LETTER REPORT

Beaver Valley Pressurized Thermal Shock (PTS) Probabilistic Risk Assessment (PRA)

Date Submitted: September 28, 2004
Revised: March 3, 2005

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Prepared for
Division of Risk Analysis and Applications
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code Y6430

ABSTRACT

One of the potentially most significant challenges to the structural integrity of the reactor pressure vessel (RPV) in a pressurized water reactor (PWR) is posed by a pressurized thermal shock (PTS) event wherein severe cooling of the core occurs together with, or followed by, pressurization.

In the early 1980s the nuclear industry and the Nuclear Regulatory Commission (NRC) staff performed a number of investigations aimed at assessing the risk of vessel failure posed by PTS, and on establishing the limits needed to reduce failures caused by PTS transients to a tolerable level. These efforts led to the publication by the Staff of a document [SECY-82-465] that provided the technical basis for subsequent development of what has come to be known as the "PTS Rule" [10CFR50.61].

As PWRs approach the end of their original 40-year operating licenses, and utilities consider requesting 20-year license extensions, compliance with the PTS Rule[10CFR50.61] can become a factor that limits the operational life of the plant. Addressing this issue on a plant-specific basis has consumed considerable resources within both the regulatory and operational communities. Additionally, it is now widely recognized that state of knowledge and data limitations in the early 1980's necessitated a conservative treatment of several key parameters and models used in the probabilistic calculations that provide the technical basis [SECY-82-465] for the current PTS rule [10CFR50.61].

The cost associated with demonstrating and checking compliance with the current PTS screening criteria, the conservatisms known to underlie the screening criteria, and the considerable technical advancements that have occurred in the 20 years since the technical basis for the PTS Rule was established all combined to motivate the NRC Office of Nuclear Regulatory Research to undertake a project aimed at developing the technical basis to support a fundamental revision of the PTS rule and the associated PTS risk and screening criteria.

NUREG-1806, *Technical Basis for Revision of the Pressurized Thermal Shock (PTS) Screening Limit in the PTS Rule (10CFR50.61): Summary Report*, is the main report documenting this latest work. In assessing the current understanding of PTS risk, analyses of the following plants were performed: Oconee 1, Beaver Valley 1, and Palisades.

This report, a companion to NUREG-1806, summarizes the probabilistic risk assessment (PRA) work (only) performed for the Beaver Valley 1 analysis. It does not address the thermal hydraulic or probabilistic fracture mechanics portions of the Beaver Valley 1 study. Other companion reports address these other aspects as well as the other plants.

While this report is meant to be a stand alone document for the PRA portion of the work, it is suggested that it be read in concert with NUREG-1806 to provide a more complete understanding of the work that was performed and its results since it is only in the main NUREG, that the complete picture of the through wall crack frequencies (TWCFs) (including the PRA, TH, and PFM perspectives combined) is provided.

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ACKNOWLEDGMENTS

This study (i.e. the probabilistic risk assessment) was part of a multi-disciplinary team approach that included support from thermal hydraulics (Information Systems Laboratories, Inc.) and probabilistic fracture mechanics (Oak Ridge National Laboratory) to help identify those accident sequences that either did or did not have the potential to be important to pressurized thermal shock (PTS). The willingness of each individual from the two organizations to work in an interactive fashion greatly facilitated this study's work.

In addition, the timely support provided by the staff at Beaver Valley Unit 1was invaluable to this study as it allowed us to consider plant-specific responses to various aspects of the pressurized thermal shock model.

Furthermore, the cooperation provided by members of the Idaho National Engineering and Environmental Laboratory during the transition of the original PTS work to Sandia National Laboratories is gratefully acknowledged.

Finally, special thanks go to our Nuclear Regulatory Commission Project Manager Mr. Hugh W. (Roy) Woods. His diligent efforts to ensure that we had the necessary resources and the time to interact with the other organizations is greatly appreciated.

ACRONYMS AND INITIALISMS

ADVs	Atmospheric dump valves
AFW	Auxiliary feedwater
AOPs	Abnormal operating procedures
ATWS	Anticipated transient without scram
CBP	Condensate booster pump
CFTs	Core flood tanks
CPF	Conditional probability of failure
DG	Diesel generator
EFW	Emergency feedwater
EOPs	Emergency operating procedures
HFEs	Human failure events
HHSI	High head safety injection
HPI	High pressure injection
IEs	Initiating events
ISLOCA	Interfacing systems loss-of-coolant accident
LHSI	Low head safety injection
LOCA	Loss-of-coolant accident
LPI	Low pressure injection
MFW	Main feedwater
MSIVs	Main steam isolation valves
MSSRVs	Main steam safety relief valves
NRC	Nuclear Regulatory Commission
PCCW	Primary component cooling water
PFM	Probabilistic fracture mechanics
PORV	Power-operated relief valve
PRA	Probabilistic risk assessment
PTS	Pressurized thermal shock
PWR	Pressurized water reactor
RCPs	Reactor coolant pumps
RCS	Reactor coolant system
RPV	Reactor pressure vessel
SDVs	Steam dump valves
SG	Steam generator
SGTR	Steam generator tube rupture
SRVs	Safety relief valves
SSCs	Systems, structures, components
SSRVs	Secondary steam relief valves
TBVs	Turbine bypass valves
TH	Thermal-hydraulics
TWCF	Through wall crack frequency
UMD	University of Maryland

1. INTRODUCTION

1.1 Summary of the PTS Issue

One of the potentially most significant challenges to the structural integrity of the reactor pressure vessel (RPV) in a pressurized water reactor (PWR) is posed by a pressurized thermal shock (PTS) event wherein severe cooling of the core occurs together with, or followed by, pressurization. Several operational sequences can thermally shock the vessel (either with or without significant internal pressure); these include a break of the main steam line, secondary depressurization through a relief valve, a loss of coolant accident (LOCA), or extended injection of high-pressure water to name just a few. During these events, water level in the primary system is restored since it will have dropped due to contraction resulting from overcooling, and in cases involving a primary system breach (e.g., a LOCA) additional water level drop occurs due to leakage from the primary. The water added is much colder water than that present in the reactor coolant system (RCS). The temperature differential between the nominally ambient temperature emergency coolant water and the operating temperature of a pressurized water reactor ($\Delta T = 550°F – 60°F = 490°F$) produces significant thermal stresses in the thick section steel wall of the RPV. These stresses could be high enough to initiate a running cleavage crack, a crack that could propagate all the way through the vessel.

In the early 1980s the nuclear industry and the Nuclear Regulatory Commission (NRC) staff performed a number of investigations aimed at assessing the risk of vessel failure posed by PTS, and on establishing the limits needed to reduce failures caused by PTS transients to a tolerable level. These efforts led to the publication by the Staff of a document [SECY-82-465] that provided the technical basis for subsequent development of what has come to be known as the "PTS Rule" [10CFR50.61].

As PWRs approach the end of their original 40-year operating licenses, and utilities consider requesting 20-year license extensions, compliance with the PTS Rule[10CFR50.61] can become a factor that limits the operational life of the plant. Addressing this issue on a plant-specific basis has consumed considerable resources within both the regulatory and operational communities. Additionally, it is now widely recognized that state of knowledge and data limitations in the early 1980's necessitated a conservative treatment of several key parameters and models used in the probabilistic calculations that provide the technical basis [SECY-82-465] of the current PTS rule [10CFR50.61].

The cost associated with demonstrating and checking compliance with the current PTS screening criteria, the conservatisms known to underlie the screening criteria, and the considerable technical advancements that have occurred in the 20 years since the technical basis for the PTS Rule was established all combined to motivate the NRC Office of Nuclear Regulatory Research to undertake a project aimed at developing the technical basis to support a fundamental revision of the PTS rule and the associated PTS risk and screening criteria.

1.2 Overview of the Technical Approach

This project makes use of three main models (shown in Figure 1.1) that, together, allow us to estimate the yearly through-wall crack frequency (TWCF) in a RPV. First a probabilistic risk assessment (PRA) event-tree analysis is performed to define both the sequences of events that are likely to produce a PTS challenge to RPV integrity and to define the frequency with which such sequences can be expected to occur. The sequence definitions are then passed to a thermal-hydraulic (TH) model that estimates the temporal variation of temperature, pressure, and heat-transfer coefficient in the RPV down-comer

characteristic of each of the sequence definitions. These pressure, temperature, and heat transfer coefficient histories are passed to a selected probabilistic fracture mechanics (PFM) model. The PFM model uses the thermal hydraulics output along with other information concerning plant design and materials of construction to estimate the time variation of the driving force to fracture produced by a particular sequence of events. The PFM model compares this estimate of fracture driving force to the fracture toughness, or fracture resistance, of the RPV steel. This comparison allows us to estimate the probability that a particular sequence of events will produce a crack all the way through the reactor pressure vessel wall were that sequence of events to actually occur. The final step in the analysis involves a simple matrix multiplication of these probabilities of through-wall cracking (from the PFM analysis) with the frequency at which a particular event sequence is expected to occur (as defined by the PRA event-tree analysis). This multiplication establishes an estimate of the yearly frequency of through wall cracking (i.e., TWCF) that can be expected for a particular plant after a particular period of operation.

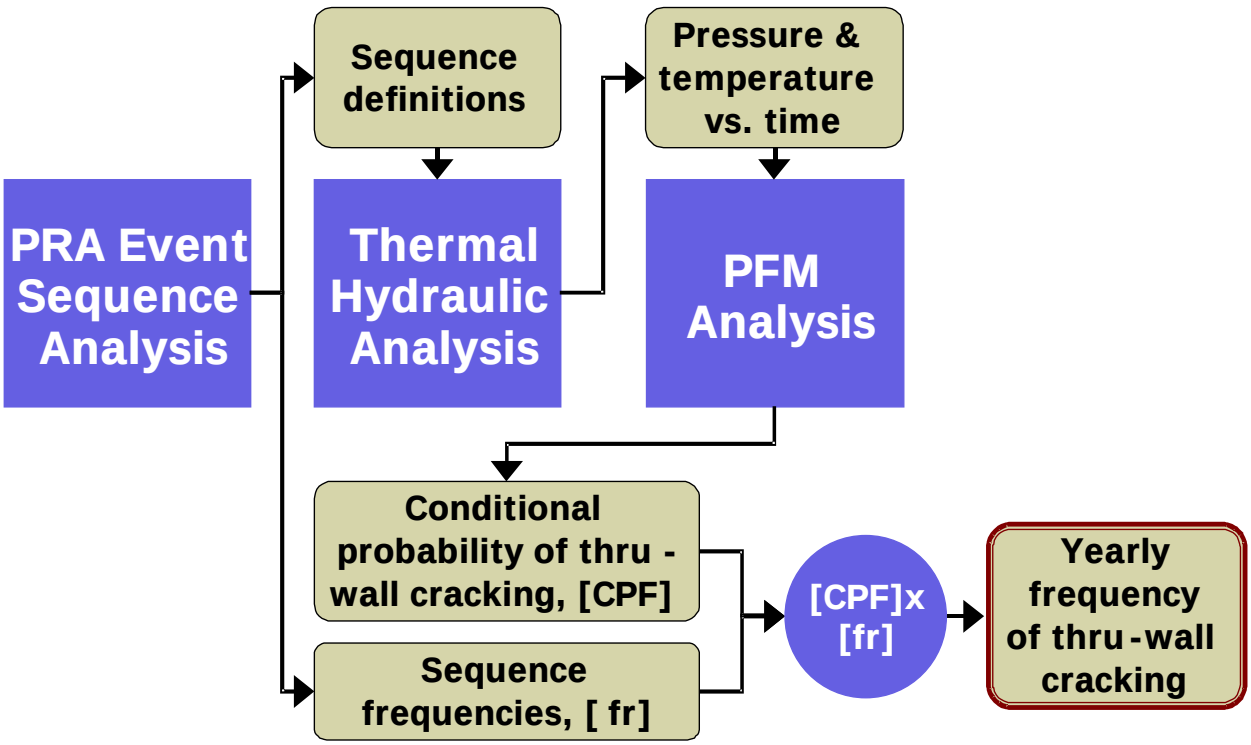

Figure 1.1. Three model approach used in the PTS analyses.

1.3 Purpose of This Report

NUREG-1806, *Technical Basis for Revision of the Pressurized Thermal Shock (PTS) Screening Limit in the PTS Rule (10CFR50.61): Summary Report* [NUREG-1806], is the main report documenting this latest work. In assessing the current understanding of PTS risk, analyses of the following plants were

performed: Beaver Valley 1, Oconee 1, and Palisades. These plants were chosen for the following reasons:

- The management and technical staff of these plants actively supported the NRC in this effort by providing access to plant personnel, plant simulators, records of construction, and other information as required.

- One of the plants (Oconee 1) was included in the original PTS studies that provided the basis for 10CFR50.61. We judged it desirable to include this plant in our re-evaluation activities to provide a linkage to past efforts[1].

- Two of the plants (Palisades and Beaver Valley 1) are among the closest plants to the 10CFR50.61 screening limit. Participation of these plants was deemed crucial since, based on our current state of knowledge, they are believed to be most "at risk."

This report is a companion to the engineering summary report [NUREG-1806] and summarizes the PRA work (only) performed for the Beaver Valley 1 analysis. It does not address the thermal hydraulic or probabilistic fracture mechanics portions of the Beaver Valley 1 study. Other companion reports address these aspects as well as the other plants.

The remainder of this report documents elements of the PRA work performed for the Beaver Valley 1 PTS analysis. First we provide an intentionally brief, high level overview of Beaver Valley design features most relevant to the PTS issue to familiarize the reader with the Beaver Valley plant. The document then follows, as applicable, the relevant documentation requirements for the various PRA requirements in the ASME Standard [ASME RA-S-2002] as the means to document the Beaver Valley PTS PRA that was performed for this project. While this report is meant to be a stand alone document for the PRA portion of the work, it is suggested that it be read in concert with NUREG-1806 to provide a more complete understanding of the work that was performed and its results since it is only in the NUREG, that the complete picture of the TWCFs (including the PRA, TH, and PFM perspectives combined) is provided.

[1] Originally the third original PTS plant (Robinson 2) had agreed to participate in this re-evaluation effort, however plant management withdrew its support for these activities mid-way through the project. Subsequently, the management and technical staff of Beaver Valley 1 agreed to participate.

2. RELEVANT BEAVER VALLEY FEATURES

The occurrence of a significant PTS challenge to the reactor vessel requires (along with material issues) the following:

- a rapid rate of cooling of the primary system,
- continuation of that cooling to a low temperature, and
- maintenance of some level of primary system pressure (the higher the pressure, the greater the concern), or repressurization before significant vessel outer wall cooling occurs.

Early PTS studies [NUREG/CR-3770, NUREG/CR-4183] and a recent Westinghouse Owners Group PTS analysis using Beaver Valley 1 as an illustrative plant [WCAP-15156] served as good references and were used to define four functions and related equipment whose status individually or in combination, are particularly relevant to the PTS issue and the above characteristics. These are:

1. Secondary pressure control (because a rapid drop in pressure can cause a rapid cooling in the primary system).

   Relevant Beaver Valley equipment related to potential loss of this function: steam lines [breaks], main steam isolation valves (MSIVs) and associated non-return valves, turbine throttle and governor valves[2], steam dump valves to condensers (18 total - 9 per each of 2 bypass lines at Beaver Valley), atmospheric dump valves (one per steam generator (SG) at Beaver Valley), 15 secondary steam relief valves (SSRVs) (5 per SG at Beaver Valley), and the single residual heat release valve common to all 3 SGs at Beaver Valley [potential openings of one or more].

2. Steam generator feed control (because over-feeding can contribute to enhanced cooling of the primary system).

   Relevant Beaver Valley equipment related to potential loss of this function: main feedwater (MFW)/ condensate and auxiliary feedwater (AFW) systems. [sources of over-feed].

3. Primary system injection and flow control (because injection can add a cooling effect to the primary system and provides the “cold” water at the downcomer of the RPV, and also can maintain or increase primary system pressure to a relatively high value; the flow characteristics can exacerbate/mitigate flow stagnation).

   Relevant Beaver Valley equipment related to potential loss of this primary system control function: reactor coolant pumps (RCPs) [status dictates forced or natural flow conditions in the RCS], high head safety injection (HHSI)/charging pumps and letdown, and potentially the accumulators as well as low head safety injection (LHSI) [injection sources].

4. Primary system pressure control (beyond that mentioned in “3.” above; failures of primary system integrity are of interest because they can cause a cooling effect in the primary system and depending on the size of the failure, may maintain high primary system pressure depending on injection control).

[2] Status of turbine throttle and governor valves not modeled because of probability considerations (two valves in series must fail to close, plus operator must fail to trip lift oil pump).

2. Relevant Beaver Valley Features

Relevant Beaver Valley equipment related to the potential loss of this function: RCS piping [breaks], power-operated relief valves (PORVs - three at Beaver Valley) and associated block valves [potential opening and reclosing/isolating], three pressurizer safety relief valves (SRVs) [potential opening and reclosing], and pressurizer sprays and heaters (although these were later found to have lesser effects and so were not explicitly modeled) [potential cooling/depressurization and heating/repressurization].

5. Other potentially relevant Beaver Valley equipment, because of the interactions with the above equipment, include:

- actuation and protection circuitry associated with the above equipment
- MFW isolation circuitry
- AFW actuation and control circuitry
- support systems including cooling water, instrument air, and electric power and instrumentation[3]

It is important to note that support systems were only superficially treated in much of the early PTS analyses. Such superficial treatment of support systems may have two effects of concern:

- Early work may have missed some initiators that can make the operator response more complex and potentially induce new human failure events (HFEs) or higher likelihoods of analyzed HFEs, and

- the frequencies of the scenarios in the early work may be optimistic by not explicitly accounting for support system failure contributions to the relevant equipment failures both individually as well as accounting for common dependency effects (i.e., acting like common cause).

It should be noted that the original PTS work for the H. B. Robinson plant [NUREG/CR-4183], examined support system effects more rigorously and included their failures subsequent to other initiators and found one support system initiator involving three additional PTS scenarios of concern. Based on the above arguments and the potential importance of some support system effects, support systems were treated much more extensively in this Beaver Valley analysis.

[3] It is assumed that HVAC is not particularly important due to its relatively slow effects on PTS-relevant equipment.

3. INITIATING EVENTS

One of the first tasks associated with the Beaver Valley PTS PRA was the identification of those challenging events (i.e., initiating events) that perturb the normal status of the plant thereby causing an abnormal event such as a transient or loss of coolant accident (LOCA) that subsequently triggers possible sequences of events (called "sequences" or "scenarios"), some of which could result in a PTS challenge. For the identified initiating events, the expected number of occurrences per year (i.e., frequency) of each was also determined since this is a necessary aspect of determining the expected frequency of each PTS challenging scenario.

