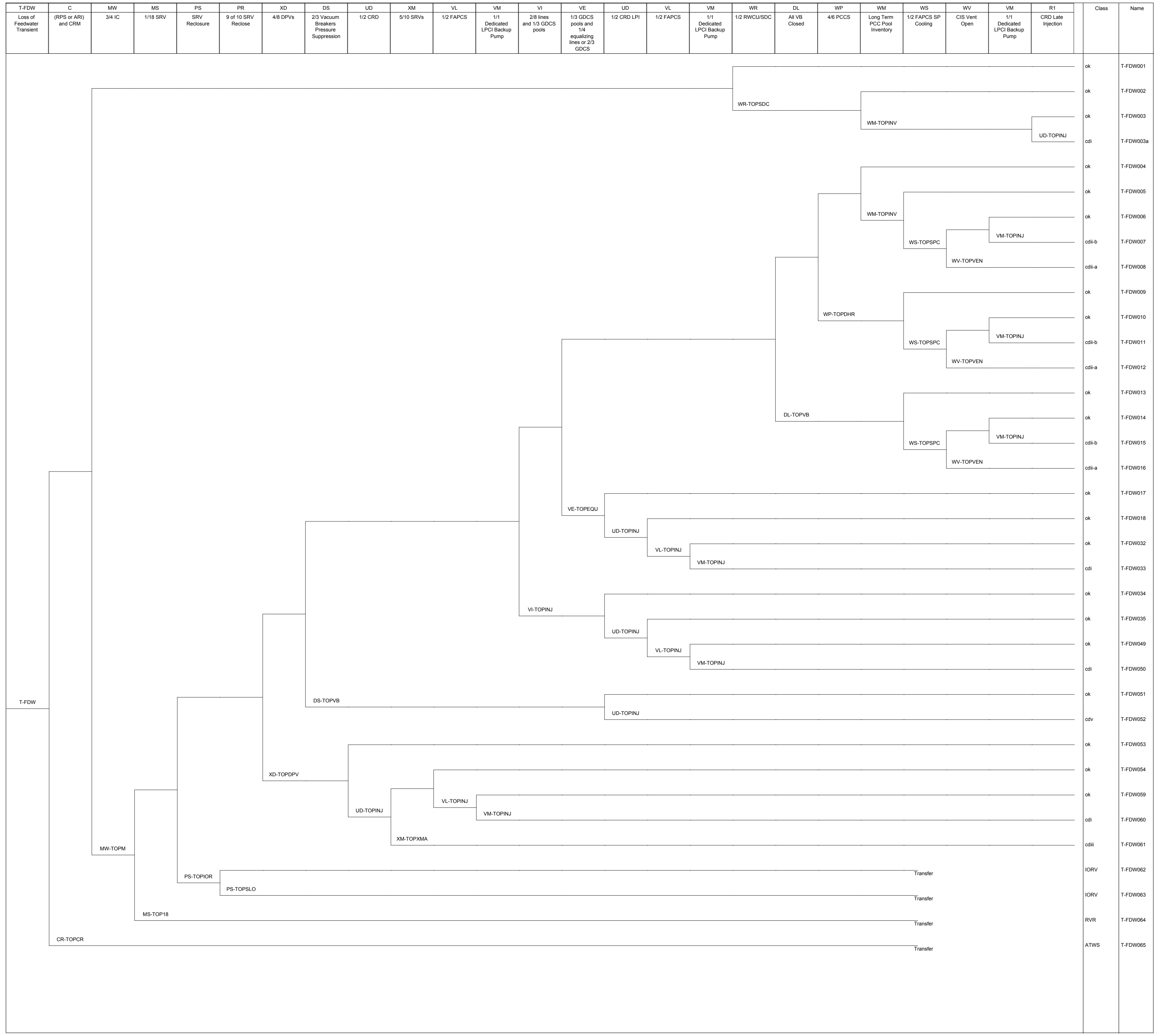

Figure 3A-2. Loss of Feedwater Transient

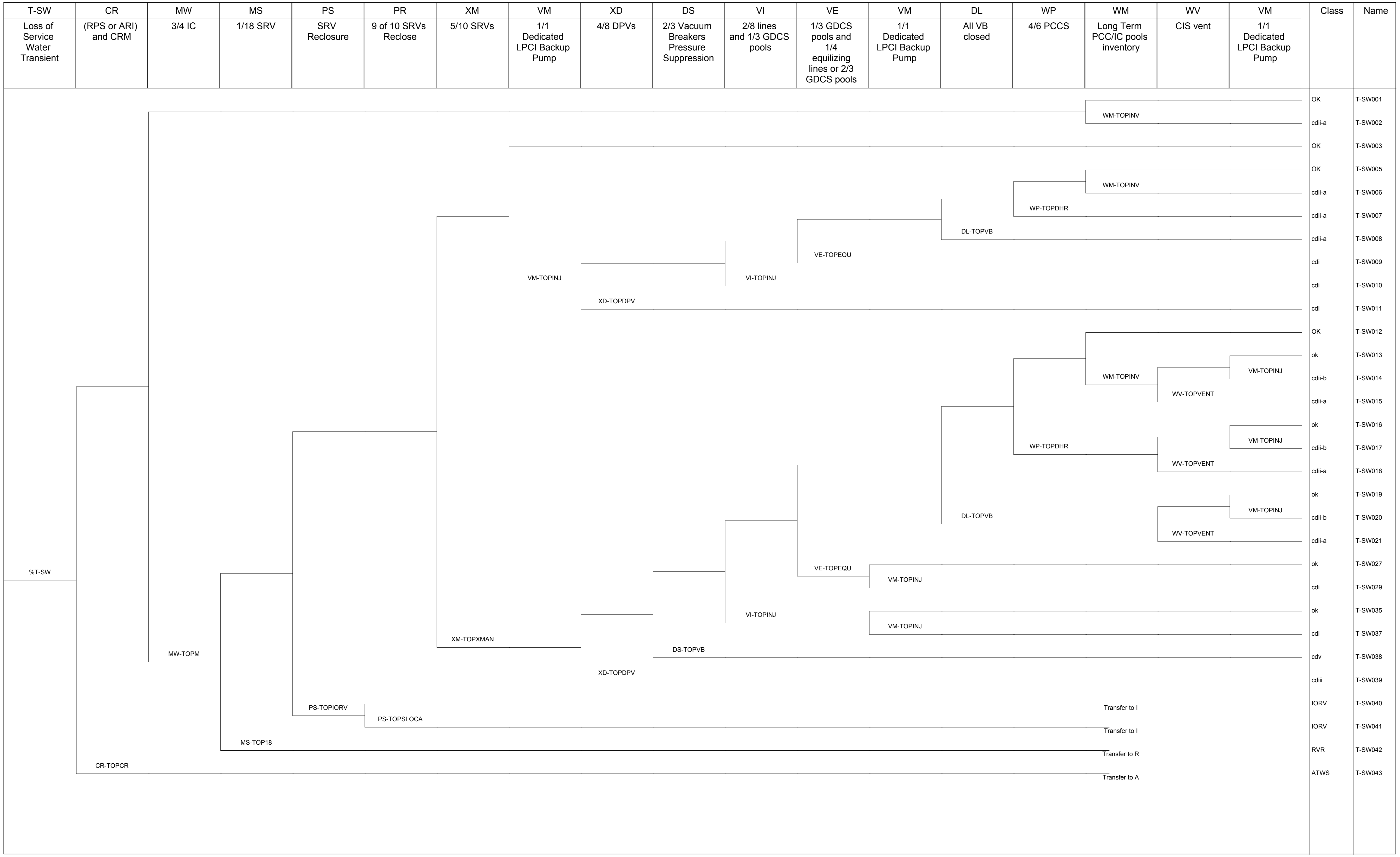

Figure 3A-3. Loss of Plant Service Water Event Tree

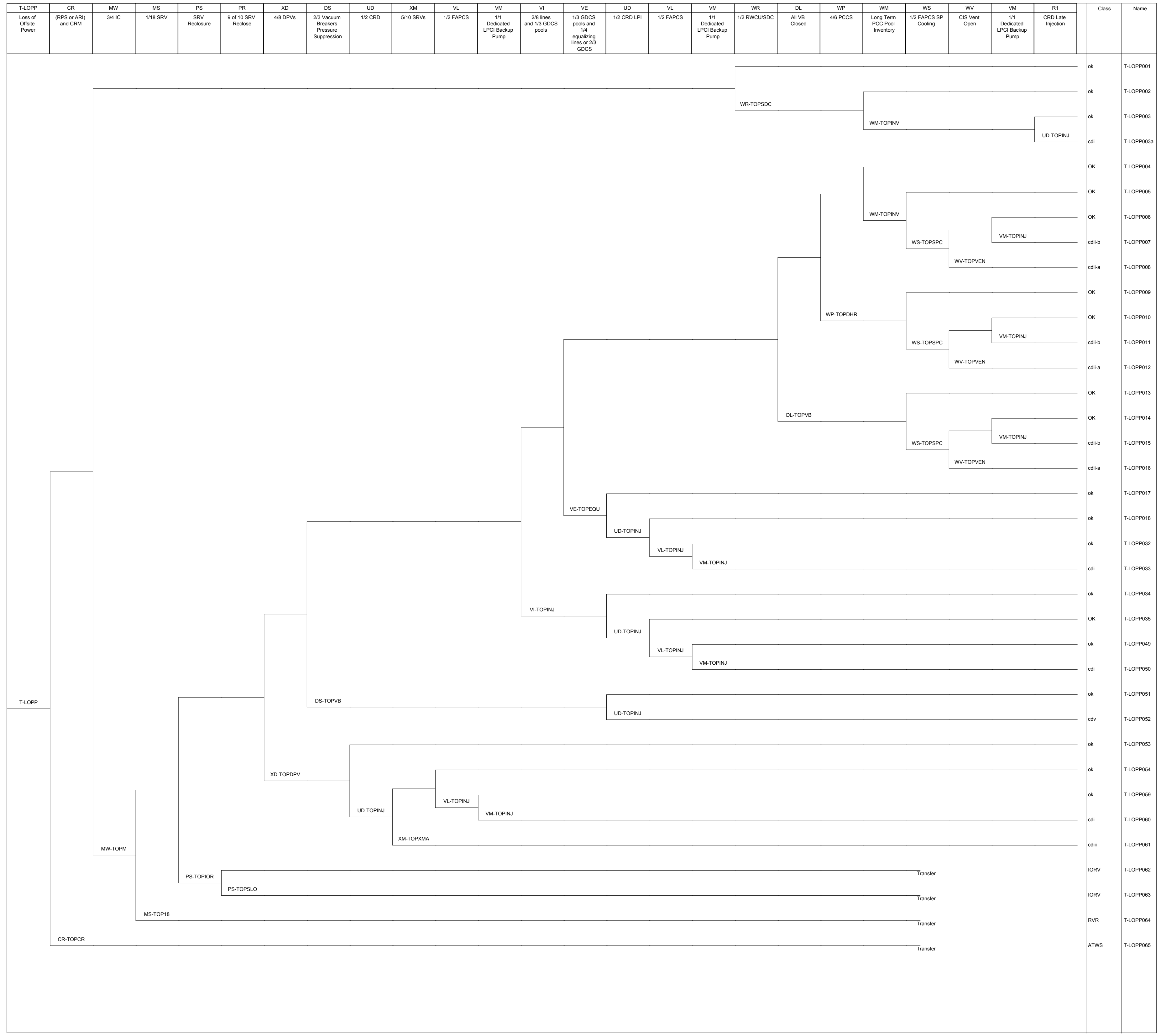

Figure 3A-4. Loss of Preferred Power Transient (T-LOPP)