3.1 Identification Process

The process used to identify initiating events for the Beaver Valley PTS analysis did not start anew but instead made vast use of already existing analyses. In this way, much of the already performed evaluations of possible initiators including losses of support systems, examination of actual Beaver Valley initiating events, interviews with plant personnel, etc. did not have to be performed extensively since much of this type of detail is already included within the existing analyses that were reviewed. Thus the approach to identify initiators primarily involved the following:

- Review of the initial Oconee [NUREG/CR-3770]and H. B. Robinson [NUREG/CR-4183] PTS analyses as well as the recent Westinghouse Owners Group study using Beaver Valley 1 [WCAP-15156] as the illustrative plant, for relevant Beaver Valley-specific initiators addressed in those studies that could either directly cause loss of one or more of the four functions (e.g., LOCA) or challenge normal operation such that subsequent plant responses could cause an overcooling transient of potential concern (e.g., reactor trip followed by a demanded and then stuck-open steam dump valve).

- Review of actual overcooling events and the associated initiators.

- Review of material from the Beaver Valley PRA [Beaver Valley IPE] focusing on initiators in that study and particularly those that may be relevant to PTS as opposed to core damage, including support system initiators.

- Brainstorming of possible initiators that could cause loss of one or more of the four functions discussed previously including consideration of the above sources and analysis of the effects of each initiator.

NUREG/CR-3770 examines nine classes of initiating events deemed to be relevant (all assuming nominal power level of >45%) because they are judged to sufficiently challenge the functions discussed above. As a point of comparison, the H. B. Robinson PTS report [NUREG/CR-4183] considers many potential relevant initiators and documents 11 relevant initiators. The more recent Beaver Valley study [WCAP-15156] arrived at a similar list of initiators as the other studies and also addressed different decay heat levels. Table 3.1 provides the comparison between the initiators considered in the original Oconee and H.B. Robinson PTS studies as well as in the more recent Beaver Valley study.

Note that the H.B. Robinson analysis specifically reviewed and ruled out events involving:

3. Initiating Events

Table 3.1. Initiator comparisons for PTS.

NUREG/CR-3770 Oconee PTS	NUREG/CR-4183 H.B.Robinson PTS	WCAP-15156(a) WOG Pilot Plant Application (Beaver Valley-1) of EPRI Alternative Method for PTS
1. Reactor/Turbine Trip understood to encompass typical, uncomplicated trips (e.g., turbine trip and inadvertent scram)	1. Reactor/Turbine Trip understood to encompass typical, uncomplicated trips (e.g., turbine trip and inadvertent scram). Did also treat a few scenarios involving loss of service water because of unique effects.	1. A general "Transient" category including the frequencies of such events as reactor/turbine trips, excessive main feed, core power increase, closure of one MSIV, loss of offsite power, etc.
2. Excessive MFW event	Excessive MFW screened out	Excessive MFW event frequency included in 1. above
3. Large Steam Line Break sufficient to depressurize the affected steam generator (SG) to below the EFW actuation setpoint of 725 psi	2. Large Steam Line Break at full power 3. Large Steam Line Break at hot 0% power	2. Steamline Rupture inside containment accounting for the frequencies of various sizes 3. Steamline Rupture outside containment accounting for the frequencies of various sizes
4. Small Steam Line Break that is insufficient to depressurize the affected SG to below the EFW actuation setpoint of 725 psi	4. Small Steam Line Break at full power 5. Small Steam Line Break at hot 0% power	See 2. & 3. above to "capture" smaller ruptures
5. Loss of MFW event	6. Loss of MFW event	4. Loss of MFW event
6. Small Break LOCA-1 that is large enough to depressurize the primary system to below the HPI setpoint (1500 psi) but small enough that the primary system can repressurize using HPI to the PORV/SRV setpoints (>2450 psi)	7. Small Break LOCA at full power for which HPI can repressurize the primary system to its shutoff head and includes, for instance, single PORV/SRV openings and reactor coolant pump seal failures 8. Small Break LOCA- hot 0% power	5. Small Break LOCA <1.5 in. diameter
7. Small Break LOCA-2 that is just like small LOCA-1 except it is large enough that the system cannot repressurize using HPI	9. Medium Break LOCA at full power for which HPI cannot keep up and a gradual pressure decrease occurs 10. Medium Break LOCA at hot 0% power	6. Medium Break LOCA 1.5-6.0 in. diameter
Large Break not analyzed	Large Break not analyzed	7. Large Break LOCA >6.0 in. diameter
8. Inadvertent Safety Injection (SI)	SI screened out	SI frequency included in 1. above
9. Steam Generator Tube Rupture (SGTR)	11. Steam Generator Tube Rupture (SGTR)	8. Steam Generator Tube Rupture (SGTR)

(a) All events analyzed with consideration of decay heat during event >1%, <0.5%, & in between 0.5-1%

- inadvertent SI or events with similar effects (e.g., loss of heat source to regenerative heat exchanger)
- excessive MFW as an initiator or events with similar effects (e.g., loss of feedwater heaters, initiation of auxiliary feedwater as an initiator)
- spurious pressurizer spray actuation.

These events were judged to be insufficient challenges for PTS concerns in the H. B. Robinson study.

Furthermore, a review was performed of possible support system failures that may contribute to other initiator scenarios or might, by themselves, be initiators that ought to be considered. This review examined:

- loss of component cooling water
- loss of service water
- loss of instrument air
- loss of certain electrical buses

Based on being able to bound the effects of these losses into the above eleven categories as well as using low frequency arguments, the H. B. Robinson study ruled out support system faults as initiators except for a loss of service water that leads to loss of air that leads to loss of MFW. Three new sequences related to the loss of service water initiator were therefore, also analyzed.

The more recent Beaver Valley analysis [WCAP-15156] treats the same initiators but with a more broadly defined “transient” category to include events such as excessive MFW and inadvertent SI. That analysis did not, however, specifically analyze support system initiators.

While the three studies came to similar conclusions about the initiators that needed to be examined, noted discrepancies include:

- whether or not excessive feedwater should be explicitly considered,
- whether or not inadvertent SI should be explicitly considered, and
- the fact that perhaps some low decay heat events (e.g., hot 0% secondary and primary system LOCAs) also need to be considered.

Noteworthy in the studies is the lack of external event considerations (these were not analyzed in the studies). These could be of particular concern because of the additional context and complexity affecting the responses to such events. Of these (e.g., seismic, fire, internal flood, external flood, high winds/tornado, transportation accidents), it would seem that fire and internal flooding (though perhaps also seismic) may be of particular interest due to:

- their relative frequencies and potential to fail equipment (especially electrical) that may cause PTS-relevant failures of control circuitry, MFW, steam dump valves, etc.
- the concern about hot shorts caused by fire that may also cause PTS-relevant failures.

3. Initiating Events

External events were treated in the updated Beaver Valley PTS analysis but in a more bounding way than the traditional PRA event tree modeling treatment. The bounding external event approach is discussed in [Kolaczkowski 04a]. Hence, this initiating event analysis and the subsequent scenario modeling discussed later in this report only address the internal initiators modeled in the updated Beaver Valley PTS study.

Overcooling events or their potential do occur from time-to-time in the industry, so there is a limited experience base associated with such events [INEEL LER Review]. Review of LERs associated with such events demonstrates that this experience base largely consists of failures to properly control or throttle feed, actual or potential loss of portions of secondary pressure control, as well as other causes but all leading to relatively minor over-cooling situations. Examples include:

- manually overfeeding in an attempt to compensate for a loss of a single MFW pump
- discovered potential failure of some main steam safety relief valves (MSSRVs) to close (did not actually occur)
- equipment failure of a steam dump valve thus holding it open
- discovered potential failure of a MFW isolation valve to be able to close (did not actually occur)
- failure associated with a feedwater control valve controller (manual control room control of the valve was used to close the valve)
- discovered inability to close MSIVs because of disconnected DC power (MSIVs were not actually demanded) during a startup
- loss of control of feedwater control valves during a test at 15% power due to test staff error, a MSSRV not completely closing during a complicated transient which was remedied by the operators decreasing pressure to reseat the valve
- MFW overfeeding due to an excessive manual bias in the feedwater controllers and a subsequent overfeeding of emergency feedwater due to a DC bus fault (all controlled rather quickly by operator action)
- failure of a steam dump valve being used during startup to close upon an upset
- a feedwater demand controller failure which resulted in actual MFW overfeed
- steam generator tube rupture (SGTR) events.

The above suggest that such events as reactor trips complicated by additional failures such as circuitry failures, valve failures (e.g., MSSRVs, steam dump valves, etc. failing to close on demand), feedwater anomalies involving overfeeds or losses of feedwater or failure of associated equipment, and SGTRs should be among those initiators considered for modeling in the Beaver Valley PTS analysis.

Considering the above comparisons and actual events, a few representative and broad categories of initiating events were examined more closely to determine the potential Beaver Valley-specific effects of such events both from a scenario perspective as well as considering potential challenges to the operating crew. This additional information was used to further aid in the final decision as to the initiators to model in the Beaver Valley PTS analysis. Table 3.2 documents this examination.

Given all the information supplied above, and consideration of the Beaver Valley PRA initiators as well as expert judgment, Table 3.3 provides a summary of the considerations used to decide which of the identified candidate initiators would be modeled in the Beaver Valley PTS study. These considerations include thermal-hydraulic effects, frequency, and any particularly challenging operator response effects. Insights into the eventual grouping of initiators are also provided.

3.2 Initiators Modeled in the Beaver Valley PTS Study

Based on the above process, Table 3.4 provides the list of internal initiating events that were modeled in the Beaver Valley PTS study.

3.3 Initiators for Hot Zero Power Conditions

The above initiating event list was specifically generated with “at nominal power” conditions in mind. At hot zero power conditions, the thermal hydraulic response of the plant will generally be worse (i.e., more severe cooling) because of the lack of substantial fission product heat that exists immediately after a trip from nominal power conditions. Further, the early PTS studies support the modeling of overcooling events at hot zero power conditions because of the different plant thermal-hydraulic responses.

After review of recent Beaver Valley experience and discussion with the Beaver Valley staff about the uniqueness (or lack thereof) of hot zero power conditions from an initiator and plant/operator response perspective, it was decided that all of the above initiators would also be modeled for when the plant is at hot zero power conditions when the initiator occurs (i.e., no significant difference was found between full power and hot zero power types of initiators). However, to properly account for the average time per year that the Beaver Valley plant is in this condition, frequency adjustments had to be made to account for this fraction of time as well as other effects on the likelihood of each initiator. This is discussed later in section 3.5 concerning the initiating event frequency assignments.

3.4 Other Initiator/Scenario Types Considered But Not Modeled

Two general and noteworthy types of scenarios commonly modeled in PRAs were not included in the Beaver Valley PTS analysis; anticipated transients without scram (ATWS) scenarios and interfacing system LOCA (ISLOCA) scenarios. Sequences resulting from such scenarios were not included based on the following considerations. First, ATWS events generally initially begin as a severe under-cooling event (i.e., there is too much power for the heat removal capability) and would likely involve other failures to achieve an overcooling situation even if it were possible to do so. While ISLOCAs, like the LOCAs modeled in the Beaver Valley PTS study, could involve overcooling from the start of the event, significant ISLOCAs are often assumed to fail mitigating equipment in PRAs which ultimately causes an under-cooling event and core damage. Second, with typical ATWS and sizeable (not just small leaks)

Table 3.2. Representative initiators and their potential effects.

Representative Initiators of Interest	Potential Effects
Reactor Trip & other complexities (e.g., involving support system failure)	Significant challenges to operator performance would not seem to exist until multiple failures or unexpected events occur along with the trip. To the extent these additional complexities involve just one function (i.e., primary integrity, secondary feed, secondary pressure, primary flow/pressure), current operator experiences and training would suggest that such events are not extremely different from operator "expectations." However, as the number of individual equipment response problems increases or as multiples of the four functions become troubled, the scenario takes on characteristics farther beyond operator experience and training (although it is acknowledged that training does sometimes include multiple function problems), thereby creating a larger mismatch between the event and operator "expectations" and thus increasing the chances of human error. Ways to cause these multiple failures include both multiple independent equipment faults (e.g., PORV demanded and stuck-open along with a stuck-open steam dump valve), as well as common support system or similar common faults affecting multiple equipment (e.g., station air failure, bus failures, loss of power, loss of cooling water to RCPs causing the need to shutdown RCPs, and fire). Timing of the faults can also worsen the nature of the challenge. For instance, it appears use of the emergency operating procedures (EOPs) is very methodical and can take time to get through E-0 especially if hardware problems occur [Beaver Valley visit]. Except for 6 specific pre-emptive actions, the status trees are not acted upon until E-0 has been nearly completed or during EOP transitions. This can delay the response to problematic function status, possibly allowing the plant condition to worsen before it is acted upon and mitigated. Also, based on observed simulator scenarios, it is noted that termination of SI is a very deliberate process and generally requires numerous other parameter conditions to stabilize and it is not called for until many steps of the EOP(s) have been performed [Beaver Valley visit]. Additionally, there does not appear to be a particular concern about letting the RCS repressurize before SI is finally terminated. The net result is a reasonable likelihood that the RCS will be allowed to repressurize (and even have the pressurizer go water solid) before SI is brought under control. These and other observations (e.g., reluctance to restart RCPs) should be considered in evaluating scenarios of concern and the associated human error probabilities. The general observation seems to be that PTS, while a concern, takes a "back-seat" to other issues (good heat sink, etc.) and operator response (and the timing thereof) is not necessarily focused on taking rapid actions to deal with PTS except for those applicable to over-cooling among the 6 pre-emptive actions.

Table 3.2. Representative initiators and their potential effects.

Representative Initiators of Interest	Potential Effects
Loss of cooling water	Loss of both river water headers seems of most interest for Beaver Valley because it causes loss of cooling to RCPs and the HHSI pumps among other effects [Beaver Valley IPE]. This is probably a rare event as the auxiliary raw water supply and the DG-firewater supply must also fail (however, common failure of all the supplies could be header valve problems). Therefore, such a failure is probably unexpected and if lost over time, could be even more challenging as actions are carried out to restore the supply and/or cope with the effects. There is thus a need to shutdown the RCPs (hence natural circulation and possible flow stagnation pending other faults) and operators would seemingly most likely shutdown the HHSI pumps except under very serious circumstances. Thus, a RCP seal LOCA with loss of injection is possible. Recovery of cooling water (or otherwise HHSI) might induce some vessel wall cooling as SI is used to recover inventory losses, etc. As is noted above, the tendency to also allow RCS pressurization seems to exist. By itself, such an event does not seem to have serious cooldown effects. However, if conditions worsened such that there was required entry into the Inadequate Core Cooling EOP, operator-induced cooldown of the plant is called for [Beaver Valley visit], so then considerable cooling may occur. For this reason, as well as having to consider possible other simultaneous hardware faults, this event still seems worthy of review as a possible PTS concern.
Loss of air	On loss of station air, besides some distraction paid to restoring air and other effects, RCS normal letdown closes down and seal injection increases causing pressurizer level and potentially RCS pressure to rise (although use of an alternate letdown and control of seal injection is called for), MFW control valves fail closed thus isolating MFW, MSIVs fail closed, steam dump valves fail closed, atmospheric dump valves (ADVs) and the residual heat removal (RHR) Heat Release Valve fail closed, and if the inboard component cooling water (CCW) air valve diaphragm leaks, it too will close (otherwise it will remain open) causing loss of cooling to the RCPs and therefore require shutdown of the RCPs. Local manual action of the ADVs or RHR Ht Release Valve is called for to control SG pressures although as a practical matter, the operators will likely “ride” the main steam safety relief valves (MSSRVs). Additionally, the TDP-AFW (turbine-driven) steam valves fail open which along with the rest of AFW or failure of MFW to isolate, could cause an overfeed if not properly paid attention to and controlled [Beaver Valley visit] [10M-53C.4.1.34.1]. Many of these effects potentially can cause or exacerbate a cooldown event (probable riding of the MSSRVs increasing the likelihood of one or more sticking open, potential loss of forced flow in the RCS, etc.). Note that loss of just containment air will also cause loss of cooling to the RCPs (therefore they need to be shutdown) and fail close the PORV paths and pressurizer spray valves making it somewhat more difficult to maintain RCS pressure control [10M-53C.4.1.34.2]. Thus loss of air, and in particular loss of station air, is of interest from the PTS point of view for its possible exacerbation of cooldown effects as well as the added difficulties and attention diversions caused by such an event.

Table 3.2. Representative initiators and their potential effects.

Representative Initiators of Interest	Potential Effects
Excessive MFW flow (or excessive feedwater cooling); especially at hot 0% power	Transitions at very low power conditions during startup or shutdown represent a time when multiple testing, unusual system configurations, changing system demands, etc. are typical and hence plant upsets are more likely. For example, at about 20% power the transition from steam pressure control of the plant to Tavg control of the plant occurs. These conditions provide unique chances for operator error (or delayed response) in dealing with upsets or hardware problems during these times. Particularly if plant conditions are being largely controlled by operator manual intervention, auto feature defenses may not be present or as redundant; hence any potential PTS-inducing upset may require human identification and control. Excessive MFW is a typical example of such upsets that would be of particular concern for PTS.
Steam line breaks (large to small; at power and at hot 0% power)	These are unexpected events (so little to no actual experience) and yet some training is periodically performed on such events thereby providing some familiarity [Beaver Valley visit]. By themselves, and with no additional complexities, human responses would seem to be relatively straightforward and the nature of the event is easy to identify (faulted SG). However, like the reactor trip discussion above, should additional failures occur especially if they cause problems in controlling other of the four functions (e.g., feed control valve fails to close), then the operators' ability to control the potential PTS condition can be more difficult and may even make for delayed or inappropriate action. Any plant condition that causes multiple steam lines to be affected (e.g., failure of turbine trip, multiple line faults) could be particularly troublesome with regard to isolating/restoring the correct steam path especially with an apparent bias toward ensuring sufficient heat sink (although if downstream of MSIVs, they should isolate the break(s)). Timely isolation of feed to the affected SG is key to the thermal transient caused by such events although because of the size of the SGs and their inventory, it seems the failures must be upstream of the MSIVs or multiple in nature to cause a serious and rapid cooldown (except, perhaps, at low power). Also note that a rapid cooling event could at first look like a RCS LOCA and perhaps increase the chance of incorrectly shutting down a RCP although if procedure criteria are strictly followed, this shouldn't happen.
Small LOCA (primary)	This is also an unexpected or infrequent event (e.g., stuck -open PORV) and yet some training is periodically performed resulting in some operator familiarity [Beaver Valley visit]. Like the steam line break and reactor trip cases above, with no additional complexities, human responses would seem to be relatively straightforward and the nature of the event is easy to identify although there may be an even stronger tendency to not terminate injection until pressurizer level and subcooling are comfortably high (thereby further increasing pressure). However, like the reactor trip discussion above, should additional failures occur especially if they cause problems in controlling other of the four functions (e.g., MSSRV sticks open), then the operator's ability to control the potential PTS condition can be more difficult and may even make for delayed or inappropriate action.

Table 3.2. Representative initiators and their potential effects.