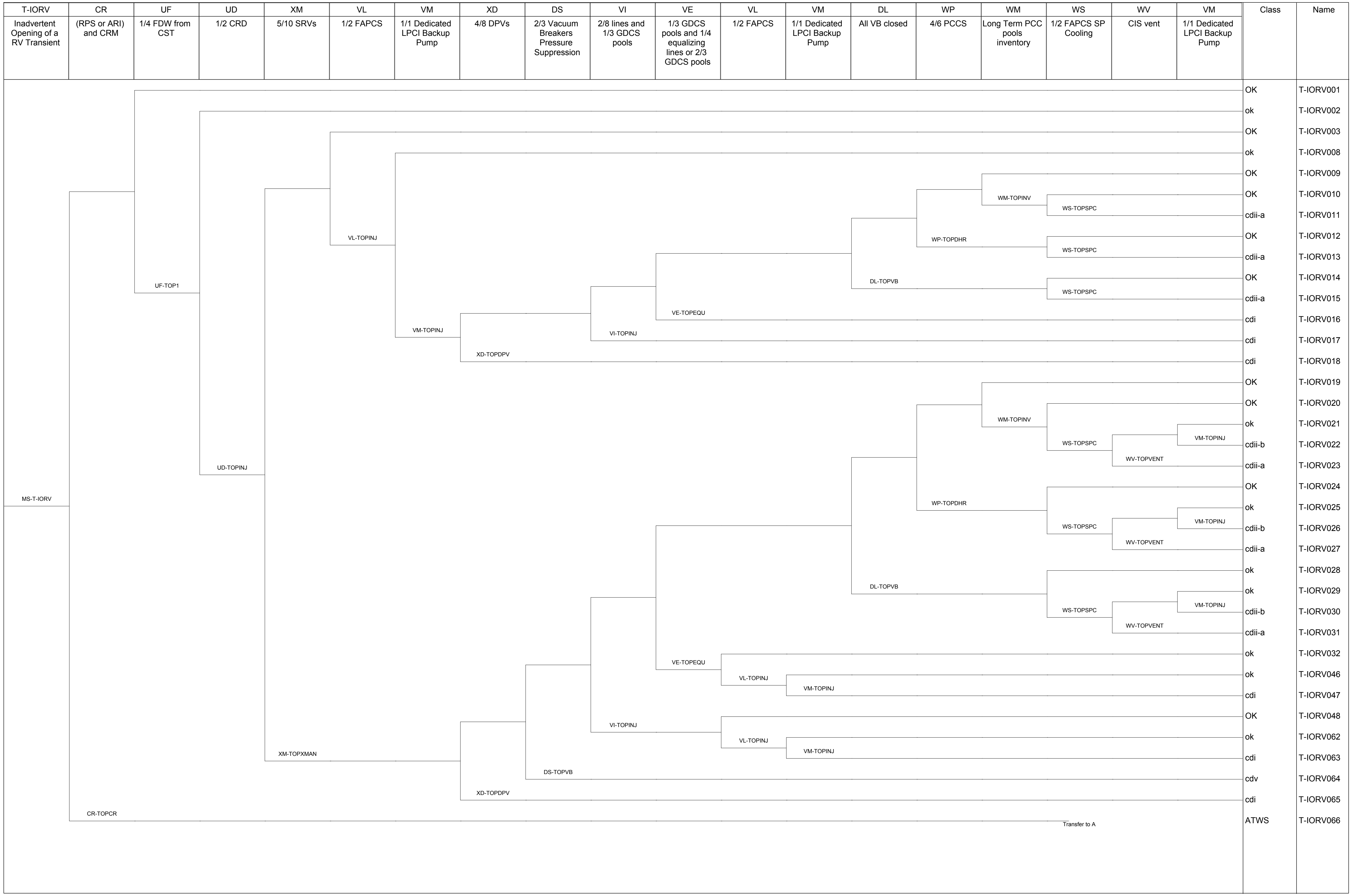

Figure 3A-5. Inadvertent Opening of Relief Valve Event Tree

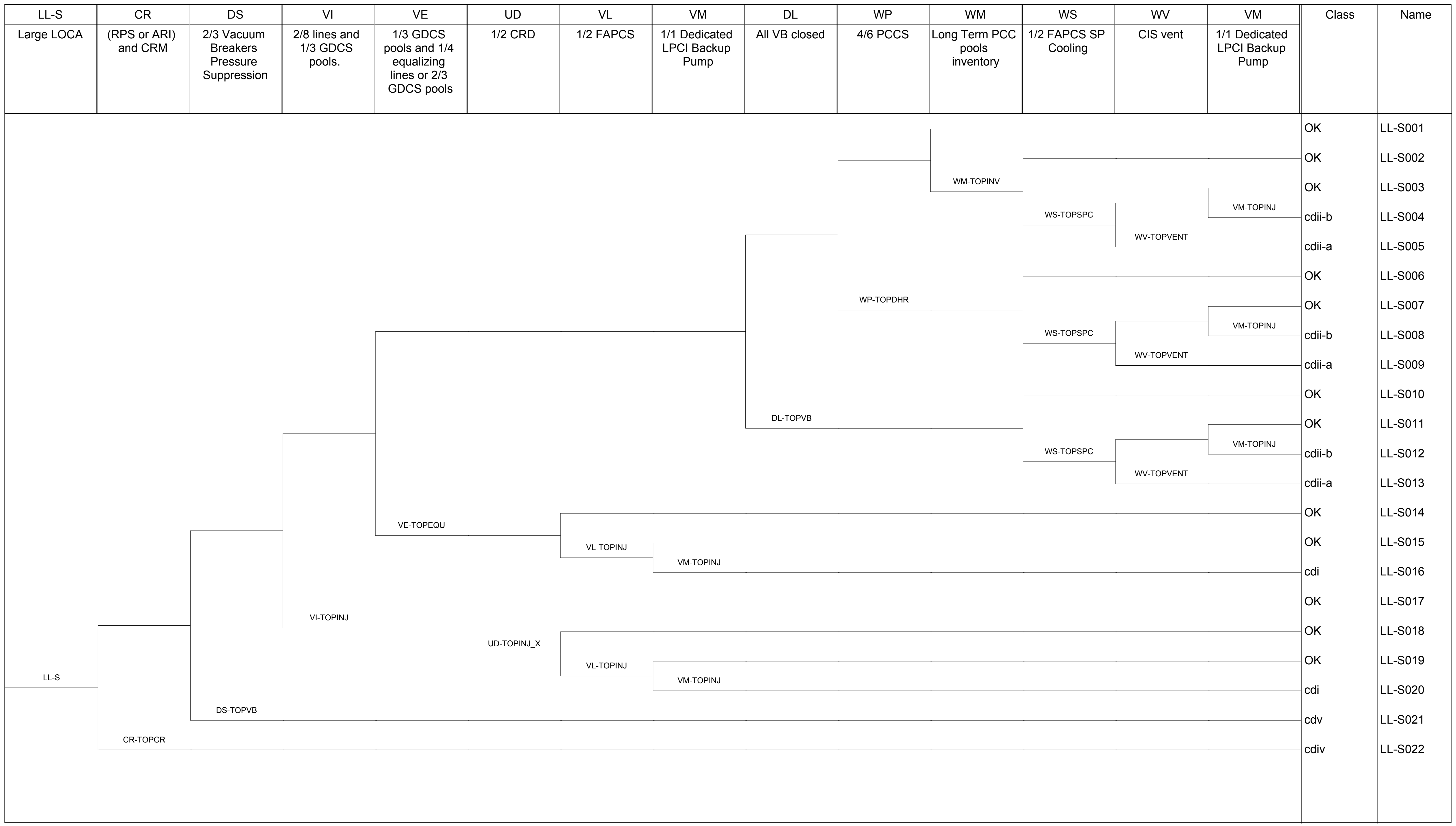

Figure 3A-6. Large Steam LOCA Event Tree

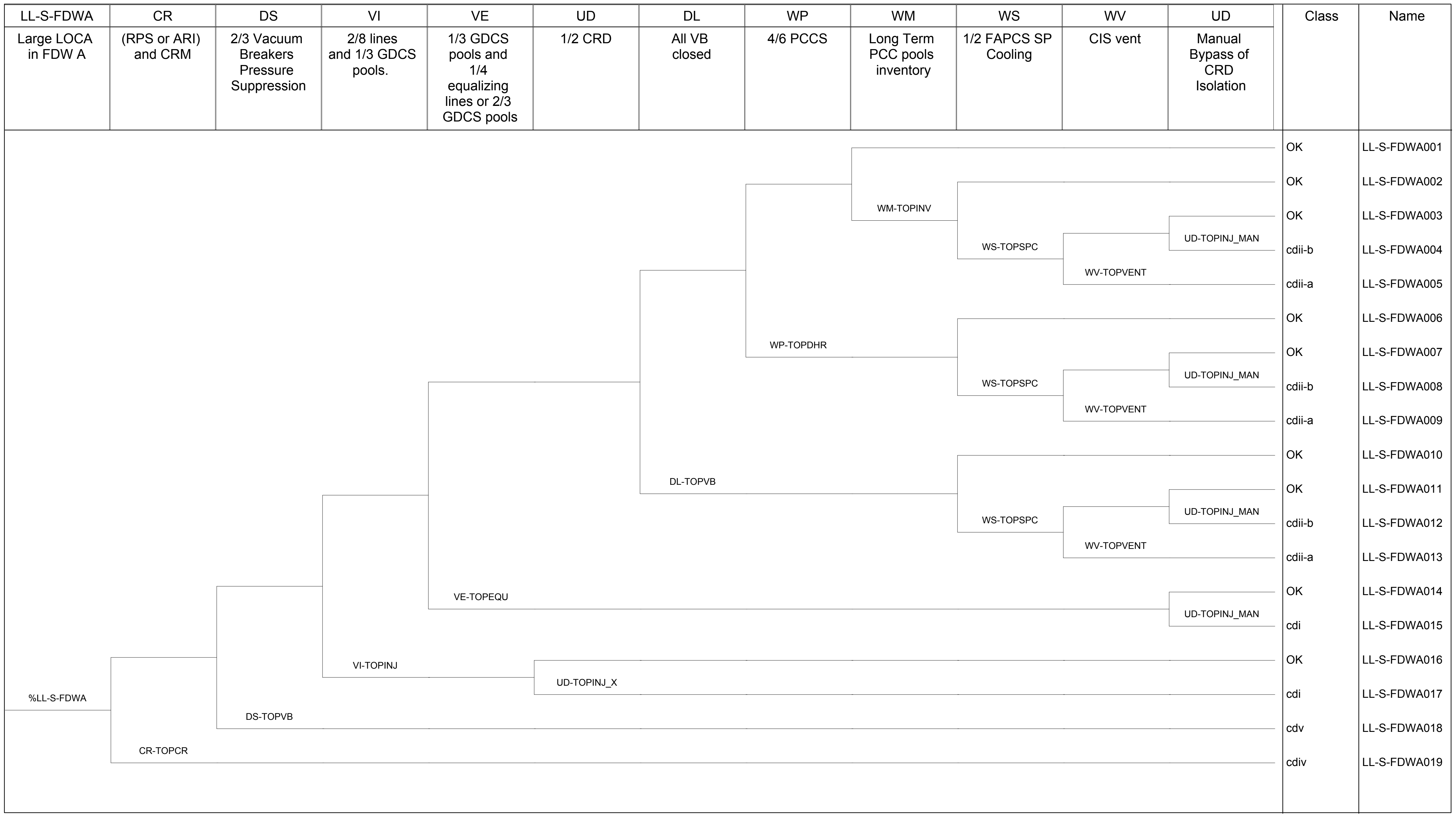

Figure 3A-7. Large Steam LOCA in Feedwater Line A Event Tree