Representative Initiators of Interest	Potential Effects
Loss of MFW (especially with additional loss of AFWS)	Besides the possibility of increased chance of PORV operation and sticking-open thus causing complexity for the operator and some cooldown, a loss of heat sink (LOHS) event calls for an operator-induced cooldown as directed by procedures to try and use condensate for SG feed [Beaver Valley visit]. Therefore, the operator will likely depressurize the SGs (if condensate is deemed available) which will cause some cooldown. If this is unsuccessful, feed and bleed via opening all three PORVs is then directed by procedures which can further exacerbate the cooling of the vessel wall by SI injection.
SGTR	Per EOP-3, the operator will be directed to cooldown the plant to depressurize the system and lessen or stop the leak of RCS inventory into the secondary side of the plant [Beaver Valley visit]. Cooldown is not restricted to technical specifications although should still be done in a controlled manner. Cooldown is performed by dumping steam to the condenser with further cooling called for via the pressurizer sprays and even the PORVs. As a directed cooldown event, this initiator should be looked at, but if properly controlled, the cooling should be manageable without other faults/failures.

Table 3.3. Considerations for including or excluding initiating events.

Initiator	TH Considerations	Frequency Considerations	HRA Considerations	Comments
Simple Reactor Trip (including subsequent stuck-open valves, etc.) [i.e., broad "transient" category]	Depending on subsequent failures, over-cooling may be possible.	Of the order of 1/yr but must have additional equipt/operator failures that cause one or more of following: - secondary depressurization - secondary overfeed - primary leak (e.g., PORV or SRV open) - primary overfeed/ pressurization. Rule out subsequent break as too improbable.	Numerous depending on failures.	With the high frequency, this ought to be modeled as its own initiator including being a catch-all for all initiators co-involving complexities such as valve openings, etc.

Table 3.3. Considerations for including or excluding initiating events.

Initiator	TH Considerations	Frequency Considerations	HRA Considerations	Comments
Loss of cooling/service water (i.e., both river water headers for Beaver Valley which in turn fails Primary Component Cooling Water to RCPs and cooling to HHSI per Beaver Valley IPE[5])	Tendency is for running equipment to fail over time which more likely causes underfeed/no flow; therefore does not tend towards possible PTS. However, the likely need to shutdown RCPs due to heatup could add to stagnation potential.	Probably in the E-3/yr range for initiator which tends to make it less important from a frequency contribution perspective.	More complex event than reactor trip. Operators have other diversions or concerns for heatup & failing of equipment. When RCP heatup occurs due to loss of Pri. Component Cooling Water, operators will likely shutdown the RCPs. Loss of river water is also loss of cooling to HHSI so RCP seal LOCA and no injection possible.	Though a low frequency event, this initiator could increase workload and add to confusion. Will likely need to shutdown RCPs due to heatup which enhances stagnation potential. Loss of cooling could cause RCP seal failure but this is a small PTS challenge for any reasonable size LOCA. Seems should treat loss of cooling separately due to possible unique effects and more challenging event for operators.
Loss of air (particularly station instrument air (IA) system at Beaver Valley)	Possible PTS tendency/concerns (TDP-AFW steam supply opens, RCPs may need to be stopped because of potential loss of CCW, demands on SSRVs)	Probably in the E-2/yr - E-3/yr range so not so low as to be easily dismissed. Other failures may not be necessary to be of concern for PTS.	More complex event than reactor trip. Operators have other diversions or concerns dealing with recovering air.	Beaver Valley IPE report indicates loss of air will isolate MFW and MSIVs, and close steam dumps which will put more demands on SSRVs which could stick open. TDP-AFW steam supply fails open. AFW and possible stuck-open SSRVs, and possible shutdown of RCPs, provides a tendency for PTS.

Table 3.3. Considerations for including or excluding initiating events.

Initiator	TH Considerations	Frequency Considerations	HRA Considerations	Comments
Loss of Electrical Bus(es)/Power	Tendency is for equipment to fail which more likely causes underfeed/no flow; therefore does not tend towards possible PTS.	Probably in the E-2 to E-3/yr range for initiator (bus loss) which tends to make it less important though some are included in the PRA. Loss of offsite power (LOSP) is in the 0.01/yr - 0.1/yr range.	More complex event than reactor trip. Operators have other diversions or concerns getting power restored which could delay any overcooling responses.	Loss of power and its subsequent effects could be unique depending on the specific loss. Frequency, especially for loss of offsite power is not so low so that modeling seems worthwhile. Will use IPE as guide for what to model.
Excessive MFW	This event, by itself, would seem to present a relatively minor PTS challenge but may be more serious at hot 0% power condition.	Seems it would take controller or operator failure, or similar. MFW pumps may tend to trip on low suction pressure and should trip on hi SG level. It is believed the level must exceed this hi level before being a PTS concern so would need additional failures of this trip.	Seems operator might be able to manually control if condition identified before any significant effect.	While seemingly unlikely to be a serious PTS challenge without other failures, it was decided to capture the unique nature of this event by handling as a form of the reactor trip initiator using actual industry experience and subsequent event tree modeling to address this type of co-existing failure with the trip.
Large steam line break (suggest this be pipe breaks only; stuck-open valves covered under reactor trip)	Potentially serious overcooling may exist before operator can respond.	In the E-3/yr range but considering the TH comment, probably still important. Likely to also cause auto AFW which further worsens cooling.	Operator isolation of the break (if possible) and isolation of feed to the affected SG can be critical as to the seriousness of the event.	Potential fast overcooling and requirement for isolation make this an initiator to be modeled.

Table 3.3. Considerations for including or excluding initiating events.

Initiator	TH Considerations	Frequency Considerations	HRA Considerations	Comments
Small steam line break (suggest this be pipe breaks only; stuck-open valves covered under reactor trip)	Less cooling effect than large.	In the E-2/yr range.	See above. Also, it may be harder to distinguish between unaffected and affected S/G for very small breaks - thereby possibly causing some delay in isolation.	See above. The potential differences in rate/degree of overcooling and timing for operator actions suggest this be its own category of initiator, separate from the large breaks.
Loss of MFW	By itself does not tend toward PTS (is an underfeed). But need to consider other failures such as lack of control of AFW or condensate feed.	In the E-1/yr range or less. Could cause demand on PORV (which could stick-open) pending AFW response.	Could involve controlling AFW or condensate especially in loss of both MFW and AFW. Feed and bleed could be ultimately necessary (with its cooldown effect).	The depressurization and use of condensate, or use of feed & bleed concerns with loss of AFW, could make this an event with unique PTS possibilities.
Small LOCA-1 (repressuriza-tion possible with high pressure injection)	Primary system cooling occurs, with stagnation and possible repressurization.	In the E-3/yr range.	Operator will likely shutdown RCPs. Possible tendency to over feed primary and perhaps repressurize.	Directly causes some overcooling and should be modeled.
Small LOCA-2 (medium/large LOCA - too large for repressurization with injection)	See above, but the repressurization cannot occur except at somewhat lower pressure (e.g., near accumulator dump pressure).	Lower than the above Small LOCA-1 case.	See above but cannot maintain any high repressurization.	As the size differences may matter as to the overcooling rate, and depending on the RCS pressure, different challenges to PTS may exist. LOCAs, as initiators, will need to be modeled into at least a few representative size ranges.

Table 3.3. Considerations for including or excluding initiating events.

Initiator	TH Considerations	Frequency Considerations	HRA Considerations	Comments
SGTR	By itself, does not seem to present much of a PTS challenge as long as the number and size of tube failures are small. May need other failures. Preliminary TH results show minor cooling.	In the E-2/yr range or a little less. If need other failures, frequency is lower yet.	Seems strong operator tendency to isolate affected SG and/or keep RCS pressure low per EOPs (so less of a PTS concern)	Unlikely to be a serious PTS challenge based on preliminary TH runs and Oconee analysis results. Hence it was decided to not address this event further, primarily due to the minor cooling involved given the "small break" size.
Inadvertent SI	By itself, does not seem to present much of a PTS challenge. Requires other failures. Some TH results show cooling effects should not be significant.	Probably in the E-1 to E-2/yr range. If requires other failures, frequency is lower yet.	Seems operator would likely be able to manually control if condition identified before any significant effect.	Preliminary TH shows low overcooling effects. Does not seem worthy of modeling.

Table 3.4. Beaver Valley PTS study initiators.

Modeling Designator	Description
LLOCA	Large LOCA ~6" or greater equivalent diameter
LOAC	Loss of 120 VAC instrument bus (red, white, blue, yellow buses)
LOCAIR	Loss of containment air
LODC	Loss of 125 VDC bus (orange, purple buses)
LOIA	Loss of instrument (station) air
LOMC	Loss of main condenser
LOMF	Loss of main feedwater
LOR-RW	Loss of river/raw water
LOSP	Loss of offsite power (including possible station blackout)
LPCCW	Loss of plant/primary (component) cooling water
LTPCCW	Loss of turbine plant component cooling water

Table 3.4. Beaver Valley PTS study initiators.

Modeling Designator	Description
MLOCA	Medium LOCA ~2.8" - 6" equivalent diameter
RT1	Reactor trip with turbine trip
SLB1	Steam line break (small) ~8" or less equivalent diameter
SLB2	Steam line break (large) - treated as main steam line guillotine rupture
SLOCA	Small LOCA ~1.4" - 2.8" equivalent diameter

ISLOCA frequency estimates in the E-5/yr to E-6/yr or even lower range, and with the need for other failures to occur to possibly cause a continuing and serious overcooling situation, sequences involving ATWS or ISLOCAs should not be significant contributors to PTS risk when compared to other modeled scenarios with initiator frequencies commonly in the 1/yr to E-3/yr range and since other LOCAs are already modeled in the PTS study.

3.5 Initiating Event Frequencies

3.5.1 Initiators Except LOCAs

A goal of the PTS work was to provide analyses that, to the extent possible, considered the design differences among the various PWRs studied but could be generically applied to all PWRs within the U.S. To accomplish this, it was decided that the modeling of the potential PTS scenarios for each study would consider specific plant design and operational features but that the data used to quantify basic events in each model (e.g., initiator frequencies) would be based primarily on actual industry-wide experience (i.e., not plant specific). As such, no PTS study is a specific assessment of the PTS risk for the particular plant being analyzed; but instead is a more generic assessment of PTS risk but considering PWRs with similar design and operational features as the plant being studied.

Hence, the initiator frequencies used in the Beaver Valley PTS study are based on actual industry-wide PWR experience. Summaries of the experience from 1987 thru 1998 and the detailed qualitative and statistical analyses of that experience is documented in two reports [NUREG/CR-5750, NUREG/CR-5750-Addendum]. The more up-to-date of these reports [NUREG/CR-5750-Addendum] was used as the source of initiator frequencies for the Beaver Valley PTS study. The reader is referred to these two reports for more information.

Table 3.5 summarizes the frequencies used in the Beaver Valley PTS study based on the above information. The far right column of the table provides a reference to the table within the NUREG/CR-5750-Addendum for each frequency. Examination of the table in the Addendum for each initiator type confirms the initiator frequency values used here.

Table 3.5. Beaver Valley PTS study initiator frequencies (excluding LOCAs).

Modeling Designator	Description	Nominal Power Frequency (per critical year)	Multiplier to Convert to Hot Zero Power Frequency	Data Source for Nominal Power Frequency
LOAC	Loss of 120 VAC instrument bus (red, white, blue, yellow buses)	6.3E-3 (plant-wide for all similar buses)	0.02	NUREG/CR-5750-Addendum, Table D-11
LOCAIR	Loss of containment air	4.6E-3	0.02	NUREG/CR-5750-Addendum, Table D-11
LODC	Loss of 125 VDC bus (orange, purple buses)	1.5E-3 (plant-wide for all similar buses)	0.02	NUREG/CR-5750-Addendum, Table D-11
LOIA	Loss of instrument (station) air	4.6E-3	0.02	NUREG/CR-5750-Addendum, Table D-11
LOMC	Loss of main condenser	6.7E-2	0.02	NUREG/CR-5750-Addendum, Table D-11
LOMF	Loss of main feedwater	6.8E-2	0.2	NUREG/CR-5750-Addendum, Table D-11
LOR-RW	Loss of river/raw water	2.1E-3	0.02	NUREG/CR-5750-Addendum, Table D-11
LOSP	Loss of offsite power (including possible station blackout)	3.8E-2	0.02	NUREG/CR-5750-Addendum, Table D-11
LPCCW	Loss of plant/primary (component) cooling water	2.1E-3	0.02	NUREG/CR-5750-Addendum, Table D-11
LTPCCW	Loss of turbine plant component cooling water	2.1E-3	0.02	NUREG/CR-5750-Addendum, Table D-11
RT1	Reactor trip with turbine trip	0.84	0.2	NUREG/CR-5750-Addendum, Table D-12
SLB1	Steam line break (small) ~8" or less equivalent diameter	1.4E-2	0.02	See discussion above in Section 3.5.1 of this document
SLB2	Steam line break (large) - treated as main steam line guillotine rupture	2.2E-3	0.02	See discussion above in Section 3.5.1 of this document

3. Initiating Events

For the small and large main steam line breaks, a separate analysis was performed by the authors of the Addendum specifically for the purpose of these PTS studies. That analysis is summarized below.

MSLB - Main Steam Line Breaks

MSLB events are segregated into two categories: 8-inch equivalent diameter or less (classified as small), and greater than 8-inch equivalent diameter (classified as large). This distinction is one of analytical convenience and provides two broad groups of breaks to account for the differences in overcooling for different size MSLBs. Although the large MSLB will be defined as anything greater than 8-inch equivalent diameter, it will be characterized as a rupture of the main steam line. The table below summarizes the MSLB events that have occurred in the U.S. PWR operating experience (1987-1998, 667 PWR critical-years).

Steam Line Break Events (U.S. industry wide, 1987-1998).

LER	**NSSS**	**Size**	**Isolated?**	**Rx-Trip**	**RCS Cooldown**
42390030	W	6"	Yes, MSIV	manual	minimal
33691012	CE	8"	Yes, MSIV	manual	minimal
45590010	W	1"	Yes, MSIV	manual	minimal
42596008	W	MFP rupture disk	Yes, MFW	auto	minimal
36889006	CE	14" w/ ADV stuck open	Yes	auto	580ºF to 522ºF
33695032	CE	8"	Yes	manual	minimal
32893001	W	<6"	Yes	manaul	minimal
31898004	CE	2"	Yes, MSIV	manual	minimal
28597003	CE	6" (est.)	Yes	manual	minimal
25587016	CE	<6"	Yes	manual	minimal
27096004	B&W	<6"	Yes	manual	579ºF to 550ºF

Based on this experience, the Small SLB frequency is estimated as (10-events/667-critical-PWR-years). The large SLB frequency is estimated as (1-event/667-critical-PWR-years). Gamma distributions accounting for the uncertainties in these estimates are used and the resulting mean values are shown in Table 3.5.

Also shown in Table 3.5 are multipliers used in the Beaver Valley PTS study for converting these frequencies to a per critical year when at hot zero power conditions. To arrive at these multipliers, Beaver Valley experience was reviewed to determine the approximate average time per year that Beaver Valley spends at hot zero power on the way up to or down from full/nominal power conditions. Recent experience shows that this is approximately 1% - 2% of the year. Hence, a 2% multiplier was used in nearly all cases to arrive at an appropriate frequency for each initiator while at hot zero power on a per critical year basis. Thus for example, the initiator frequency used in the Beaver Valley PTS study for LOIA (loss of instrument air) is 4.6E-3/yr x 0.02 = 9.2E-5/yr.

A review of transients that typically occur while at hot zero power suggests that there is no evidence that certain initiators are significantly more prone to occur at hot zero power than at full power except for inadvertent reactor/turbine trips and loss of main feedwater trips due to transient conditions that arise while purposely changing feedwater and steam conditions along with changing power and other parameters in the plant. While no statistical treatment of this observation was attempted, engineering judgment was used to suggest that these trips seem more likely than would be accounted for by simply using the 2% multiplier. A factor of ten increase in the likelihood of such trips while at hot zero power was assumed resulting in the 20% multiplier shown for those cases (RT1 and LOMF) in Table 3.5.

3.5.2 LOCA Initiators

During Beaver Valley PTS model construction and determination of preliminary results, the LOCA frequencies used in the Beaver Valley PTS study came from the same source as the other initiator frequency data [NUREG/CR-5750-Addendum]. In particular, the frequencies are provided in Table D-11 of the Addendum and are based on information in Appendix J of the Addendum and its predecessor report. Those frequencies are shown in Table 3.6 as the "original" LOCA frequencies used in the Beaver Valley PTS study.

Table 3.6. Beaver Valley PTS study LOCA initiator frequencies.

Modeling Designator	Description	Nominal Power Frequency	Multiplier to Convert to Hot Zero Power Frequency
LLOCA	Large LOCA ~6" or greater equivalent diameter	*original:* 4E-6 per calendar year (converts to 5E-6 per critical year) *revised:* 7E-6 per critical year	0.02
MLOCA	Medium LOCA ~2.8" - 6" equivalent diameter	*original:* 3E-5 per calendar year (converts to 4E-5 per critical year) *revised:* 6E-5 per critical year	0.02
LOCA	Small LOCA ~1.4" - 2.8" equivalent diameter	*original:* 3.1E-4 per critical year *revised:* 6E-4 per critical year	0.02

As the Beaver Valley study was nearing completion, a separate effort was underway at NRC to review and revise the LOCA frequencies from NUREG/CR-5750 for use particularly in work associated with 10CFR50.46 but with applicability for other risk-informed applications such as the PTS project. There was a concern that the LOCA frequencies in NUREG/CR-5750 did not account for age-related factors important to deriving the frequencies and an expert elicitation effort at NRC was conducted to account for these adjustments [Mayfield memo].

The results from that elicitation were not entirely appropriate for use in the Beaver Valley PTS study because the elicitation structure and results involved both piping and non-piping causes for the various

size breaches. To fit our specific application, we needed only the piping contribution. Since the elicitation had not been formatted in a way to decompose the two parts, it was not possible to directly discern the appropriate frequencies to use for our purposes. A discussion was held with personal associated with the elicitation effort and following affirmation of the differences between the elicitation and our PTS study needs, it was agreed that values approaching 1.5 - 2 times the original LOCA frequencies would be appropriate for the small and medium LOCAs in the PTS study. Further, the elicited value of 7E-6/yr should be used as is for the large LOCA. This agreed upon direction resulted in the revised LOCA frequencies shown in Table 3.6. These are the LOCA frequencies used in the “final results” for the Beaver Valley PTS study.

4. ACCIDENT SEQUENCE ANALYSIS

This section describes how potentially important pressurized thermal shock (PTS) accident scenarios were identified (i.e., developed) and then grouped (or binned) into thermal-hydraulic (TH) bins. The accident sequence (i.e., event tree) analysis in this study differs from a traditional Level 1 core damage analysis in that, instead of being interested in identifying scenarios that lead to core damage, the objective of the PTS analysis was to identify scenarios comprised of initiating events (IEs), equipment successes and failure, and human actions (or the lack of such) that lead to overcooling conditions where PTS may be important. Thus, for each of the IEs identified in section 3, an event tree was constructed to identify the overcooling scenarios. Once the individual overcooling scenarios were developed, TH bins were constructed by grouping scenarios with similar TH characteristics. This binning process was necessary to reduce the large number of overcooling scenarios to a manageable number of TH calculations, and ultimately, to reduce the number of FAVOR [NUREG/CR-6855 and Dickson] calculations necessary to estimate reactor vessel through-wall-crack frequency.