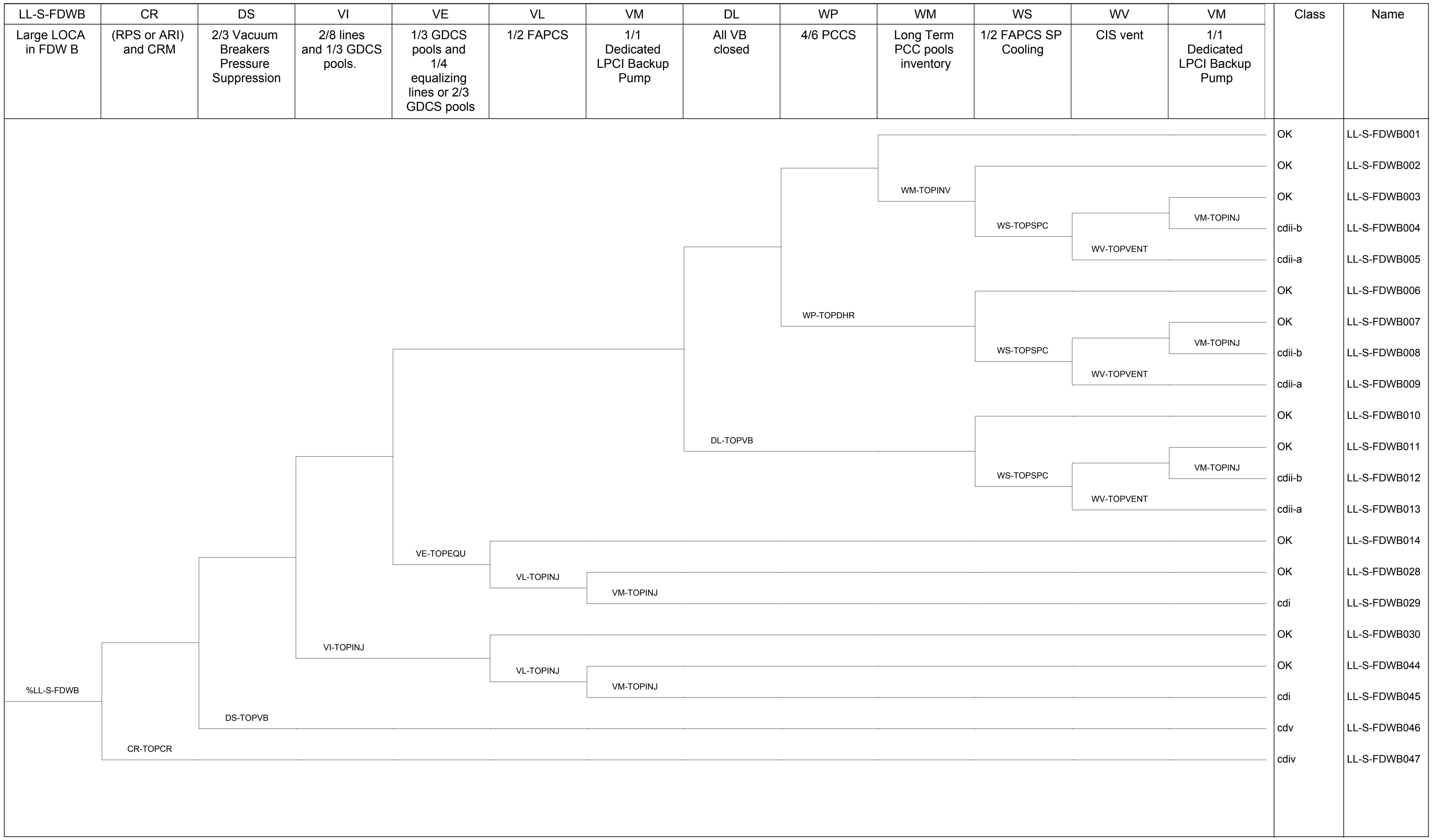

Figure 3A-8. Large Steam LOCA in Feedwater Line B Event Tree

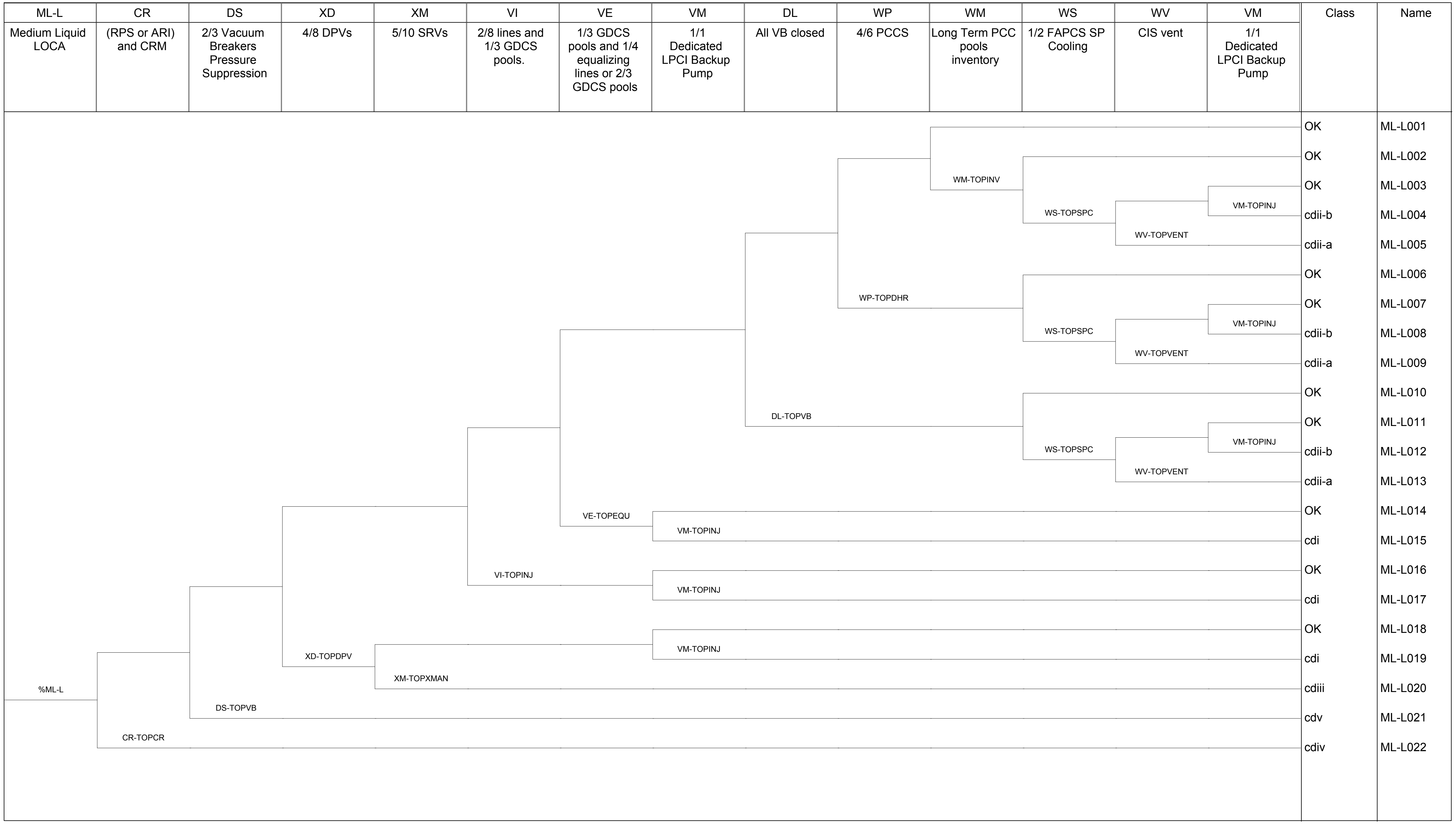

Figure 3A-9. Medium Liquid LOCA Event Tree

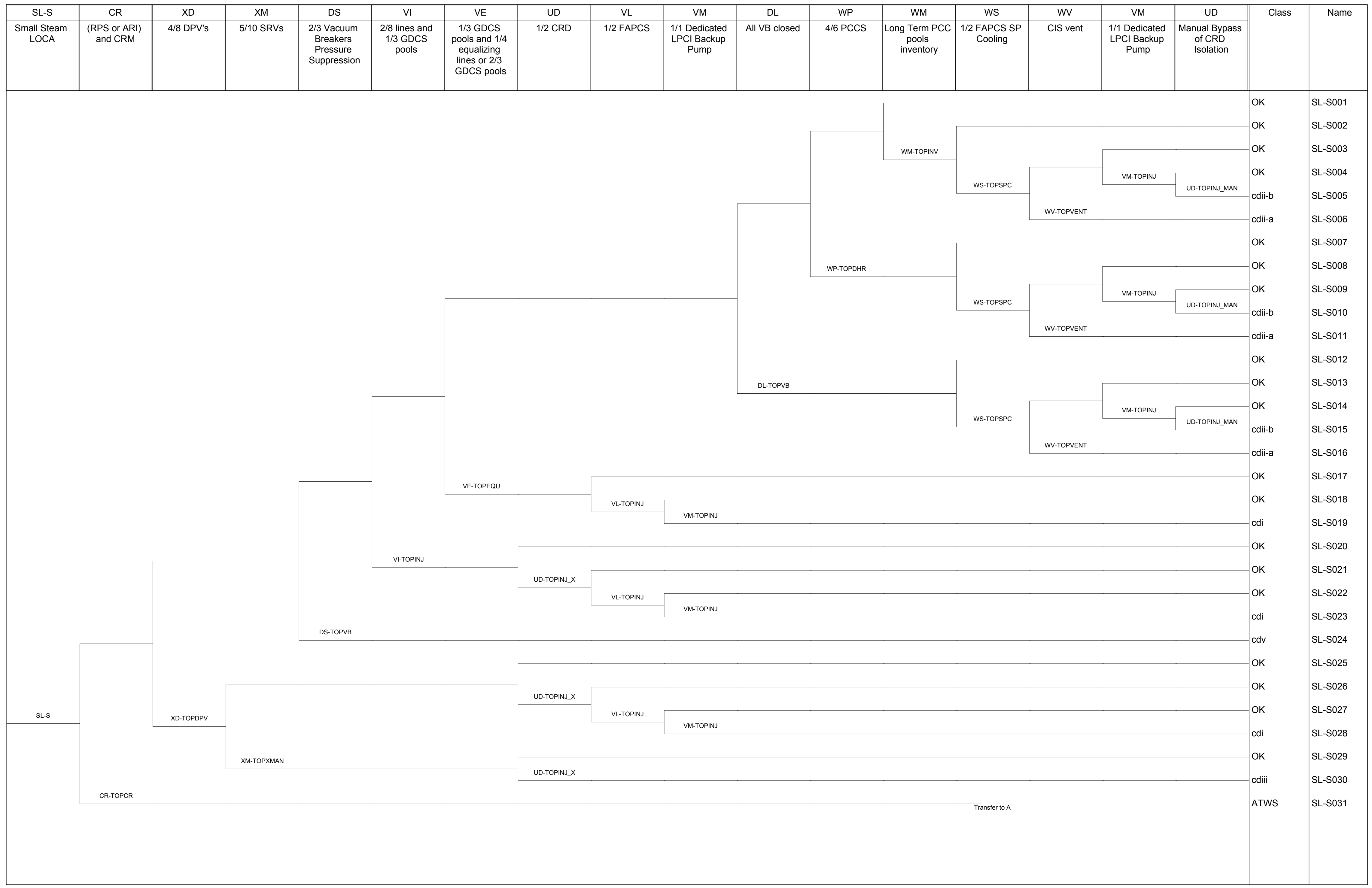

Figure 3A-10. Small Steam LOCA Event Tree

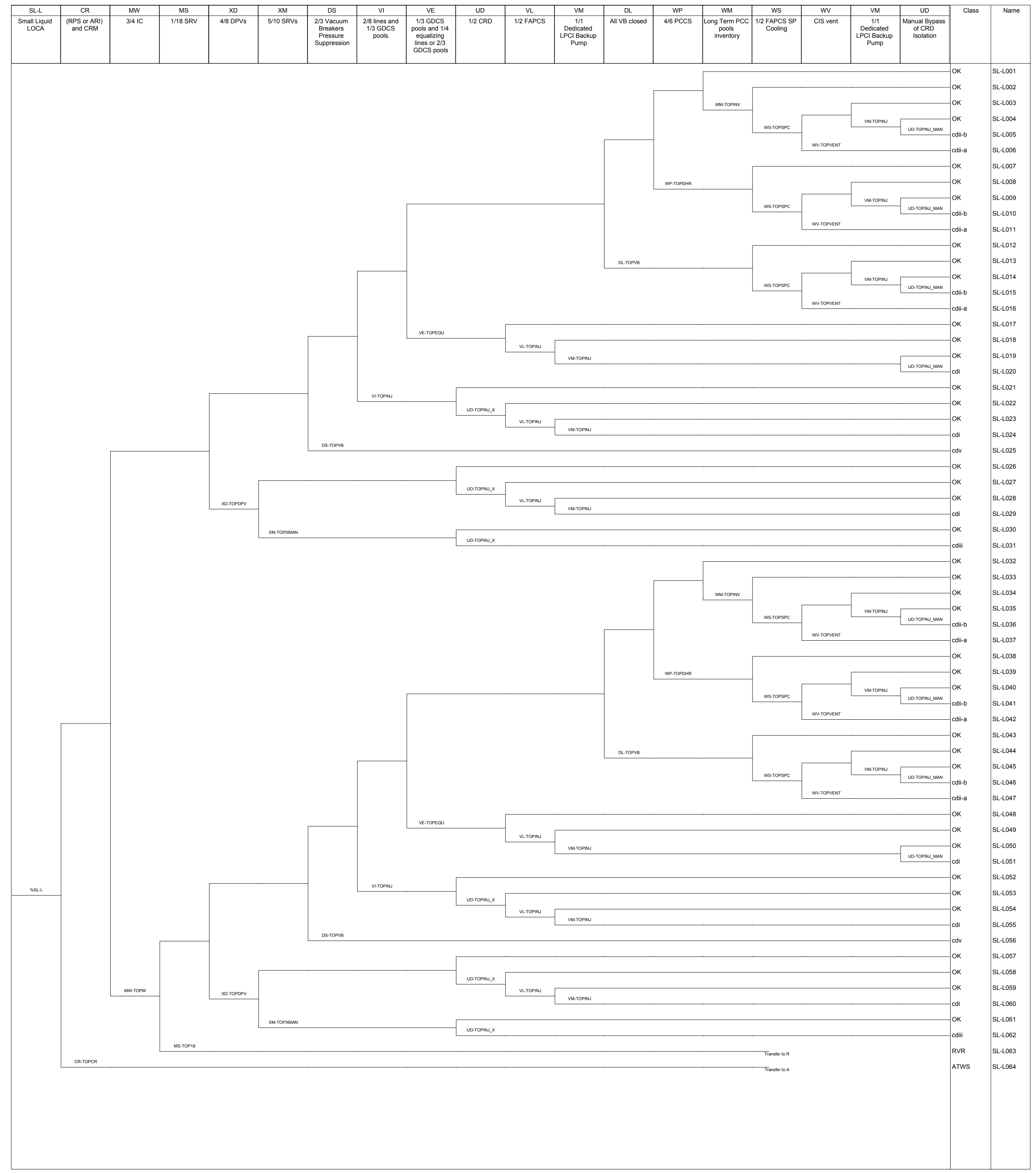

Figure 3A-11. Small Liquid LOCA Event Tree

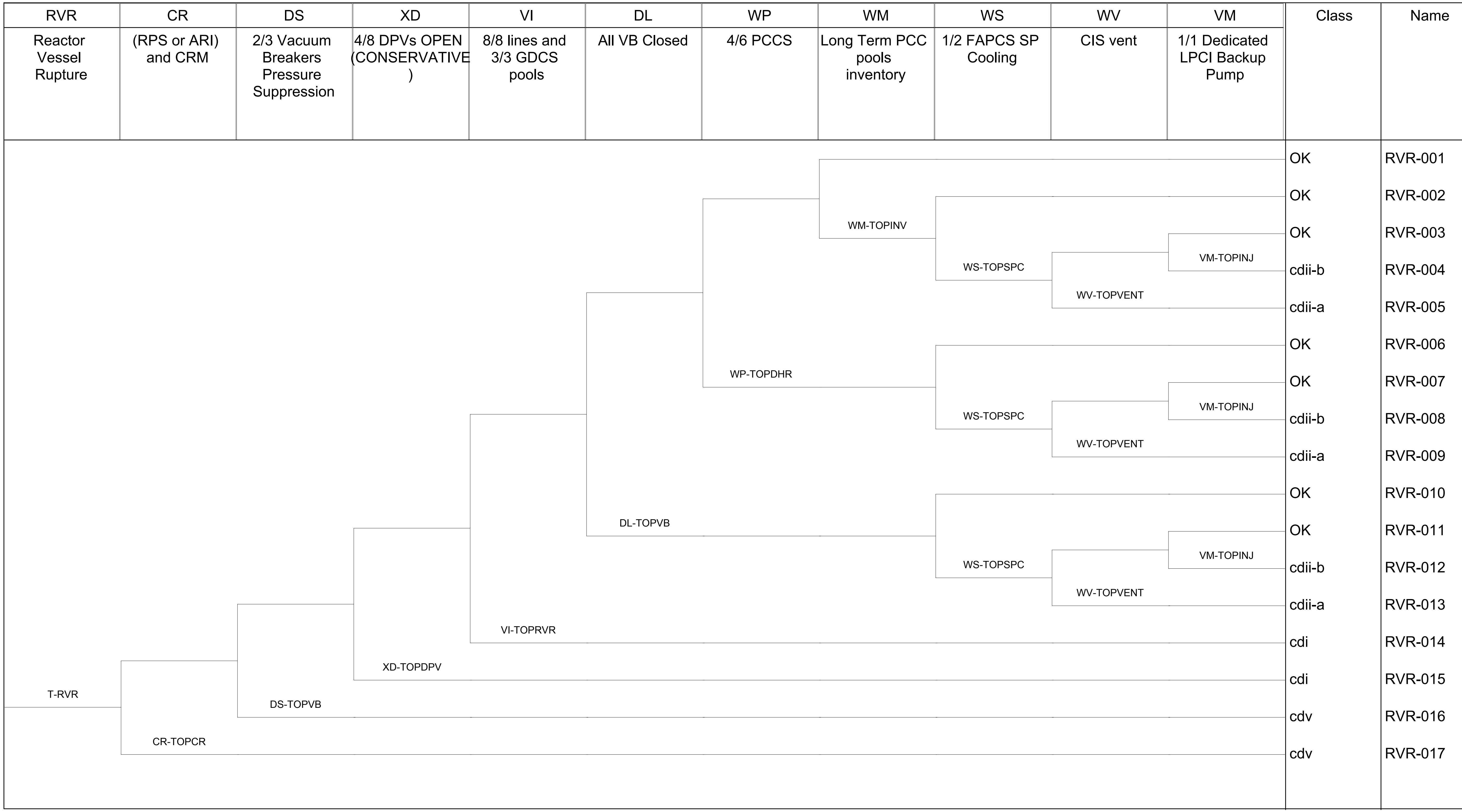

Figure 3A-12. Reactor Vessel Rupture Event Tree

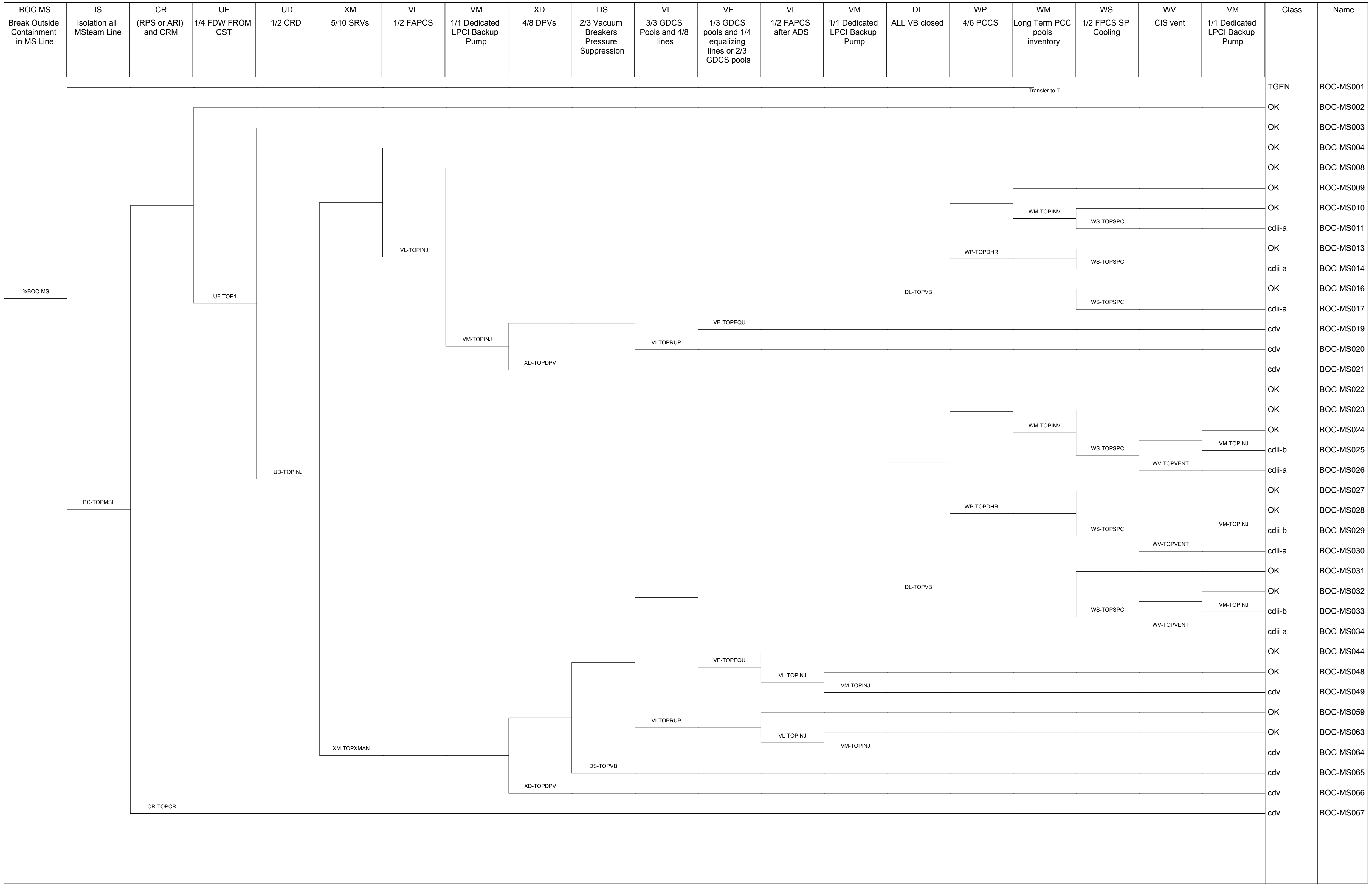