4.1 Event Tree Development

4.1.1 General Development

Primarily as a result of the review of past PTS analyses [NUREG/CR-3770, WCAP-15156, NUREG/CR-4183, AND NUREG/CR-4022], the event trees in this analysis are based on the status and interactions of four plant functions and their associated systems. These four functions are important to PTS for the following reasons:

- Primary integrity: The status of this function determines, at least in part, the potential RCS pressure which influences the rate of cooldown in some situations and the injection source capability as well as incoming and outgoing flow rates thus influencing the vessel downcomer temperature.

- Secondary pressure: The status of this function determines, at least in part, the pressure and temperature in the RCS since the RCS and the secondary side of the plant are thermal-hydraulically coupled in most types of scenarios. Thus, for instance, a rapid drop in secondary pressure can cause a corresponding rapid cooling of the RCS affecting both the downcomer temperature and potentially the RCS pressure depending on subsequent RCS injection flow and heat removal.

- Secondary feed: The status of this function determines, at least in part, the pressure and temperature in the RCS since the RCS and the secondary side of the plant are thermal-hydraulically coupled in most types of scenarios. Thus, for instance, an overfeeding situation can contribute to enhanced cooling of the RCS affecting both the downcomer temperature and potentially the RCS pressure depending on subsequent RCS injection flow and heat removal.

- Primary pressure/flow: The status of this combination of conditions determines, at least in part, the RCS pressure and flow conditions (forced flow or natural circulation) during the overcooling event as well as the nature of the injection that can cool the vessel wall. The flow characteristics either exacerbate or mitigate flow stagnation which can also affect the downcomer region temperature.

Figure 4.1 presents a function-level event tree depicting these four functions and subsequent general types of sequences treated in this PRA analysis.

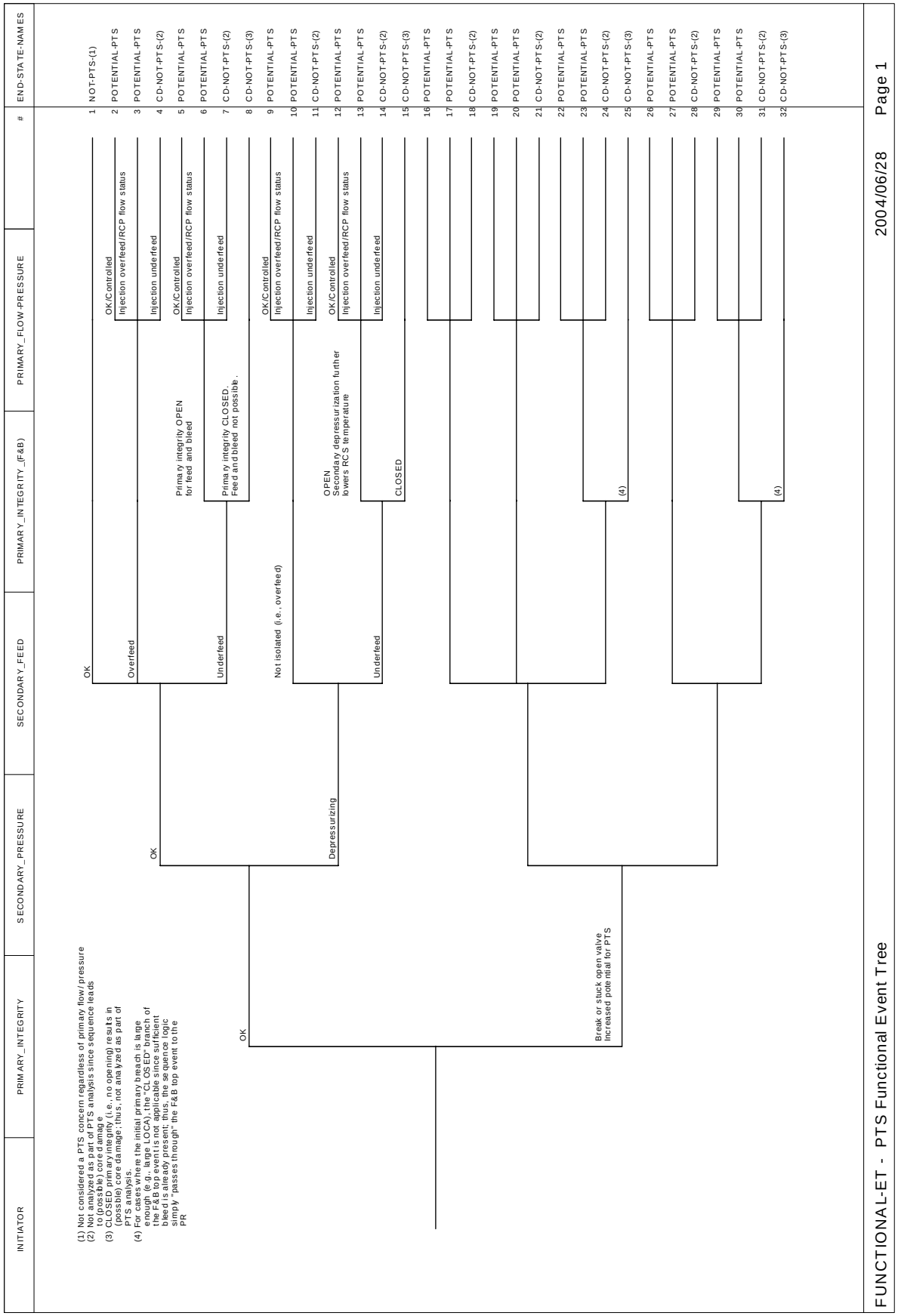

Figure 4.1. Functional event tree as the basis for PTS PRA analyses.

Development of the system-level event trees used in this analysis required the identification of the relevant Beaver Valley equipment related to the potential loss of the four functions identified in Figure 4.1. For Beaver Valley, the relevant equipment versus function is as follows:

1. Primary integrity:
   - RCS piping [different size breaks],
   - power-operated relief valve (PORV) and associated block valve [potential opening and reclosing of PORVs and isolation of block valve],
   - pressurizer safety relief valves (SRVs) [potential opening and reclosing], and
   - pressurizer sprays and heaters (although these were later found to have small effects and so were not modeled) [potential cooling/depressurization and heating/repressurization].

1. Secondary pressure:
   - steam lines [different size breaks],
   - main steam isolation valves (MSIVs) and associated nor-return valves,
   - turbine throttle and governor valves[4],
   - steam dump valves (SDVs) to condensers,
   - atmospheric dump valves (ADVs), and
   - secondary steam relief valves (SSRVs) [potential openings of one or more].

1. Secondary feed:
   - main feedwater (MFW),
   - condensate, and
   - auxiliary feedwater (AFW) system.

1. Primary flow/pressure:
   - reactor coolant pumps (RCPs) [status dictates forced or natural flow conditions in the RCS],
   - high head safety injection (HHSI)/charging pumps and letdown,
   - the accumulators, and
   - low head safety injection (LHSI) pumps.

4.1.2 Model Simplification

4.1.2.1 Introduction

Experience with the Oconee PTS analysis [Kolaczkowski 04b] indicated that some simplification of the accident sequence modeling approach as applied to Beaver Valley was possible. Such simplification facilitated the completion of the Beaver Valley effort by reducing resource and schedule requirements while retaining the requisite degree of detail necessary for adequate decision-making.

In the Oconee analysis, we found that the overcooling events that had the higher through-wall crack frequencies (TWCFs) tended to be primary system breaches with significant cooldown rates. The

[4] Status of the turbine throttle and governor valves not modeled because of probability considerations (two valves in series must fail to close, plus operator must fail to trip lift oil pump).

secondary breaches tended to be lower in frequency (usually ~ 2 orders of magnitude). One factor contributing to the lower frequencies for the secondary system breaches is that secondary breaches are generally characterized by lower cooldown rates than seen for the primary breaches. This indicates that the primary breach scenarios should account for a significant percent of the total PTS risk.

A review of the Beaver Valley TH runs, and a comparison of those runs with "like" Oconee runs, shows relatively good agreement in both cooldown rates and minimum temperatures. Additionally, consideration of the two plants' databases indicate that the frequencies for similar events are comparable. Thus, one would expect a relatively similar distribution in the final partition of PTS risk between the primary and secondary systems of Beaver Valley.

For these reasons, it was concluded that prudent simplifications could be made to the model that would facilitate a more efficient treatment of the Beaver Valley PTS analysis. These simplifications are discussed below.

4.1.2.2 Lesson's Learned from the Oconee Analysis

Being the first of the four plant PTS analyses to be performed, the Oconee PTS analysis was approached largely from the standpoint of including and quantifying virtually all combinations of equipment failures and operator actions that could contribute to overcooling events. Very few shortcuts were taken to prematurely screen potentially unimportant scenarios from either a frequency or consequence (degree of cooling) perspective.

In following such an approach, considerable effort was expended on failure combinations that mattered very little to the PTS results. For instance, effort was expended in modeling the detailed combinations of main steam safety relief valves (MSSRVs) and/or turbine bypass valves (TBVs) that could be sources of secondary depressurization. This was done because stuck-open TBVs can be isolated while stuck-open MSSRVs cannot. Additionally, considerable effort was expended on modeling various ways that MFW or emergency feedwater (EFW) could overfeed the steam generators (SGs). Further, no attempts were made to eliminate modeling of event tree scenarios that were known to be of low frequency. Because these scenarios were retained, they were also quantified. The retention of these scenarios required the expenditure of resources to write, evaluate, and correct the necessary TH binning rules (if-then-else logic rules used to group "like" sequence cut sets). The complexity of the detailed logic involved and the number of event name substitutions required to make the binning work caused multiple trials and errors in the writing of those rules. In the end, it was found that virtually all of the detailed combinations of secondary side events that had been modeled and the subsequent TH binning rules that were created were unimportant to the overall results.

4.1.2.3 Beaver Valley Insights

The following general Beaver Valley insights are provided:

- The preliminary phases of the Beaver Valley modeling found that the TH responses of Beaver Valley scenarios track those of Oconee for "like" sequences (e.g., temperature and pressure as a function of time).

- Because the Beaver Valley steam generators are of the U-tube design, the operators have more time to address SG overfeed events whereas the once-through design of Oconee is more demanding in terms of required response time. This additional time should help ensure that the probabilities of operator failures are at least no higher than similar actions at Oconee.

- Beaver Valley equipment failure probabilities are similar to Oconee probabilities for “like” TH scenarios.

- Beaver Valley’s three steam generator design provides an additional set of safety relief valves to alleviate overpressure events on the secondary side. Perhaps most importantly, the Beaver Valley design incorporates highly reliable ADVs whose setpoints are lower than the MSSRVs. By comparison, Oconee has no ADVs (i.e., they are actually locked closed per the modeling) and must rely exclusively on MSSRVs for secondary pressure relief whenever the TBVs are unavailable.

- Perhaps most significantly, Beaver Valley incorporates highly reliable MSIVs that automatically isolate secondary depressurizations downstream of their location.

In addition, preliminary FAVOR results (produced in mid-February 2002) for certain TH runs provide the following more specific observations:

1. All primary loss of coolant accidents (LOCAs) greater than approximately 1.5"–2" have relatively high conditional probabilities of failure (CPFs).

2. One stuck-open pressurizer PORV with RCPs off and with full HHSI (TH Case 12) yields a zero (0) probability for CPF.

3. One stuck-open pressurizer PORV with RCPs off, with full HHSI, and the PORV isolated by the crew by 20 minutes (TH Case 13) yields downcomer temperatures well above 400F. Thus, this does not present a serious PTS challenge. Even if the PORV isolation (or self-reclosure) did not occur for well over an hour, the transient would still be relatively benign.

4. One stuck-open pressurizer SRV with RCPs off and with full HHSI (TH Case 14) yields a zero (0) probability for CPF.

5. Three stuck-open steam generator ADVs or MSSRVs with full HHSI (TH Cases 18 and 24 respectively) and with faulted SGs never isolated by either stopping feed or isolating/reclosing the valves yields CPFs less than 5E-7. This coupled with a likelihood of three stuck-open valves of ~1E-5/yr (from Beaver Valley database) and still with no credit given for operator intervention yields a very small but still conservative overall TWCF (~5E-12/yr).

6. Two stuck-open steam generator ADVs or MSSRVs with full HHSI (TH Cases 19 and 25 respectively) and faulted SGs never isolated by either stopping feed or isolating/reclosing the valves yields CPFs less than 2E-8. This coupled with the likelihood of two stuck-open valves of ~7E-5/yr (from Beaver Valley database) and still with no credit given for operator intervention yields a very small but still conservative overall TWCF (~1E-12/yr). This also implies that the

one stuck-open valve case is also benign (TH Cases 20 and 26) since the initial temperature drop in the downcomer is even less than the two valve case that already has low CPFs.

7. Combinations of one stuck-open ADV (similar to the effect of a MSSRV) with either one stuck-open PORV or one stuck-open SRV (TH Cases 22 and 23 respectively) yield CPF values of less than E-11. For one stuck-open SRV and one stuck-open MSSRV (TH Case 41), the CPF value is ~7E-9. Additionally, the likelihood of such an event is very small making this scenario too low in frequency as well.

8. Feed and bleed with all three PORVs open, RCPs off (as they should be), and full HHSI flow (TH Case 31) has a relatively high CPF value (~2E-4).

9. Two stuck-open PORVs with RCPs off and with full HPI (TH Case 33) yields a CPF value of approximately 9E-9. This coupled with the likelihood of two stuck-open PORVs at <E-3 (even accounting for contributions of bus failures that can increase the chance of stuck-open PORVs) from the Beaver Valley database and still with no credit given for operator intervention yields a very small but still conservative overall frequency (~9E-12/yr).

10. Two stuck-open pressurizer SRVs with RCPs off and with full HHSI (TH Case 34) yields a CPF of approximately 2E-5. This is high enough that such a scenario should be examined since the probability of 2 stuck-open SRVs is approximately 2E-5.

11. A steam generator tube rupture (SGTR) event with full HPI and with RCPs remaining on is a benign event (TH Case 37). (Note: The same case but with RCPS off [TH Case 50] was later found to be benign.)

12. Overfeed of one, two, or three SGs by MFW was found to be benign (TH Cases 28, 29, 30).

13. TH Cases 15, 16, 32, and 36 show that if the MSIVs close as designed, the resulting transient is very benign.

4.1.2.4 Simplifications to the Beaver Valley Model

Based on the insights and observations in the prior sections, the following model simplifications were incorporated into the Beaver Valley analysis:

1. One stuck-open PORV that either remains open or recloses does not need to be modeled (observations 2 and 3). Two stuck-open PORVs that remain open do not need to be modeled (observation 9). More than two stuck-open PORVs that either remain open or reclose does not need to be modeled because it was assumed that three stuck-open PORVs would be unlikely.

2. One stuck-open SRV that remains open does not need to be modeled (observation 4). More than two stuck-open SRVs that either remain open or reclose does not need to be modeled because it was assumed that three stuck-open PORVs would be unlikely.

3. Secondary failures downstream of the MSIVs do not need to be modeled either because of closure of the MSIVs (observation 12) or because depressurizations downstream of the MSIVs will be probabilistically unimportant (~E-8 before consideration of CPI) based on the following:

    a. the likelihood of a secondary depressurization is in the E-2/yr to E-3/yr range (see Beaver Valley data for steamline breaks and for stuck-open valves),

    b. the failure of a MSIV is approximately E-3, and

    c. the failure of the operators to stop feeding a faulted SG within a time period to prevent a serious overcooling is approximately E-3.

4. Different combinations of various numbers of stuck-open secondary valves, either by themselves or with feed continuing (essentially a simultaneous overfeed) do not need to be modeled even though these events cannot be isolated by MSIVs (observations 5 and 6).

5. Combinations of secondary valve openings and primary PORV/SRV openings or LOCAs do not need to be modeled since the single valve cases can be eliminated (observation #7), and the highest combinations involving at least two secondary valves and a PORV/SRV or LOCA will have frequencies of no more than ~7E-8/yr (Beaver Valley database) with no credit at all for operator intervention. Assuming a pessimistic value of 0.1 for the operators failing to isolate the ADVs and/or stop feed to the SG(s) results in a frequency of E-8/yr. With corresponding CPFs probably no higher than an E-3 range, the overall result should be ~E-11/yr or less, not a risk dominant concern.

6. SGTRs, by themselves, with RCPs either remaining on or stopped, do not need to be modeled (observation 11). Combinations of a SGTR event and stuck open valves (primary or secondary) do not need to be modeled (simplifications 1, 2, 3, and 4 plus observation 11).

7. Overfeed of SGs by MFW does not need to be modeled (observation 12). Overfeed of SGs by AFW does not need to be modeled (Observation 5, TH case 18 has a CPF of ~1E-8). This CPF combined with failure of operators to prevent overfeeding, an ~1E-3 value, yields an overall result of ~1E-11/yr, which should not be risk significant). (Note: Overfeed of three SGs by MFW or AFW was actually incorporated into the model to determine whether such overfeed was important.)

4.2 Event Tree Top Events

4.2.1 Power Model Top Events

With the list of relevant equipment versus function information identified in section 4.1.1 and the model simplifications identified in section 4.1.2, system-level event trees were developed for each of the initiators identified in Section 3.2. These system-level event trees, including transfer trees, are shown in Figures 4.2 through 4.89. The following sections define the top events included in the system-level event tree used to model each initiating event.