Figure 3A-13. Break Outside Containment in Main Steamline Event Tree

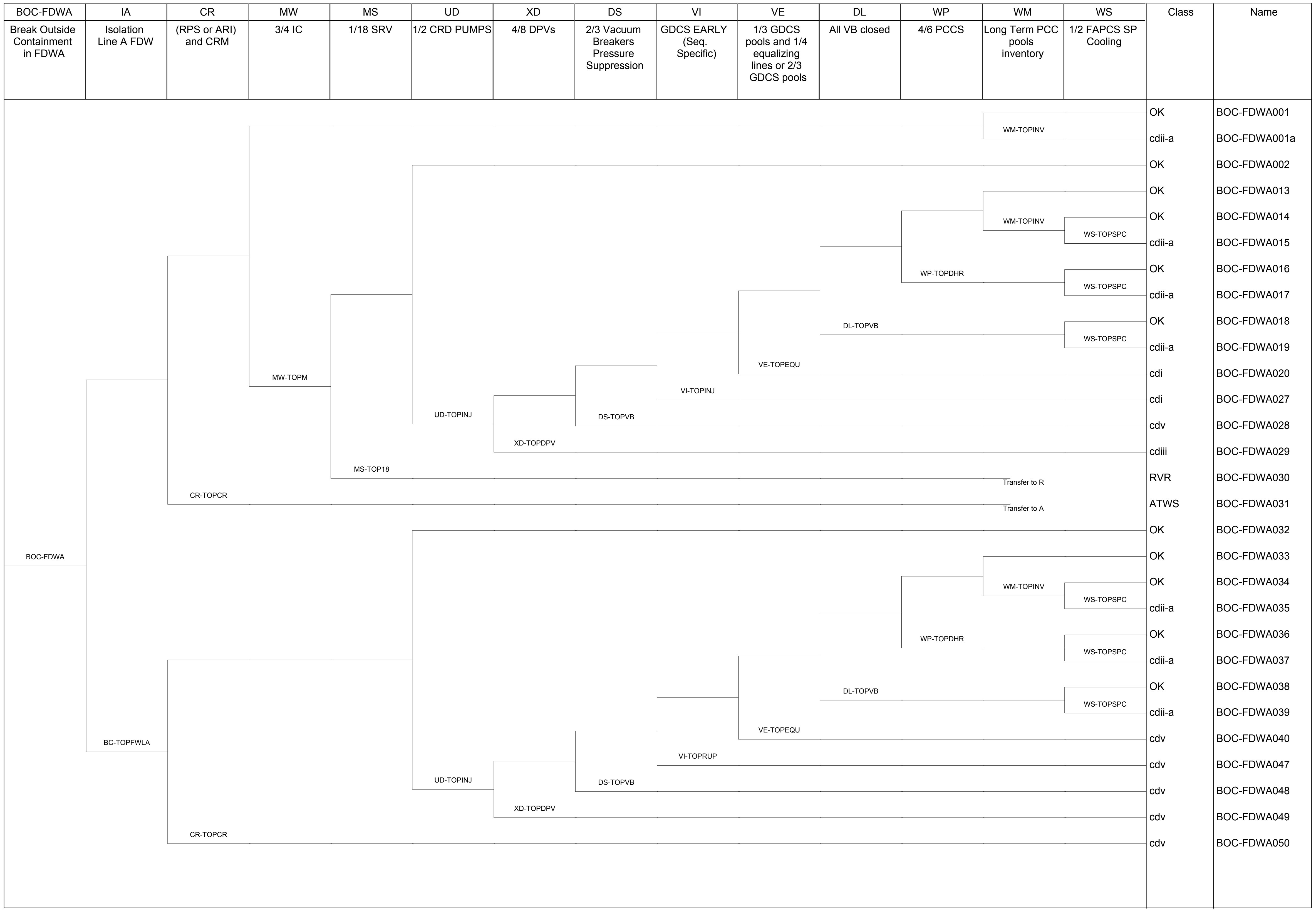

Figure 3A-14. Break Outside Containment in Feedwater Line A Event Tree

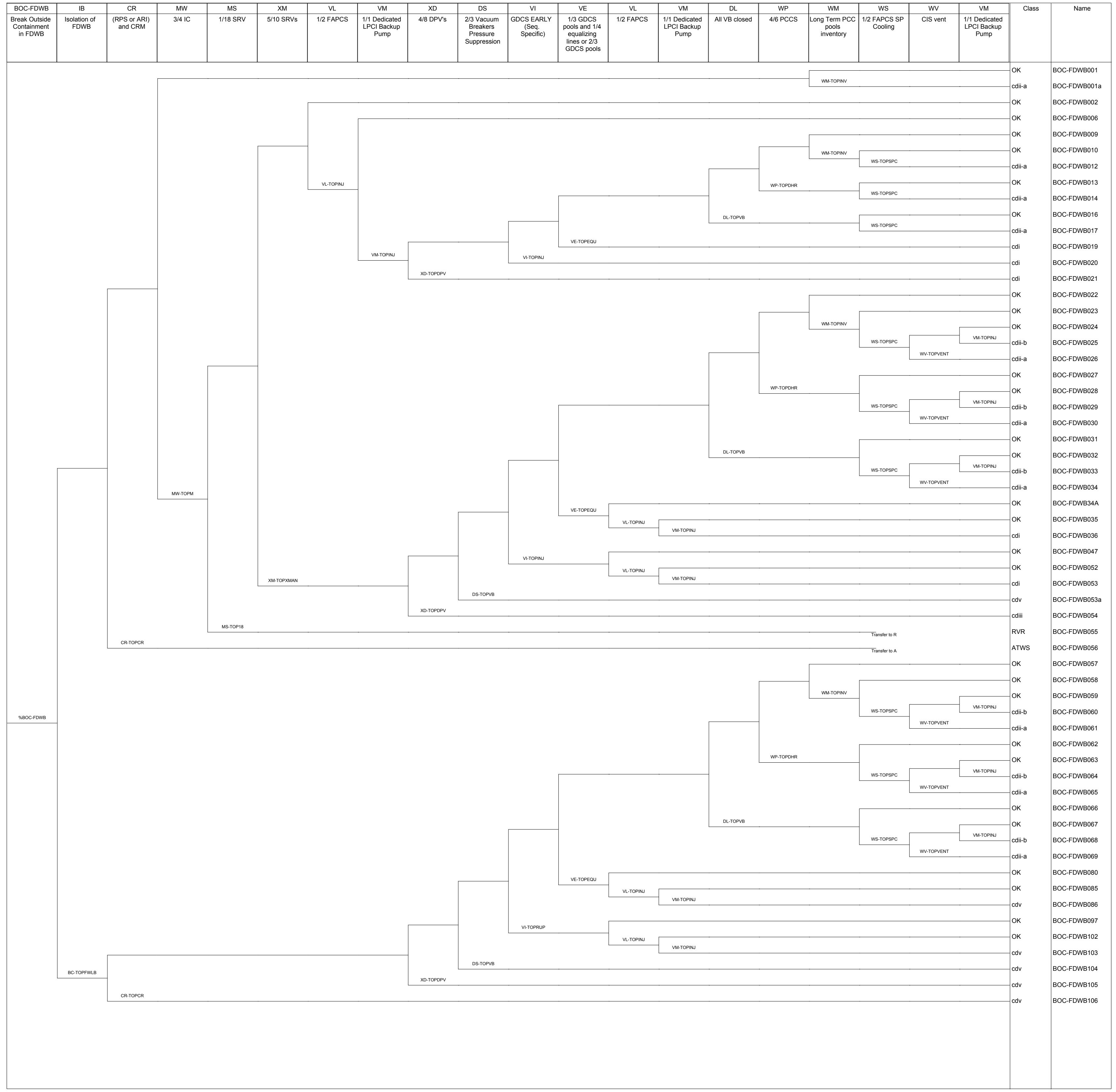

Figure 3A-15. Break Outside Containment in Feedwater Line B Event Tree