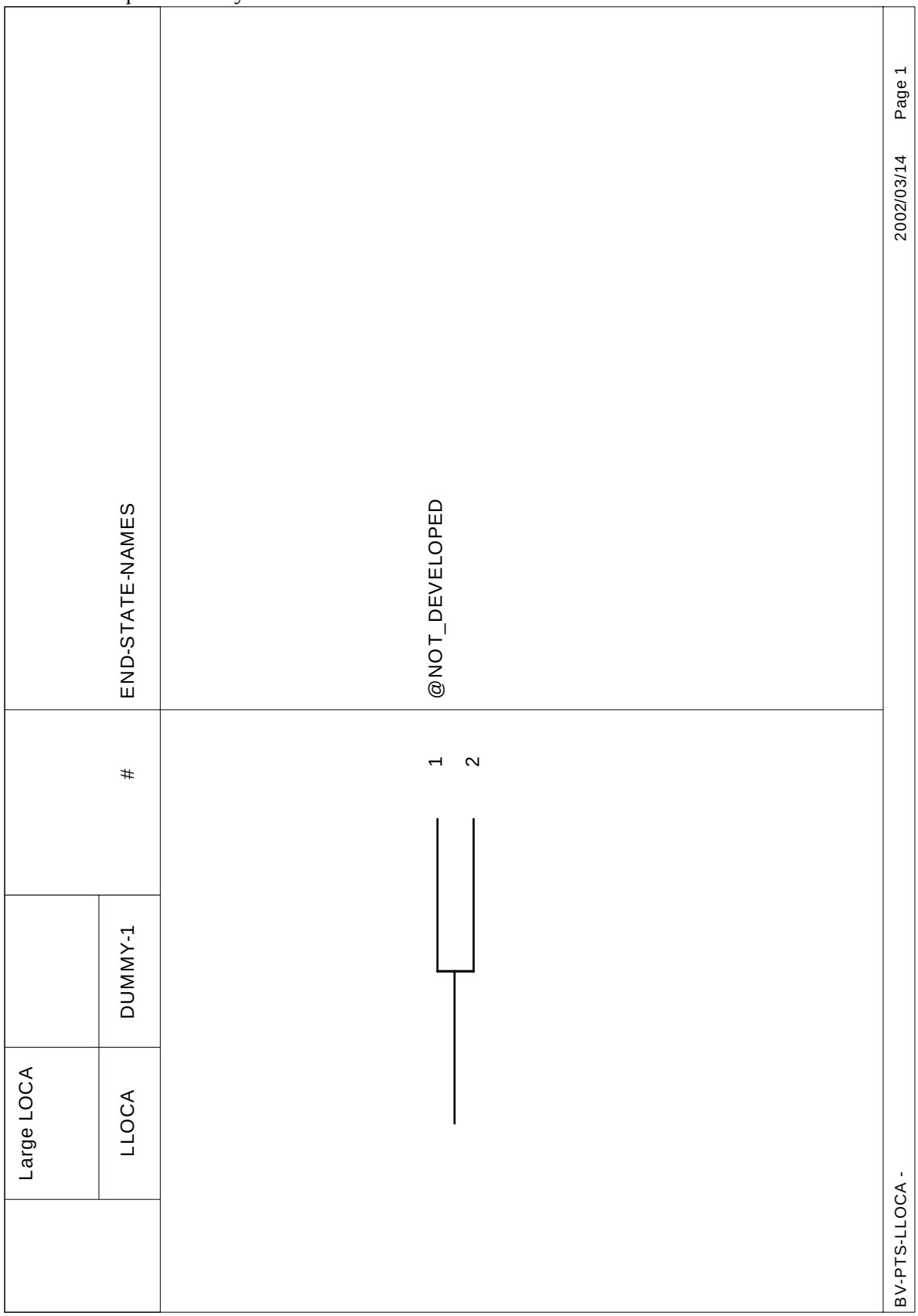

Figure 4.2. Beaver Valley LLOCA: large LOCA.

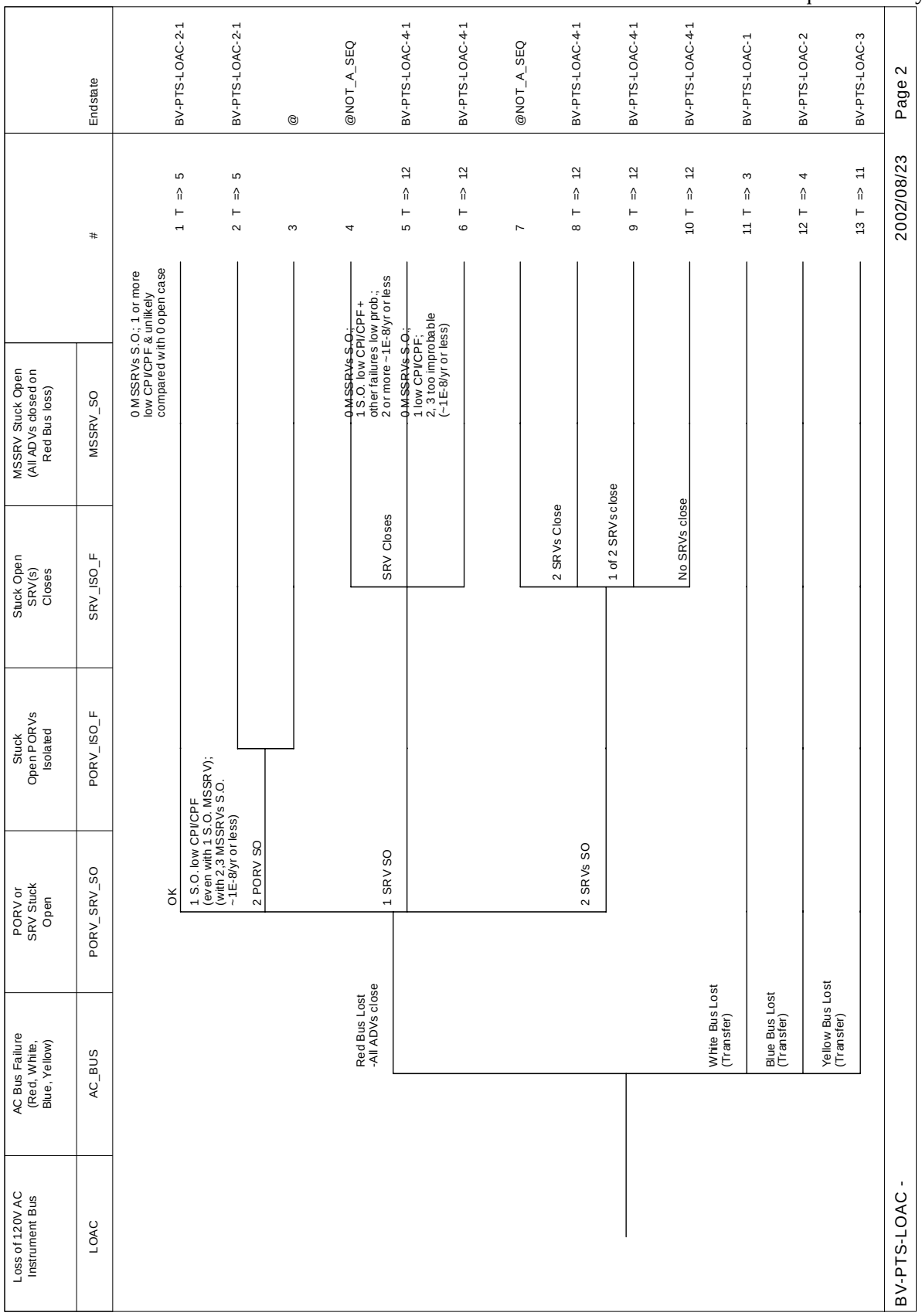

Figure 4.3. Beaver Valley LOAC: Loss of 120V AC (red bus lost).

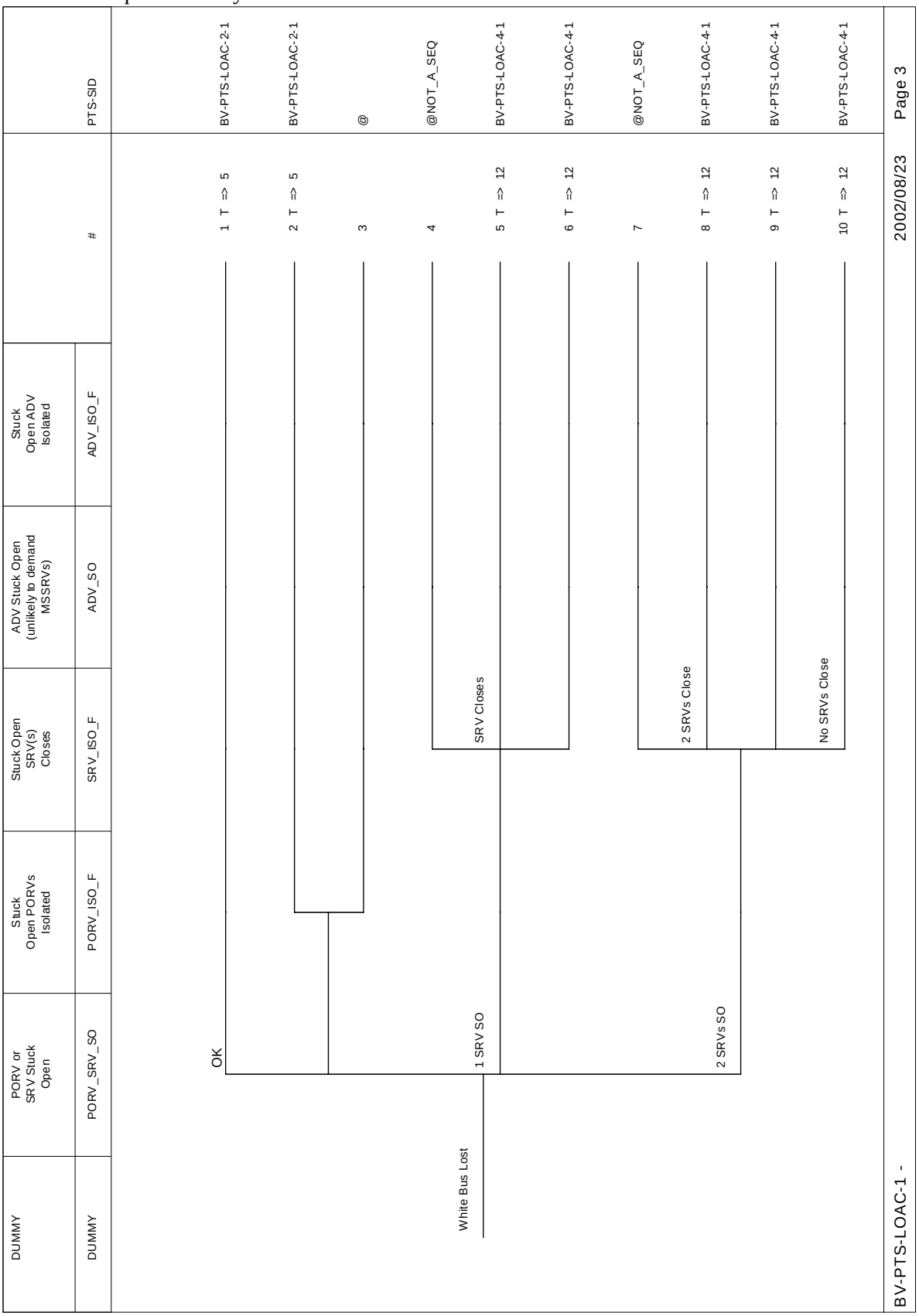

Figure 4.4. Beaver Valley LOAC-1: Loss of 120V AC (white bus lost).

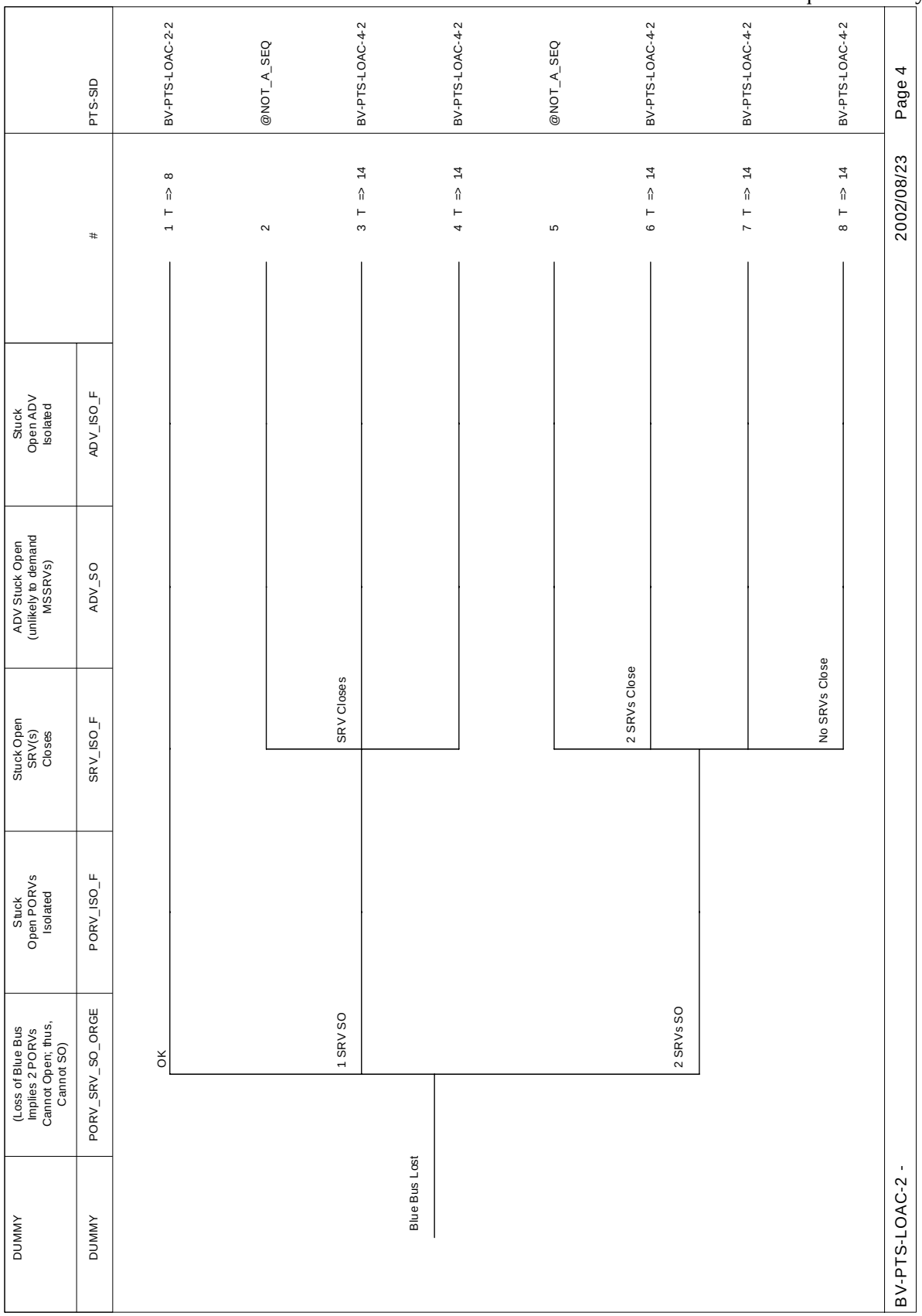

Figure 4.5. Beaver Valley LOAC-2: Loss of 120V AC (blue bus lost).

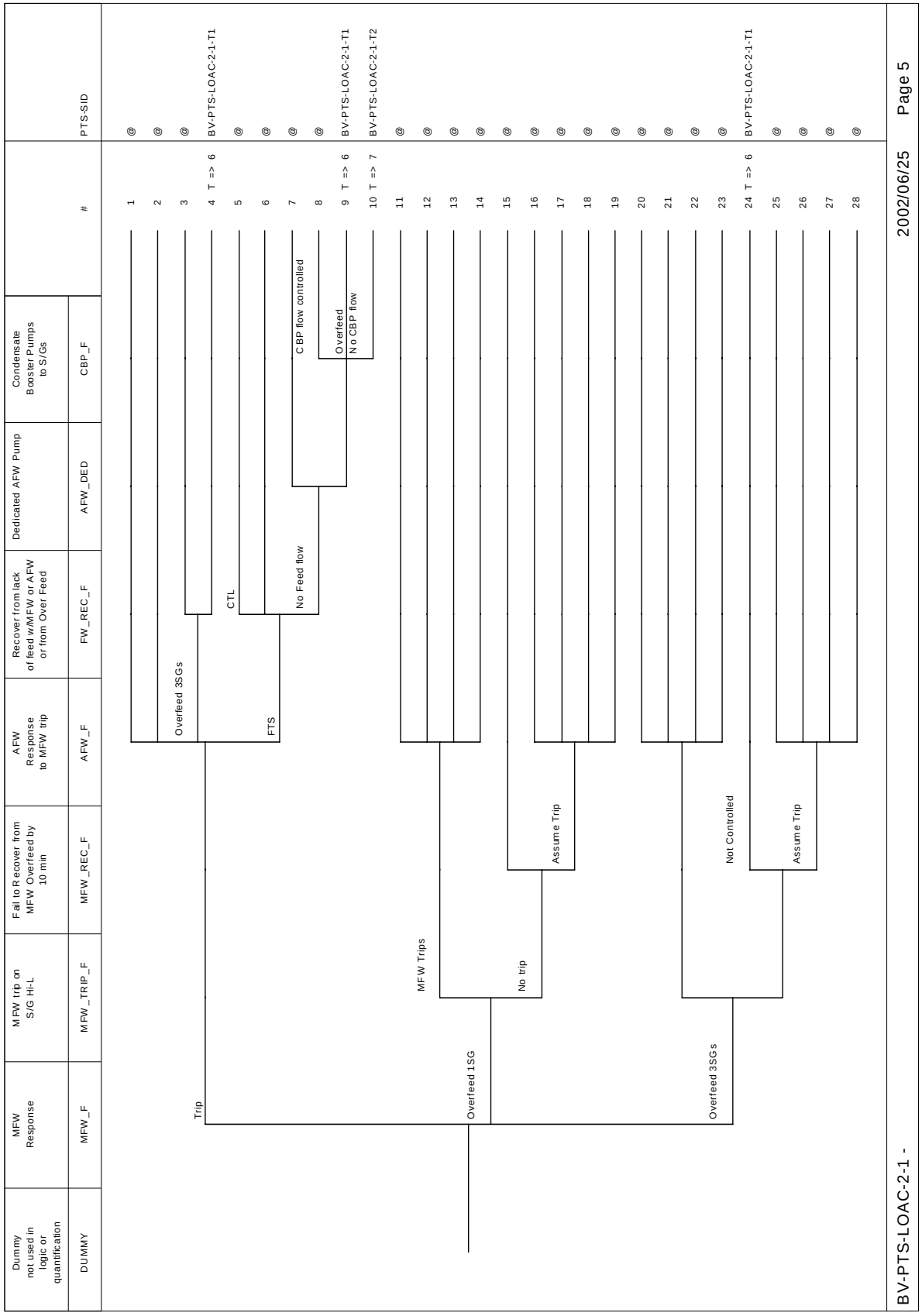

Figure 4.6. Beaver Valley LOAC-2-1: Loss of 120V AC red or white bus (primary system intact).

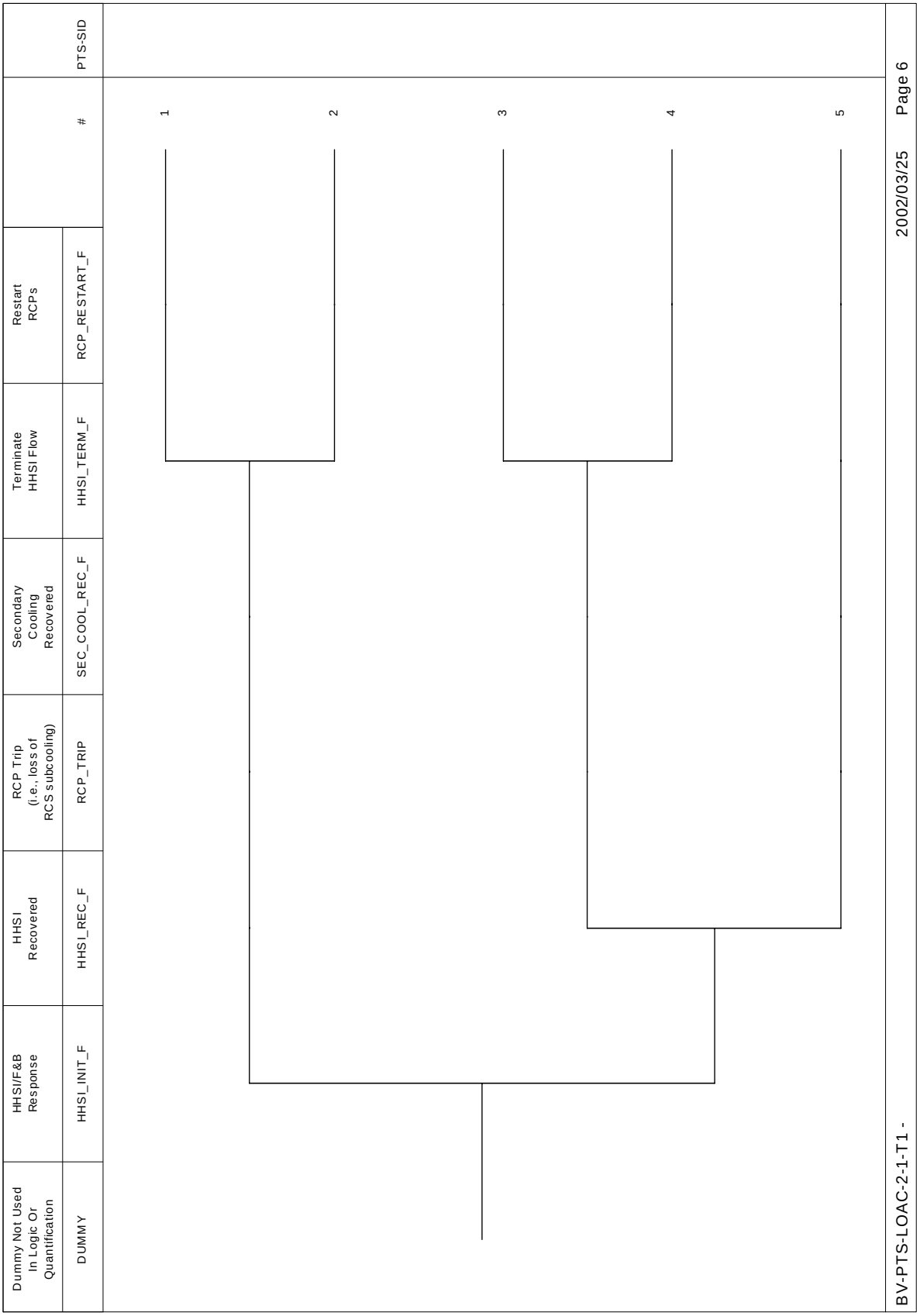

Figure 4.7. Beaver Valley LOAC-2-1-T1: Loss of 120V AC red or white bus–primary system intact (HHSI not F&B).

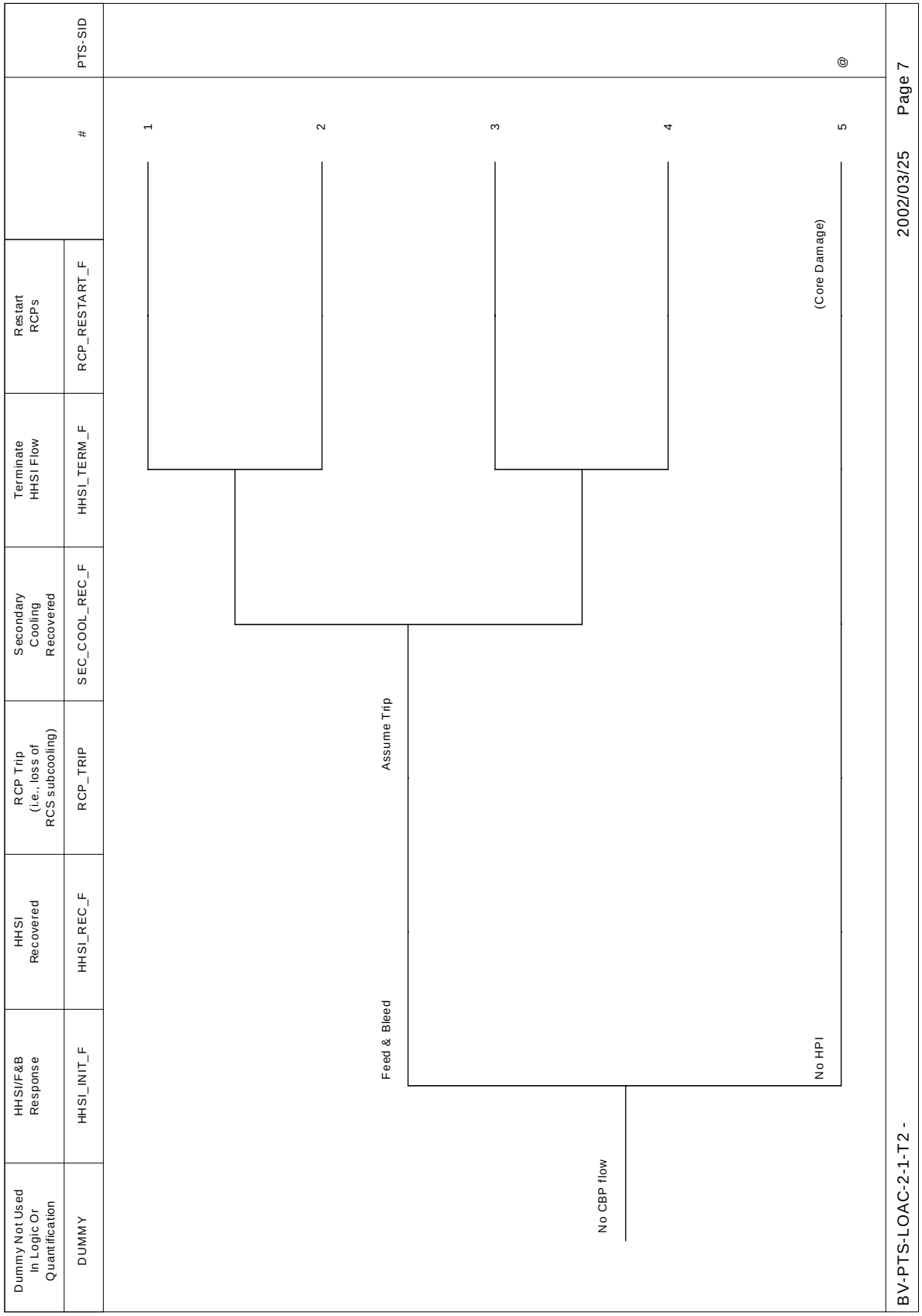

Figure 4.8. Beaver Valley LOAC-2-1-T2: Loss of 120V AC red or white bus–primary system intact (HHSI F&B).

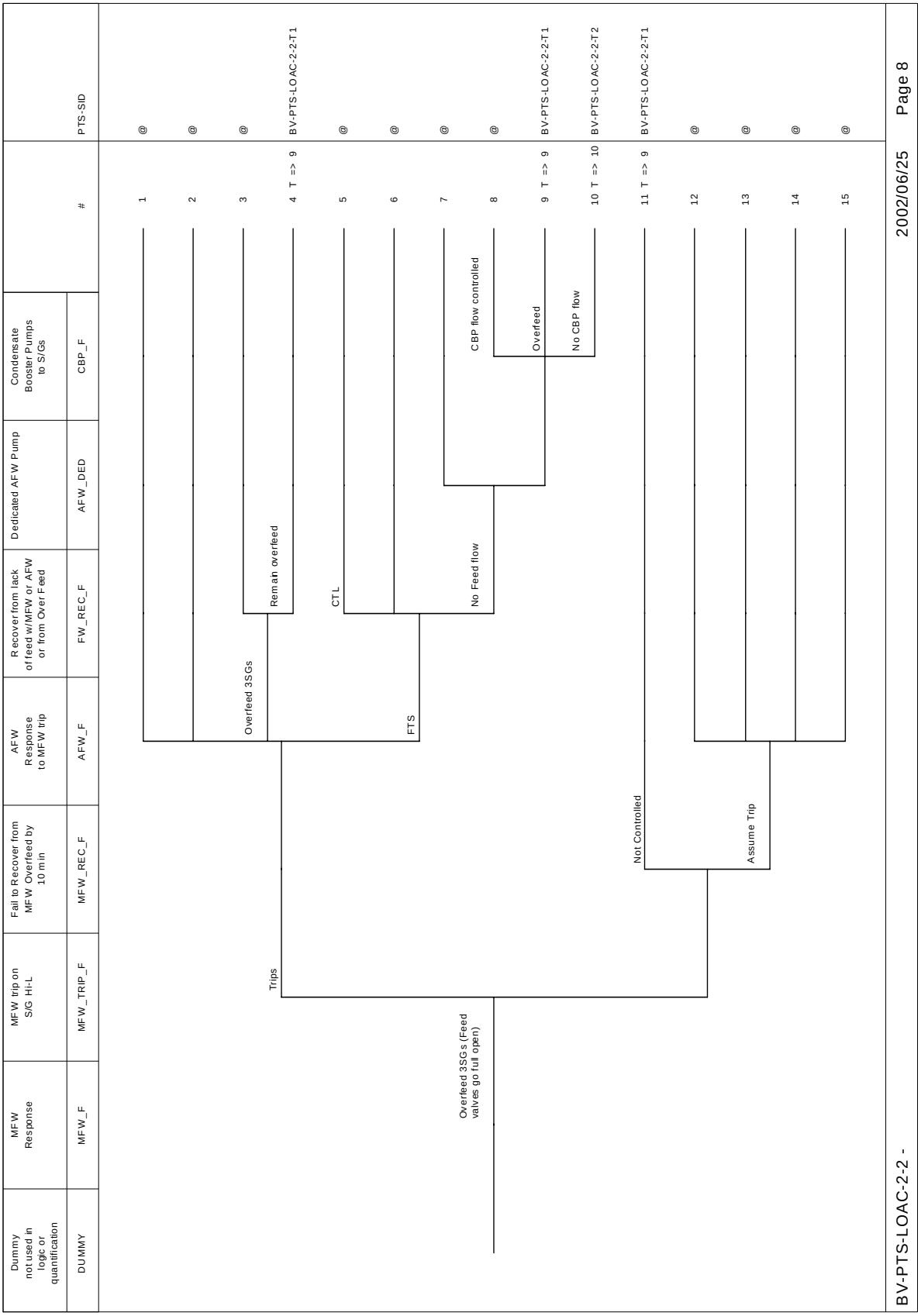

Figure 4.9. Beaver Valley LOAC-2-2: Loss of 120V AC blue or yellow bus (primary system intact).

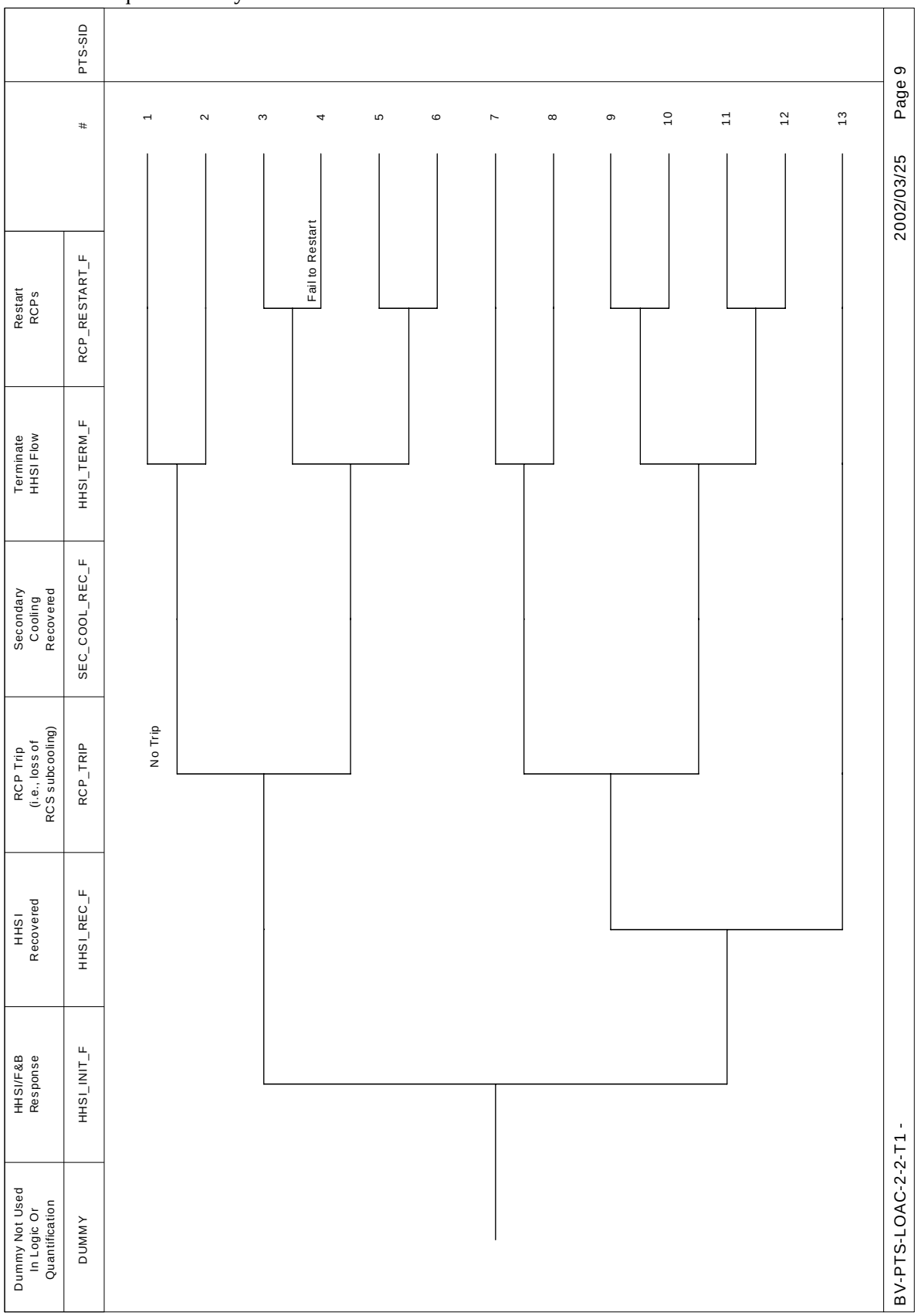

Figure 4.10. Beaver Valley LOAC-2-2-T1: Loss of 120V AC blue or yellow bus–primary system intact (HHSI not F&B).

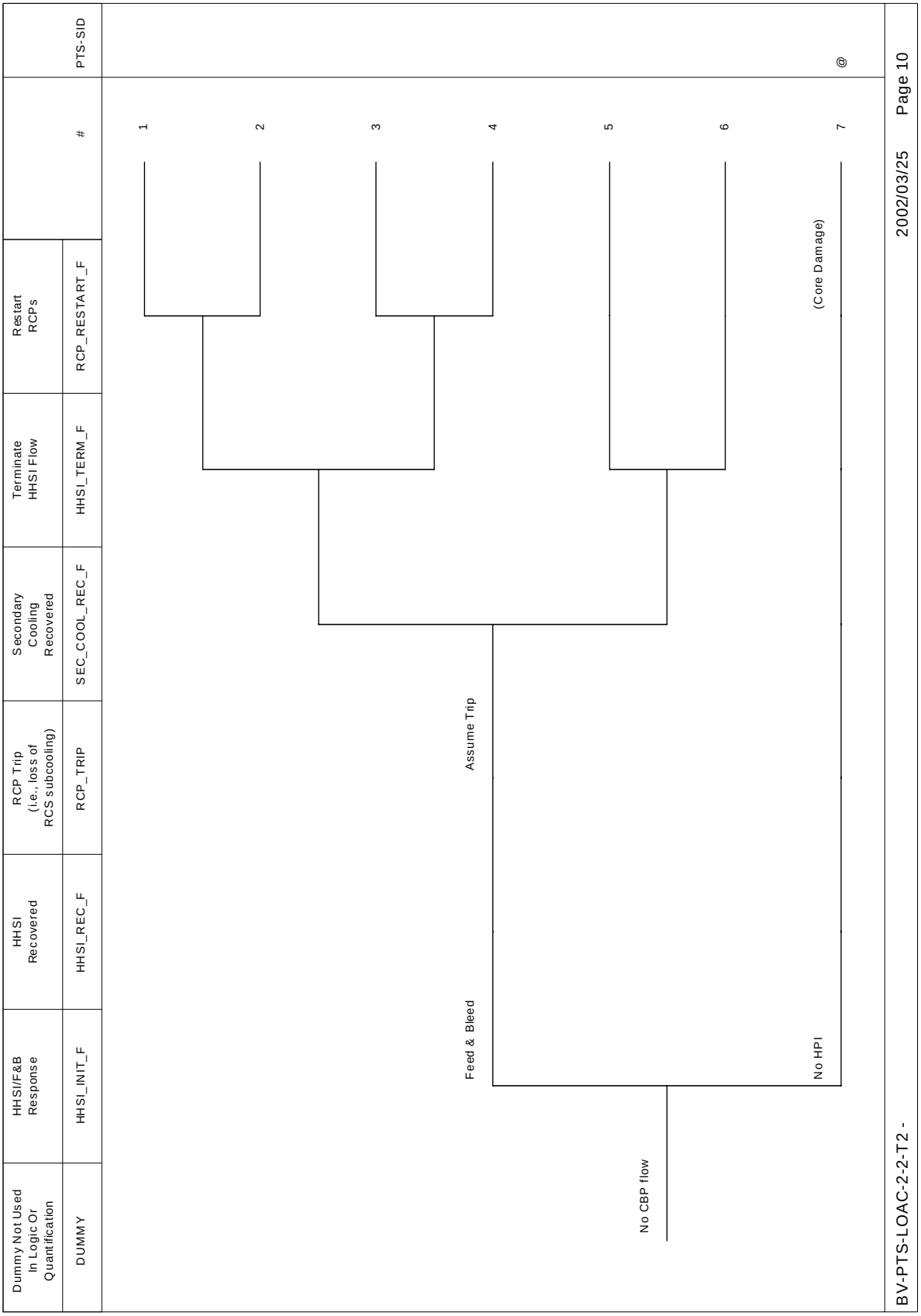

Figure 4.11. Beaver Valley LOAC-2-2-T2: Loss of 120V AC blue or yellow bus–primary system intact (HHSI F&B).