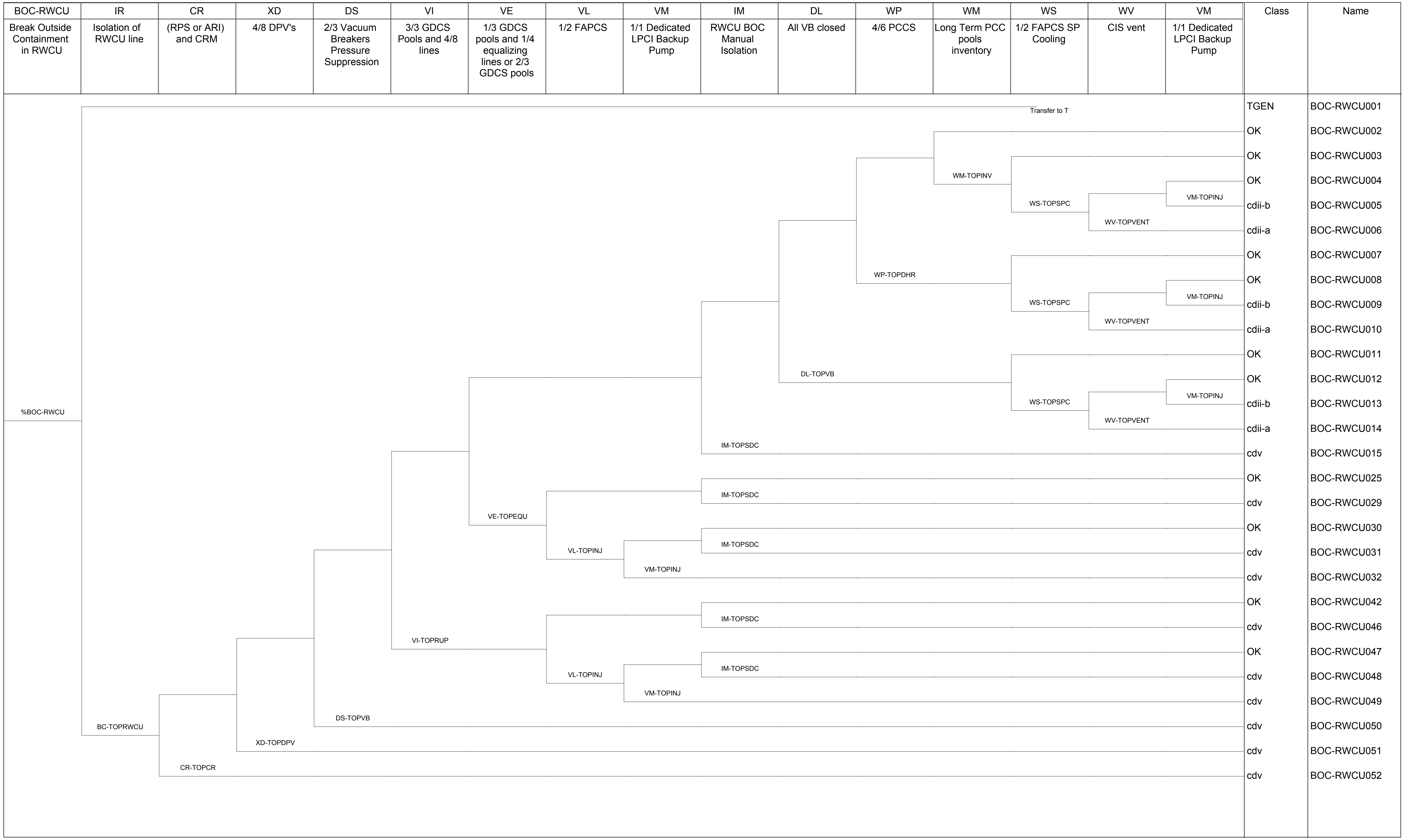

Figure 3A-16. Break Outside Containment in RWCU Event Tree

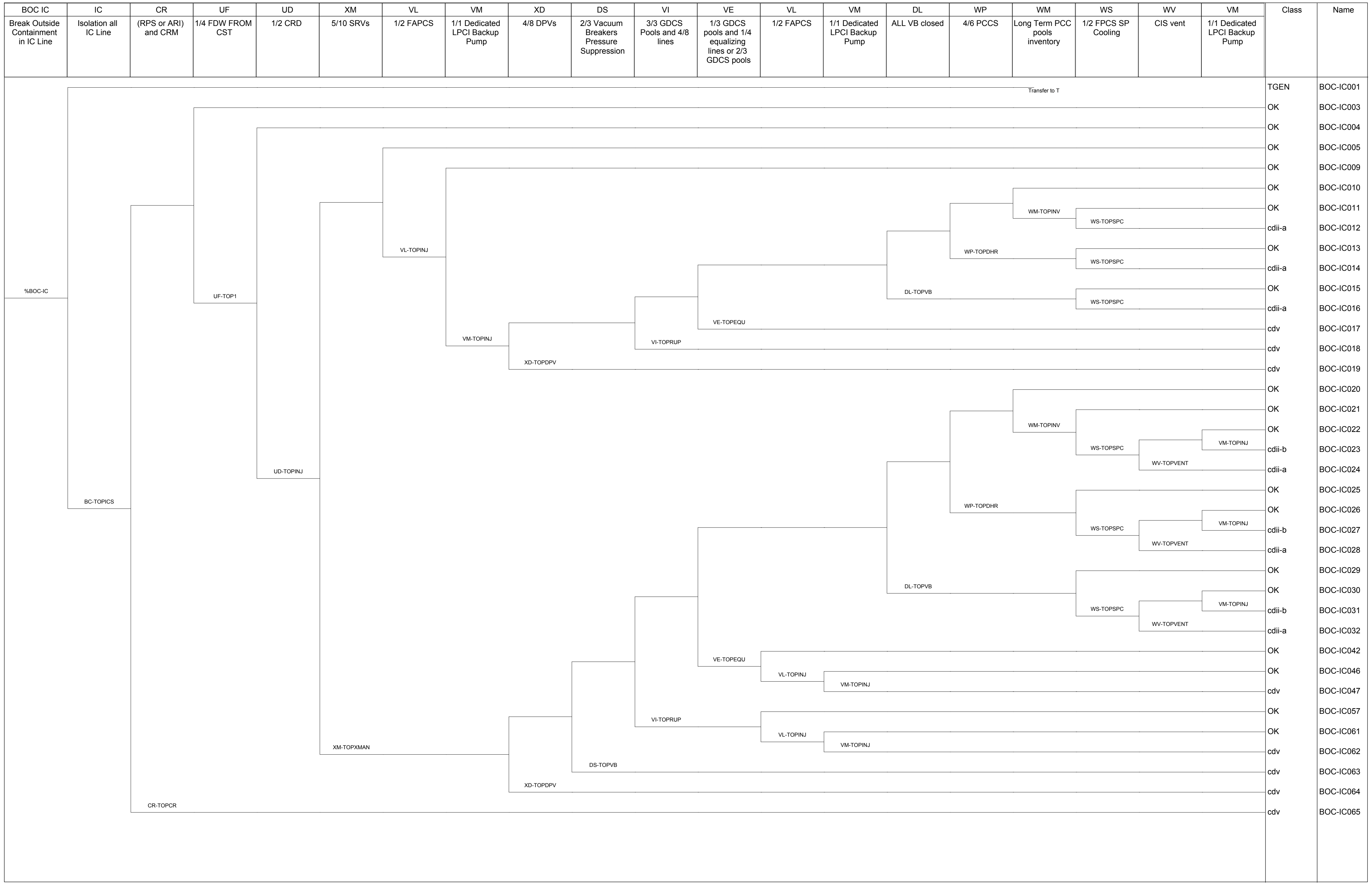

Figure 3A-17. Break Outside Containment in ICS Event Tree

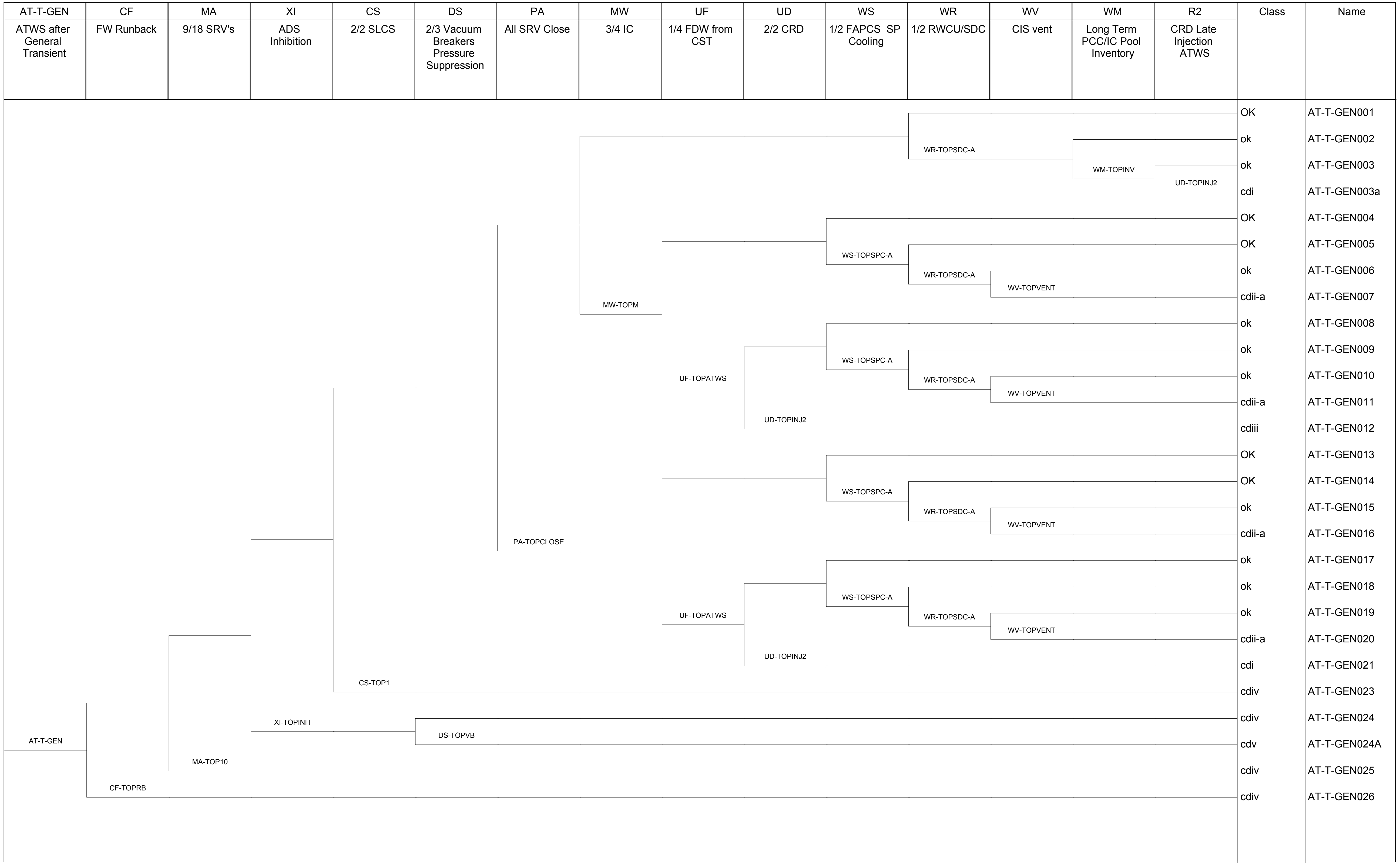

Figure 3A-18. General Transient ATWS Event Tree

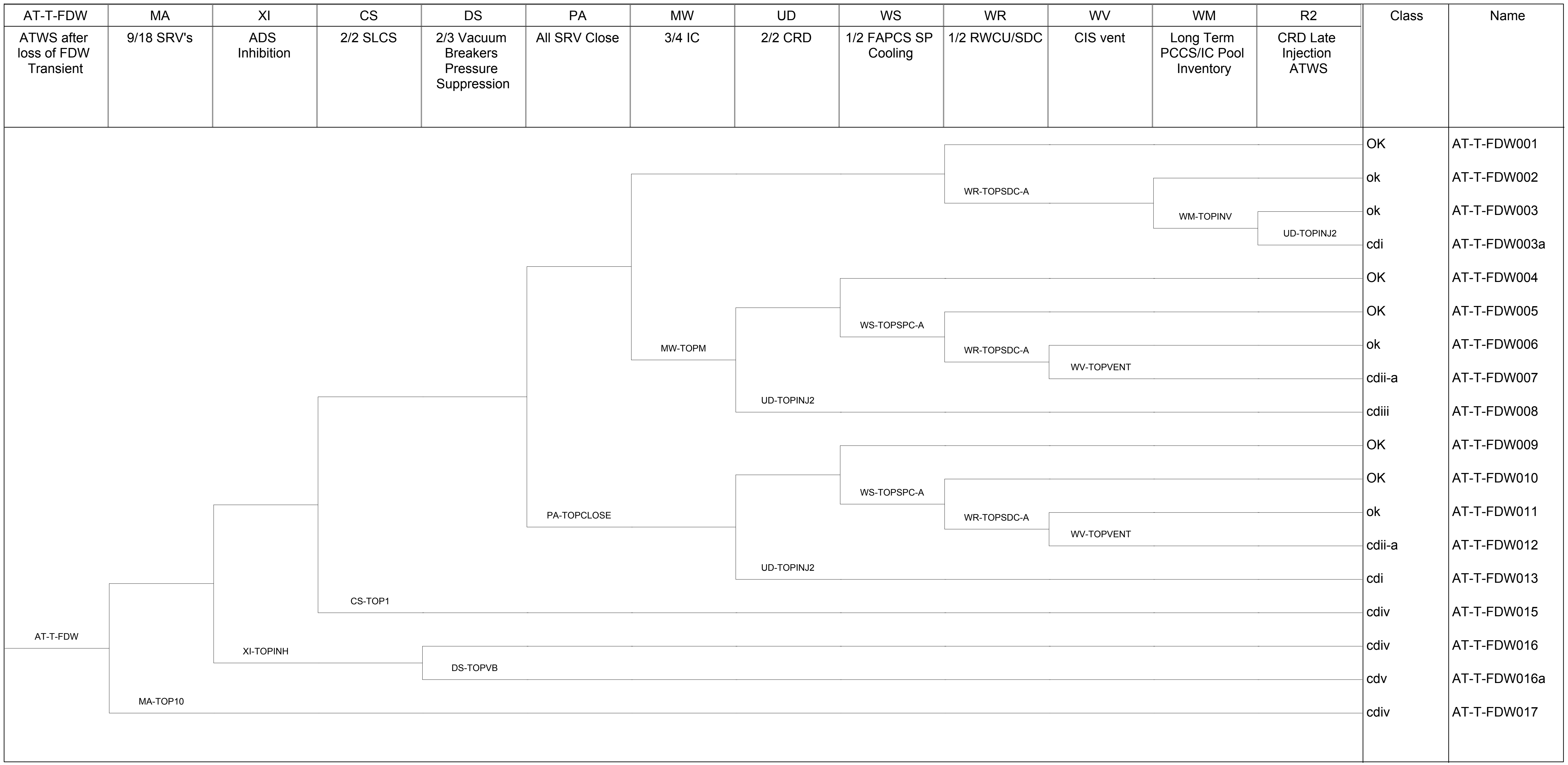

Figure 3A-19. Loss of Feedwater ATWS Event Tree

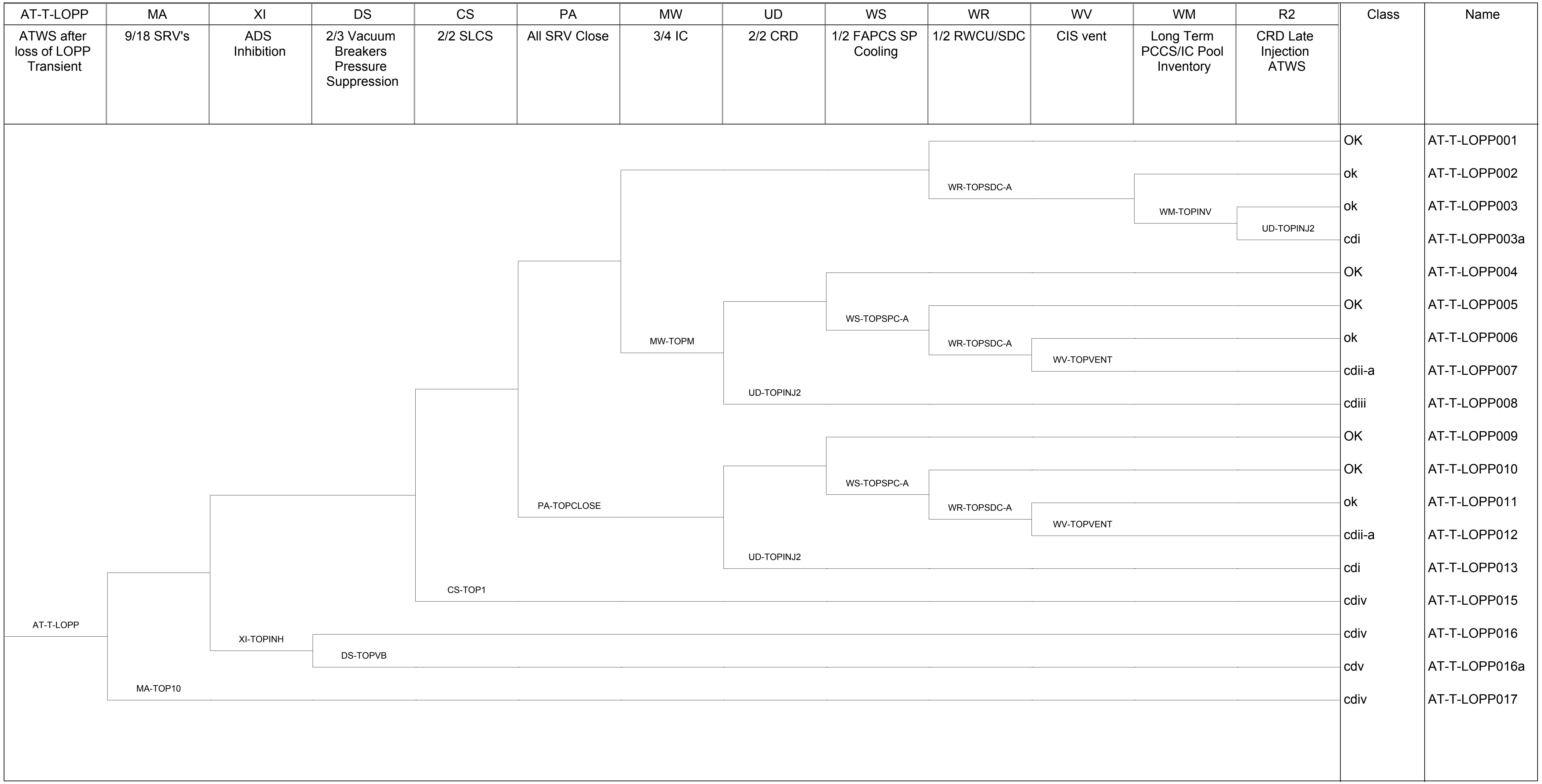

Figure 3A-20. Loss of Preferred Power ATWS Event Tree

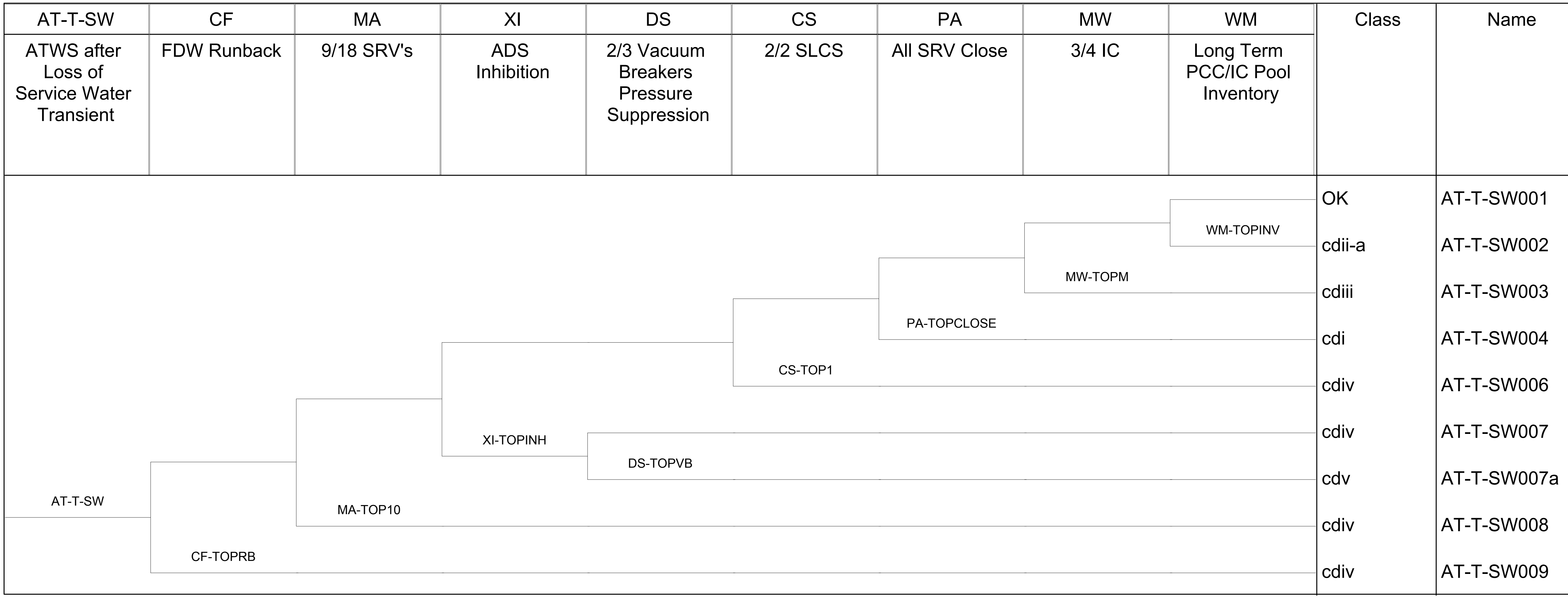