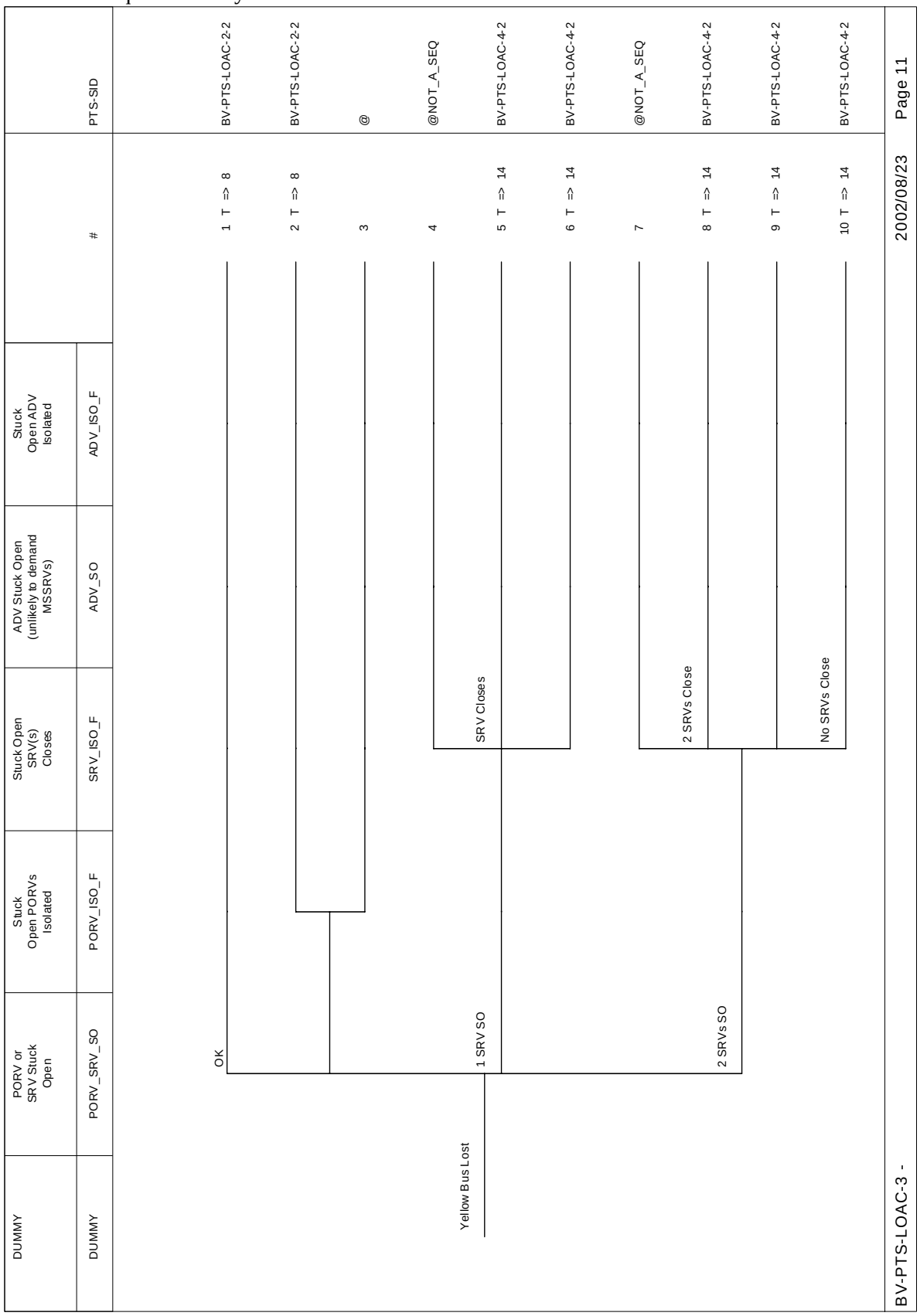

Figure 4.12. Beaver Valley LOAC-3: Loss of 120V AC (yellow bus lost).

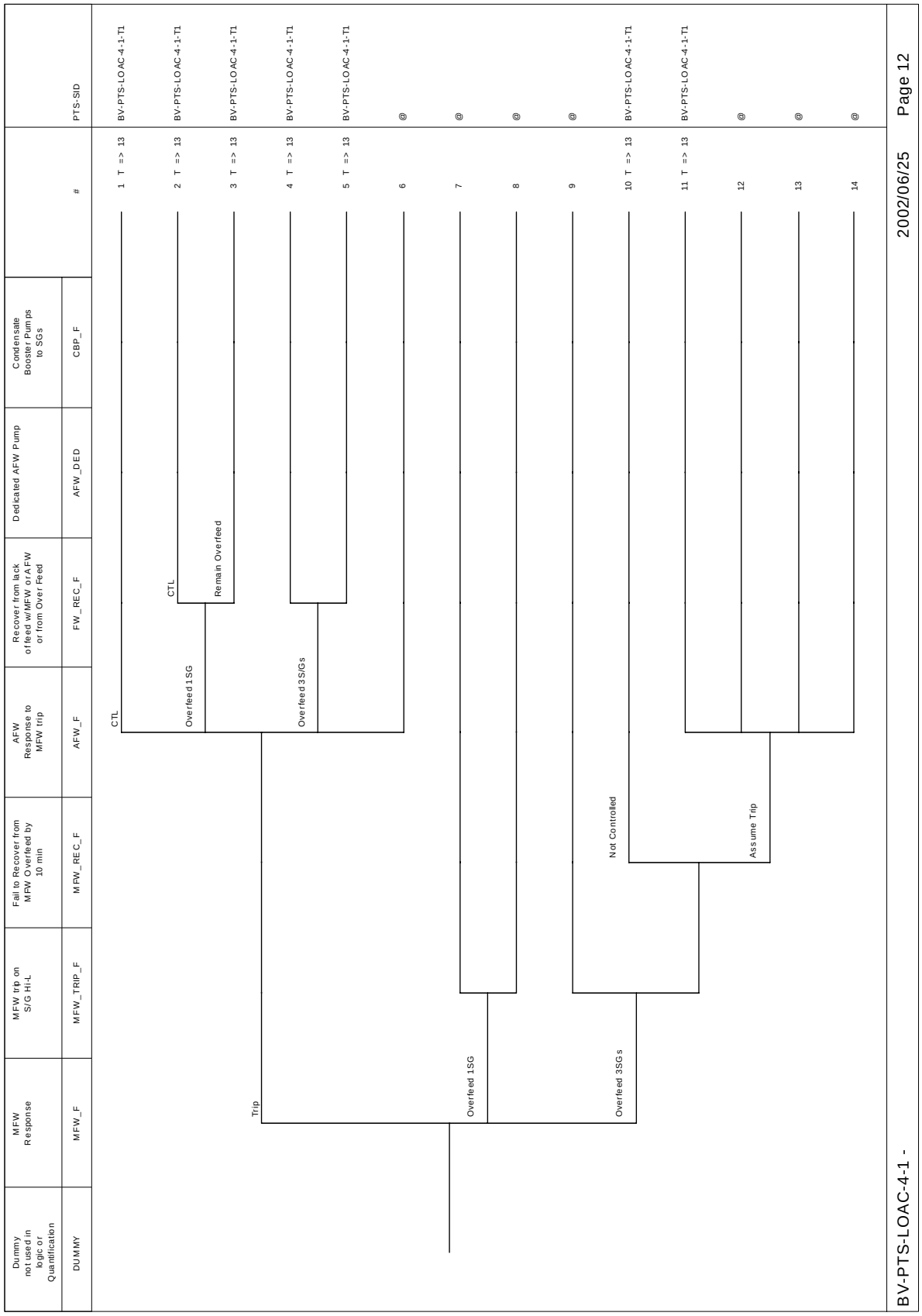

Figure 4.13. Beaver Valley LOAC-4-1: Loss of 120V AC red or white bus (at least one SRV initially open).

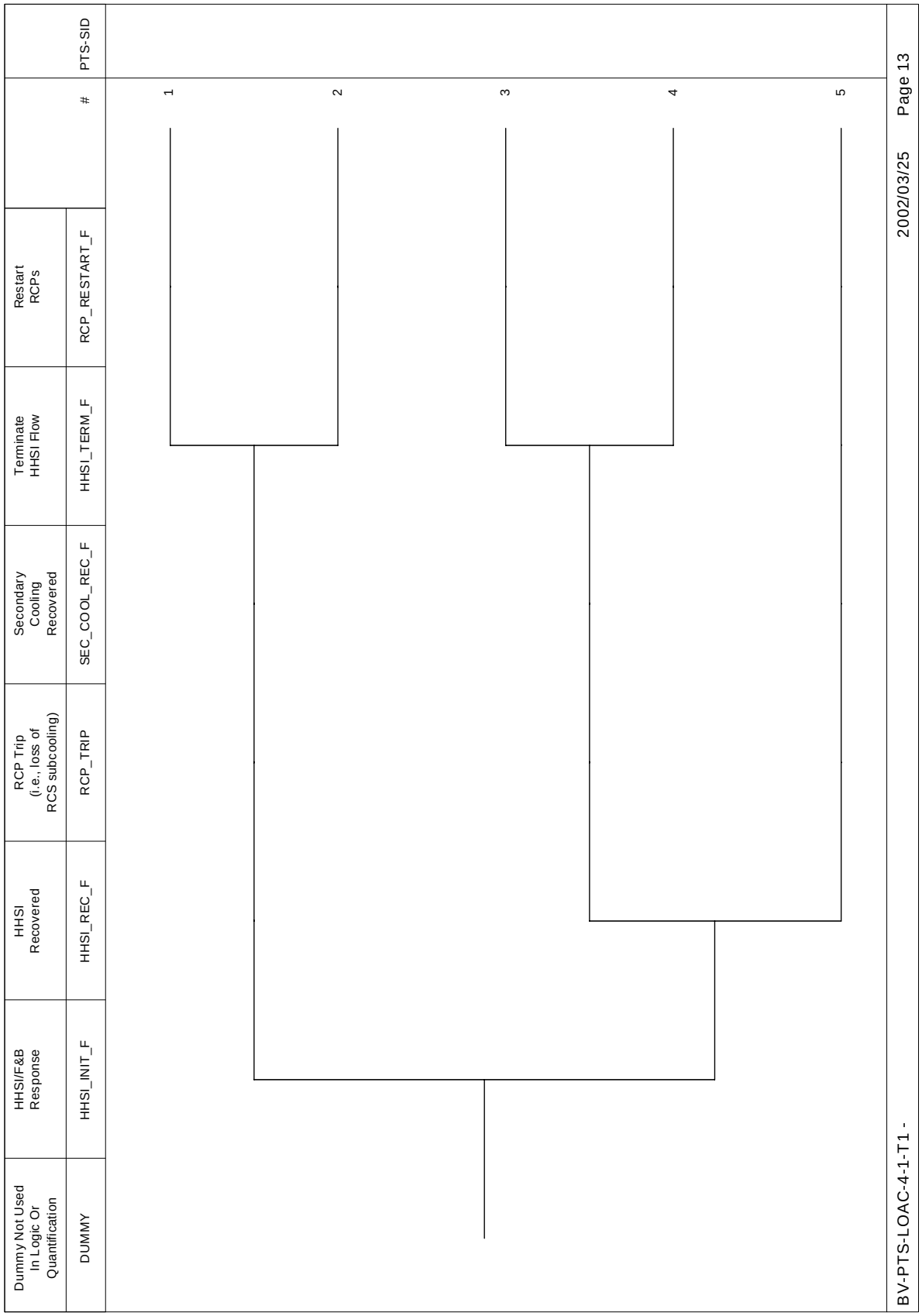

Figure 4.14. Beaver Valley LOAC-4-1-T1: Loss of 120V AC red or white bus–at least one SRV initially open (HHSI not F&B).

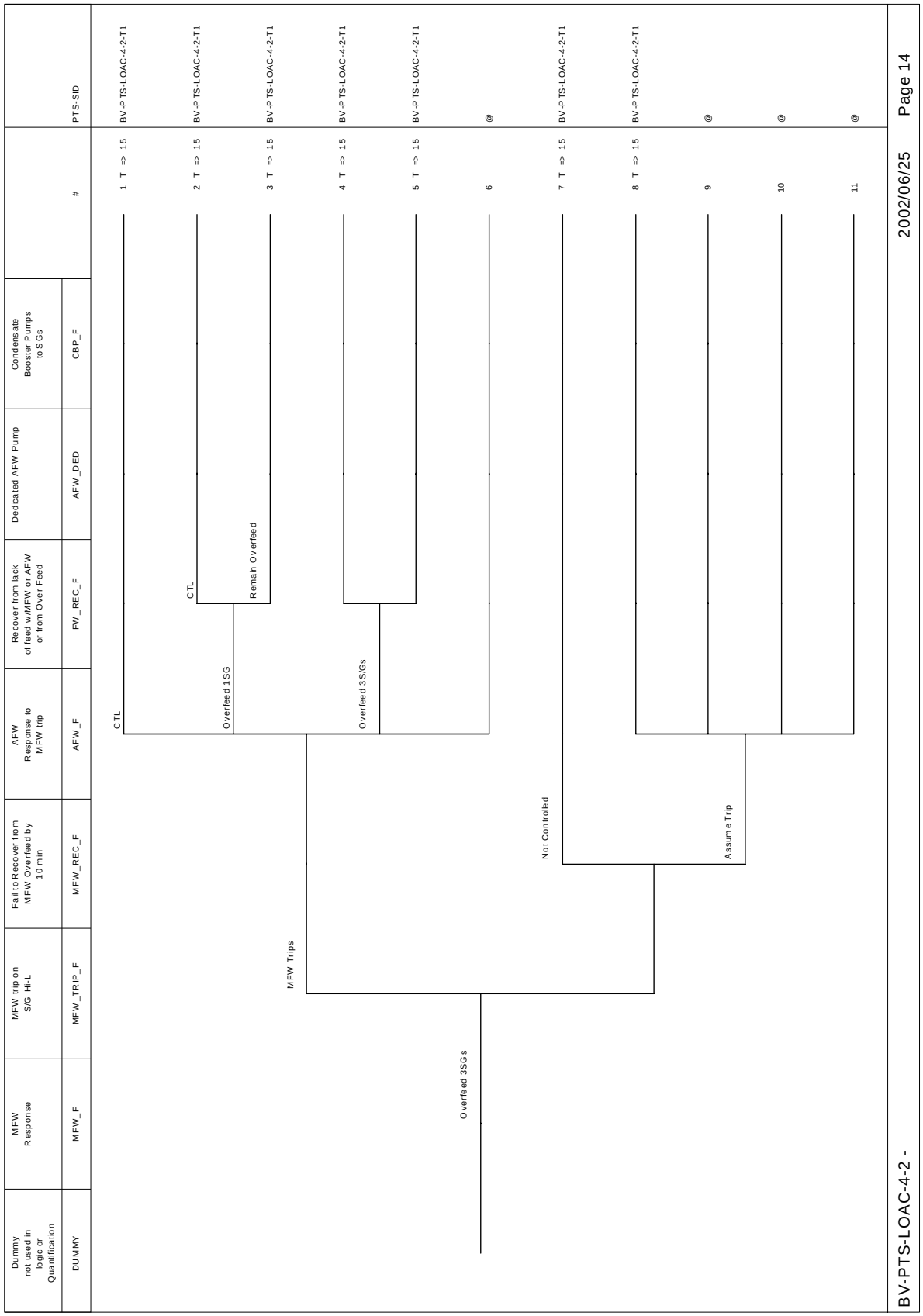

Figure 4.15. Beaver Valley LOAC-4-2: Loss of 120V AC blue or yellow bus (at least one SRV initially open).

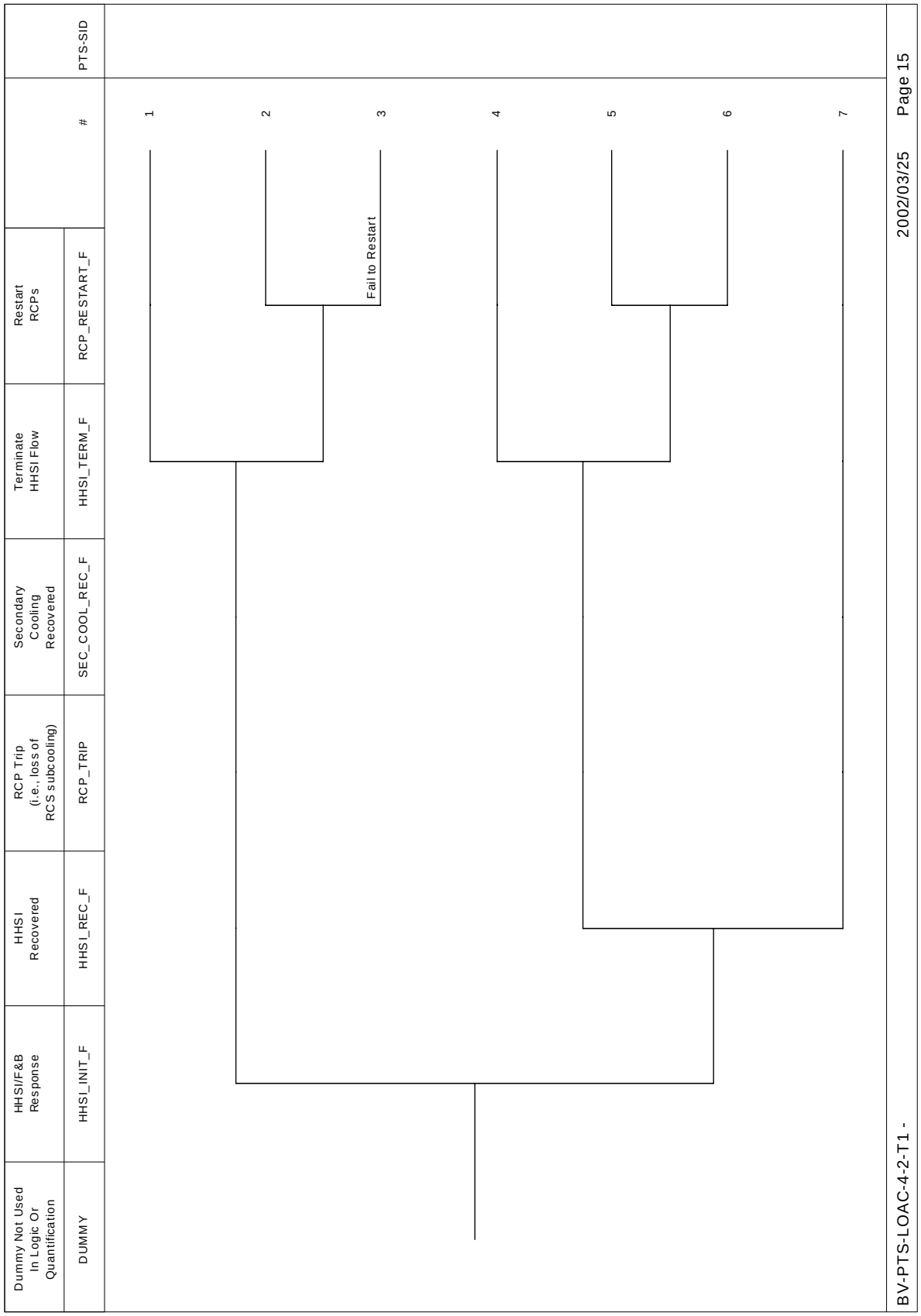

Figure 4.16. Beaver Valley LOAC-4-2-T1: Loss of 120V AC blue or yellow bus–at least one SRV initially open (HHSI not F&B).