Figure 3A-21. Loss of Plant Service Water ATWS Event Tree

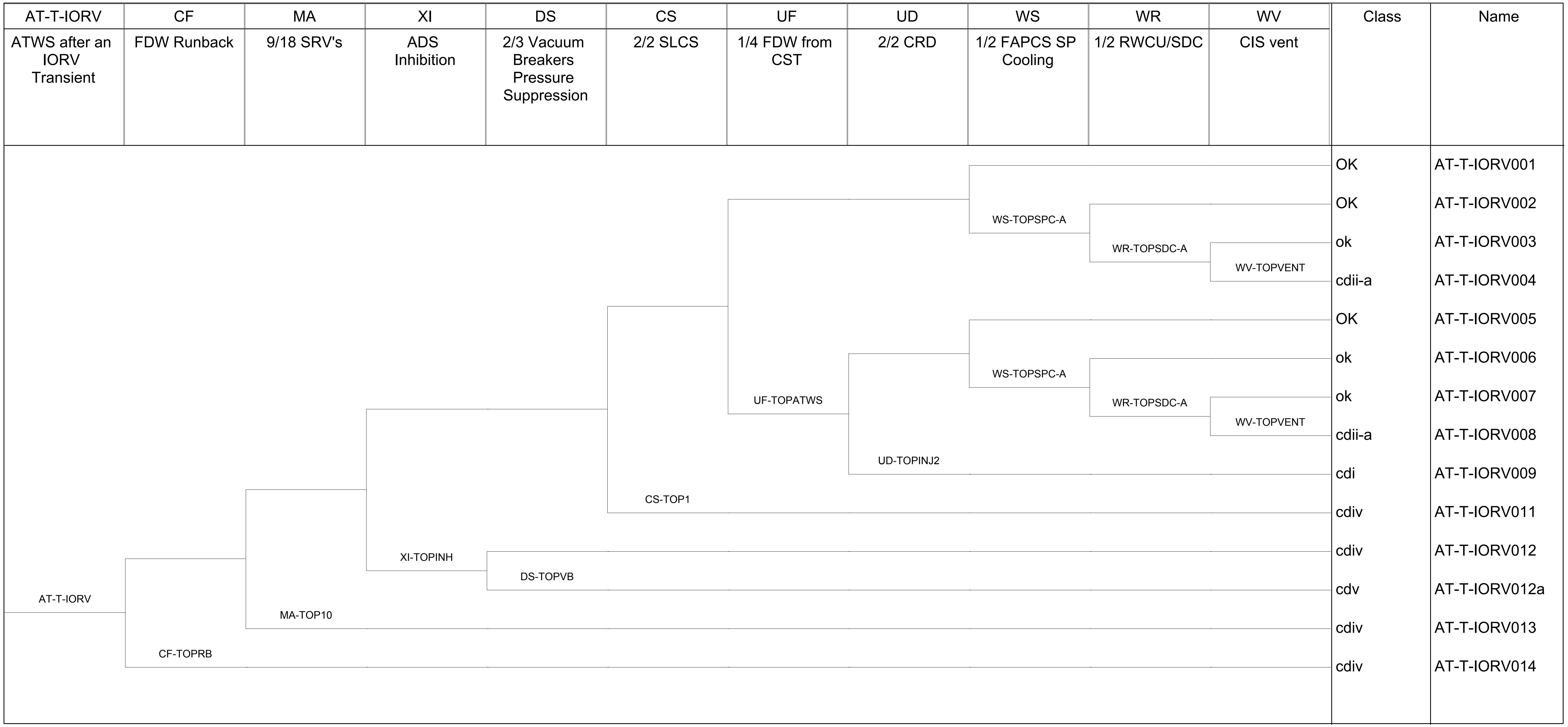

Figure 3A-22. Inadvertent Opening of Relief Valve ATWS Event Tree

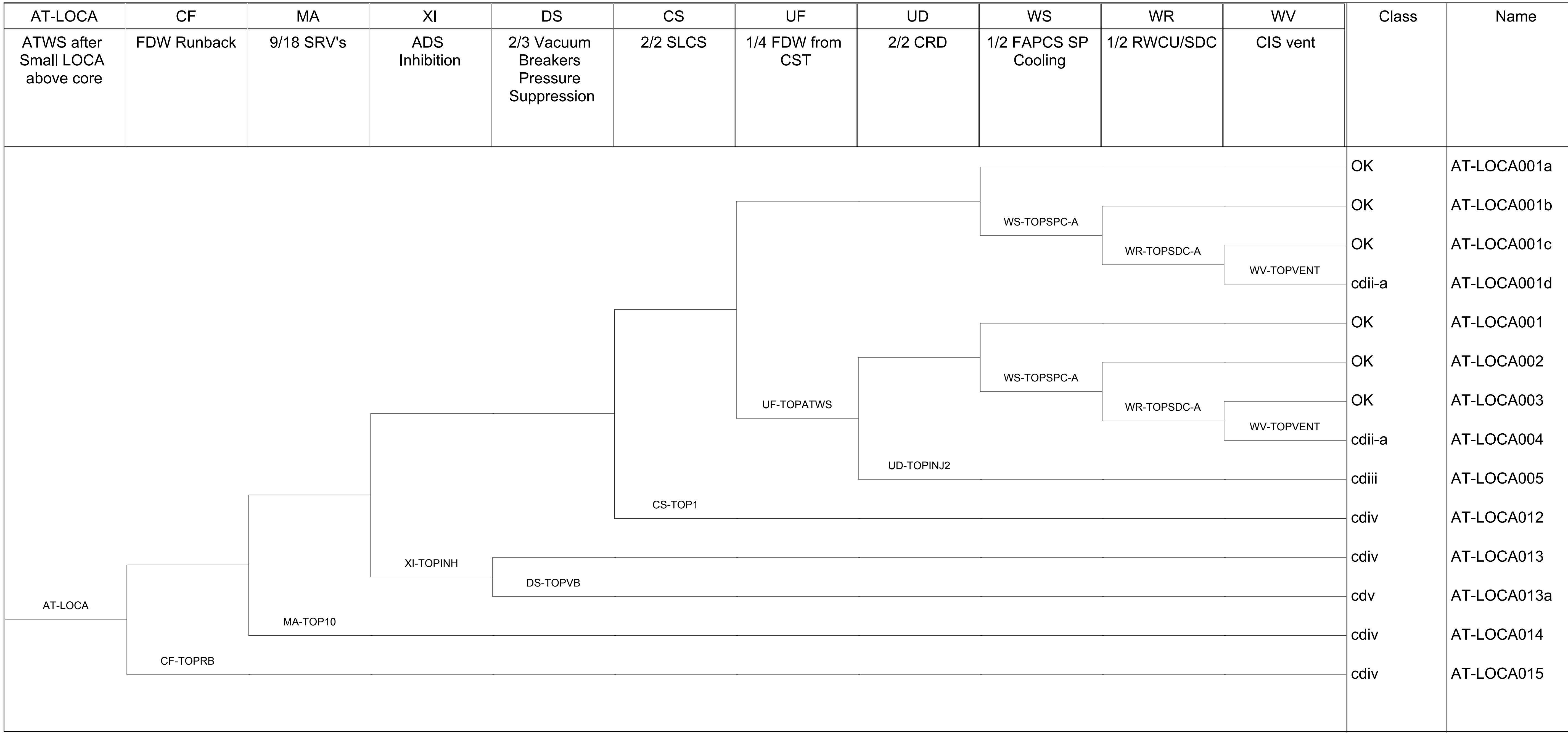

Figure 3A-23. Small LOCA ATWS Event Tree