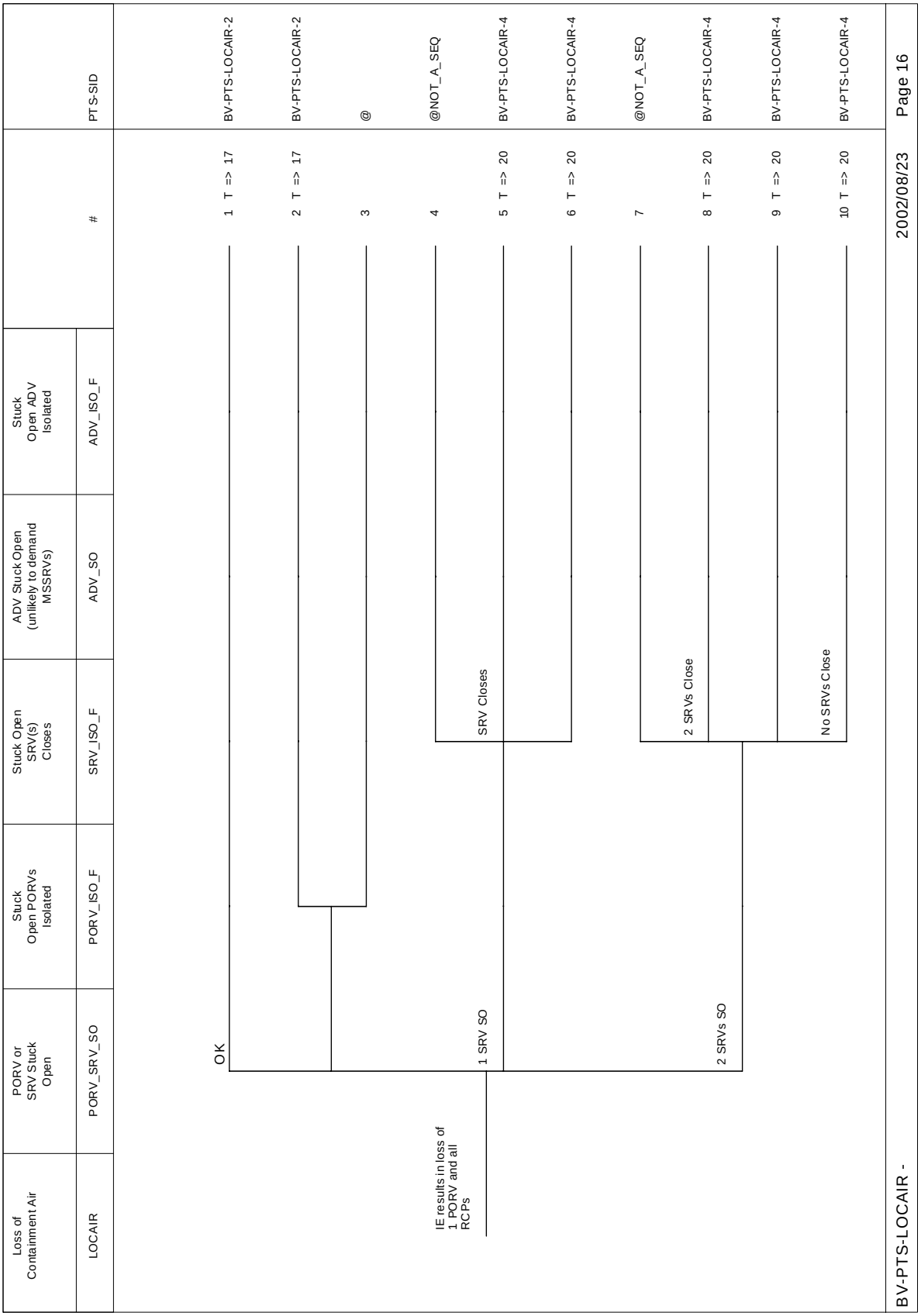

Figure 4.17. Beaver Valley LOCAIR: Loss of containment air.

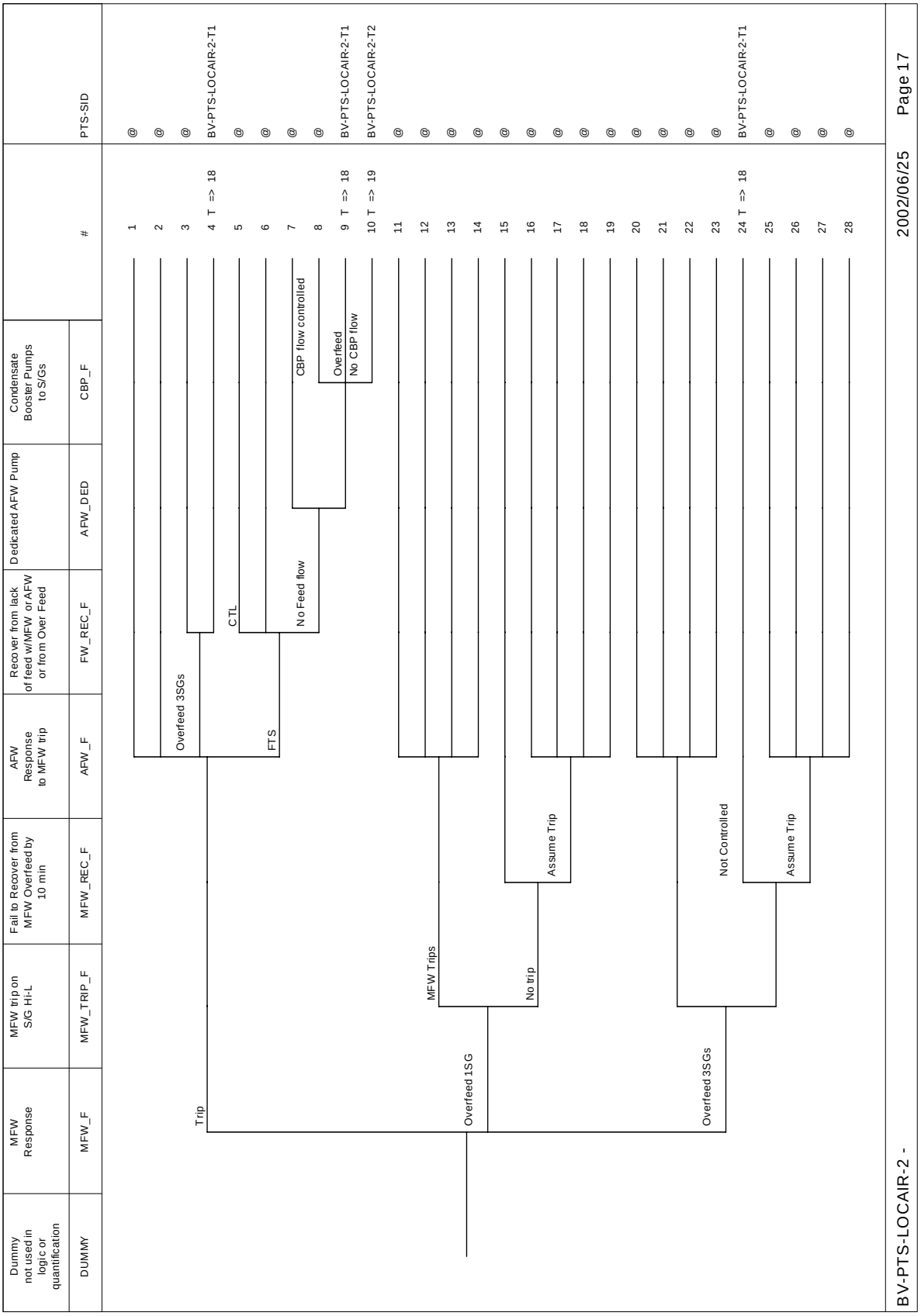

Figure 4.18. Beaver Valley LOCAIR-2: Loss of containment air (primary system intact).

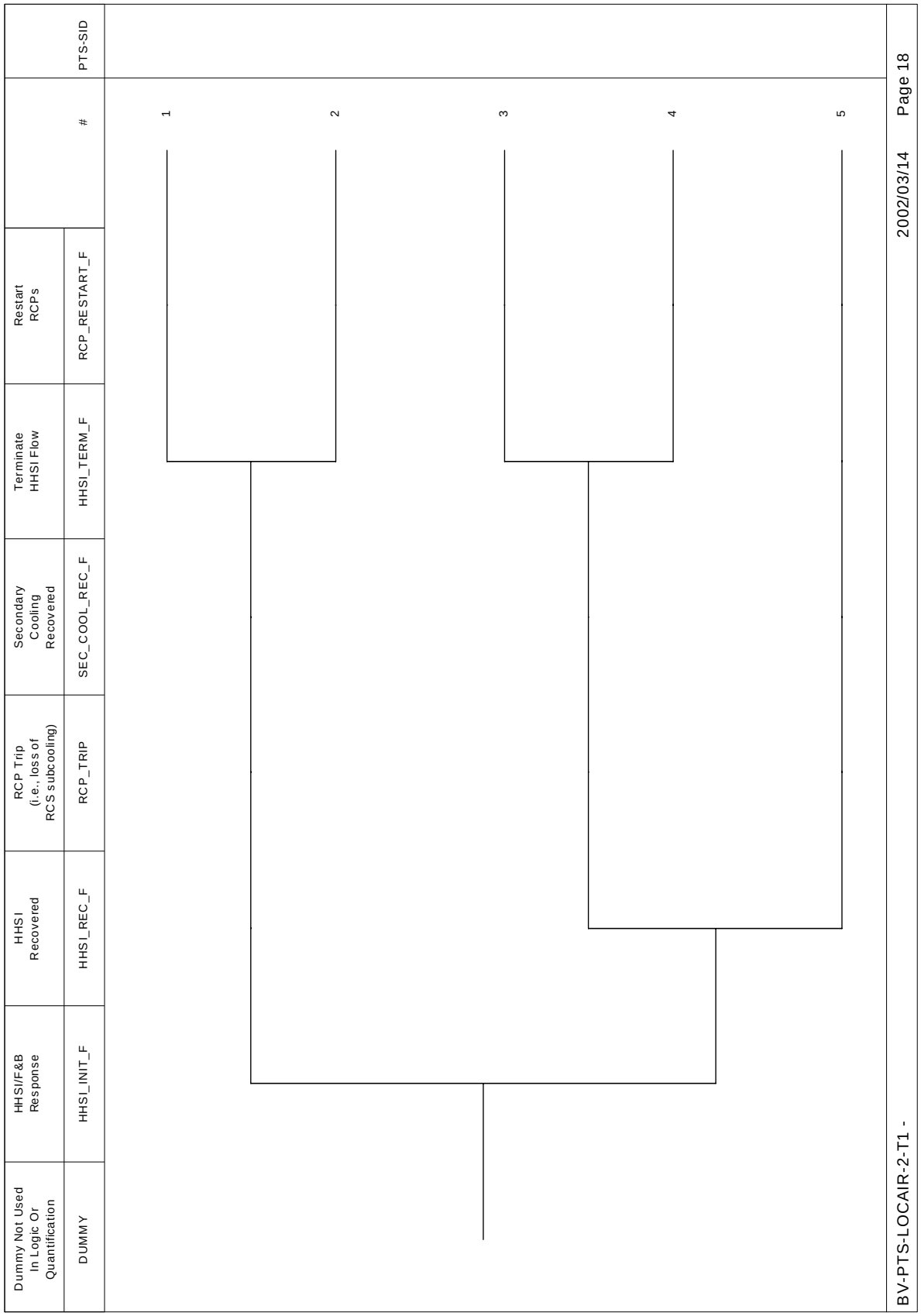

Figure 4.19. Beaver Valley LOCAIR-2-T1: Loss of containment air–primary system intact (HHSI not F&B).

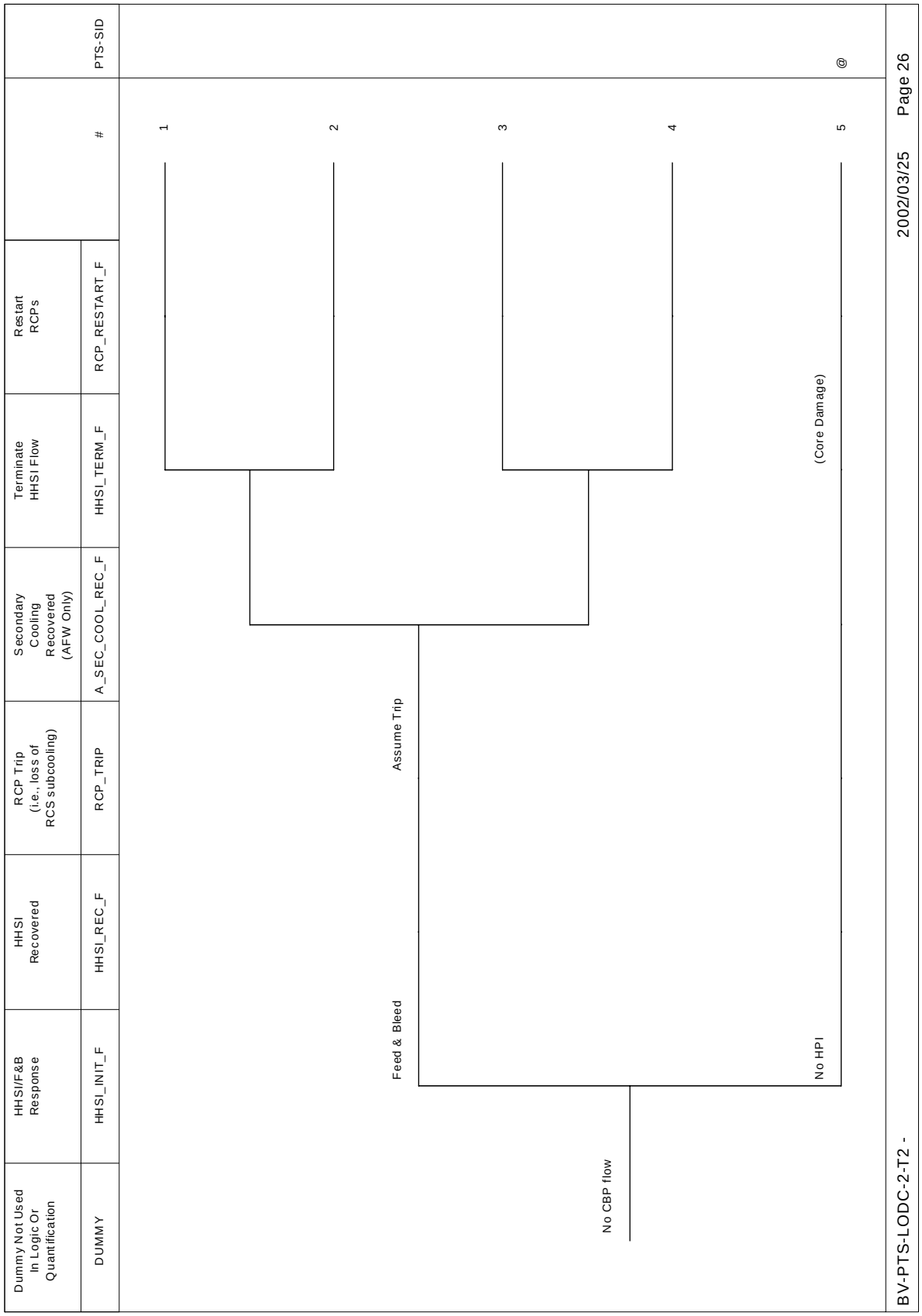

Figure 4.20. Beaver Valley LOCAIR-2-T2: Loss of containment air–primary system intact (HHSI F&B).

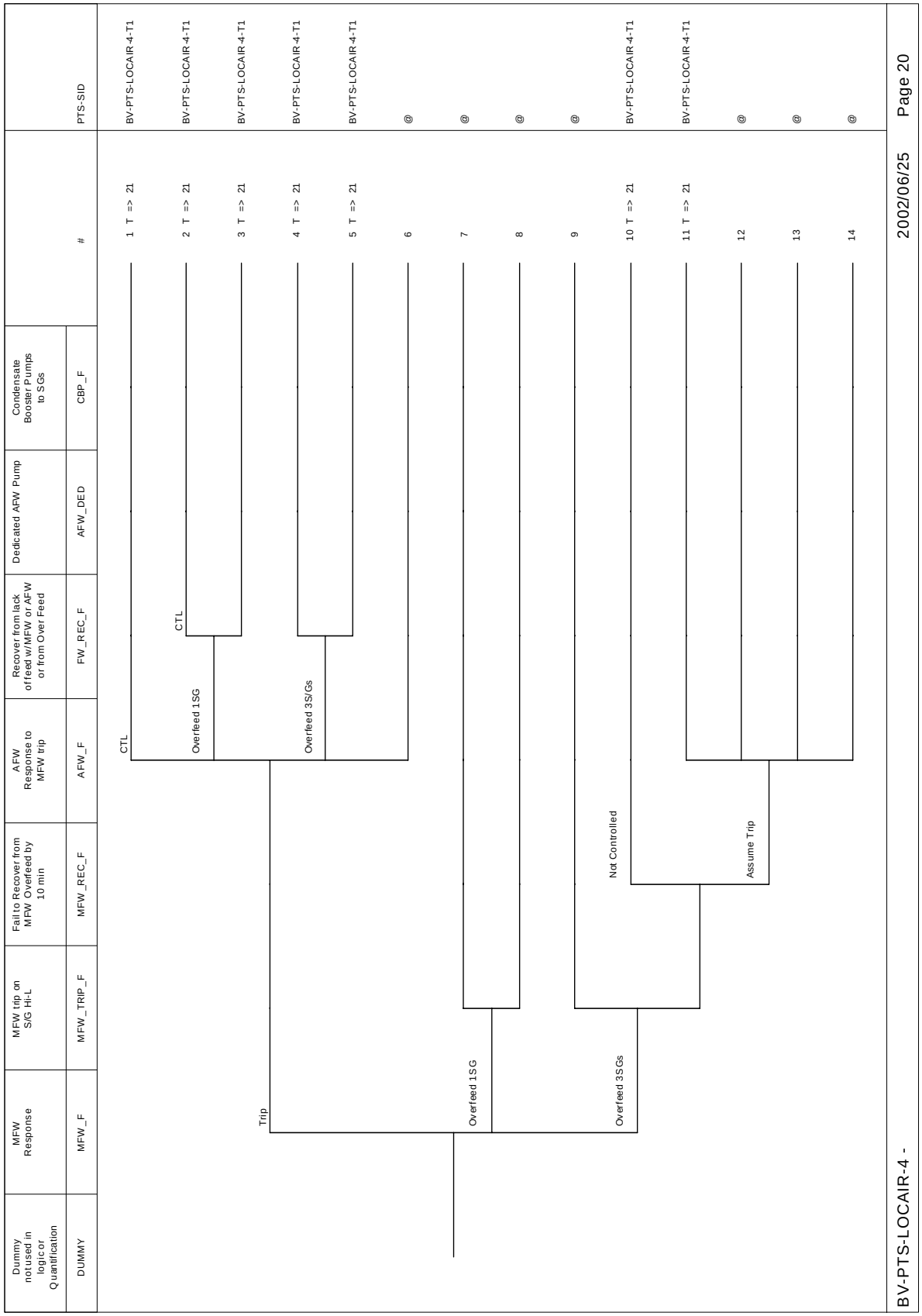

Figure 4.21. Beaver Valley LOCAIR-4: Loss of containment air (at least one SRV initially open).

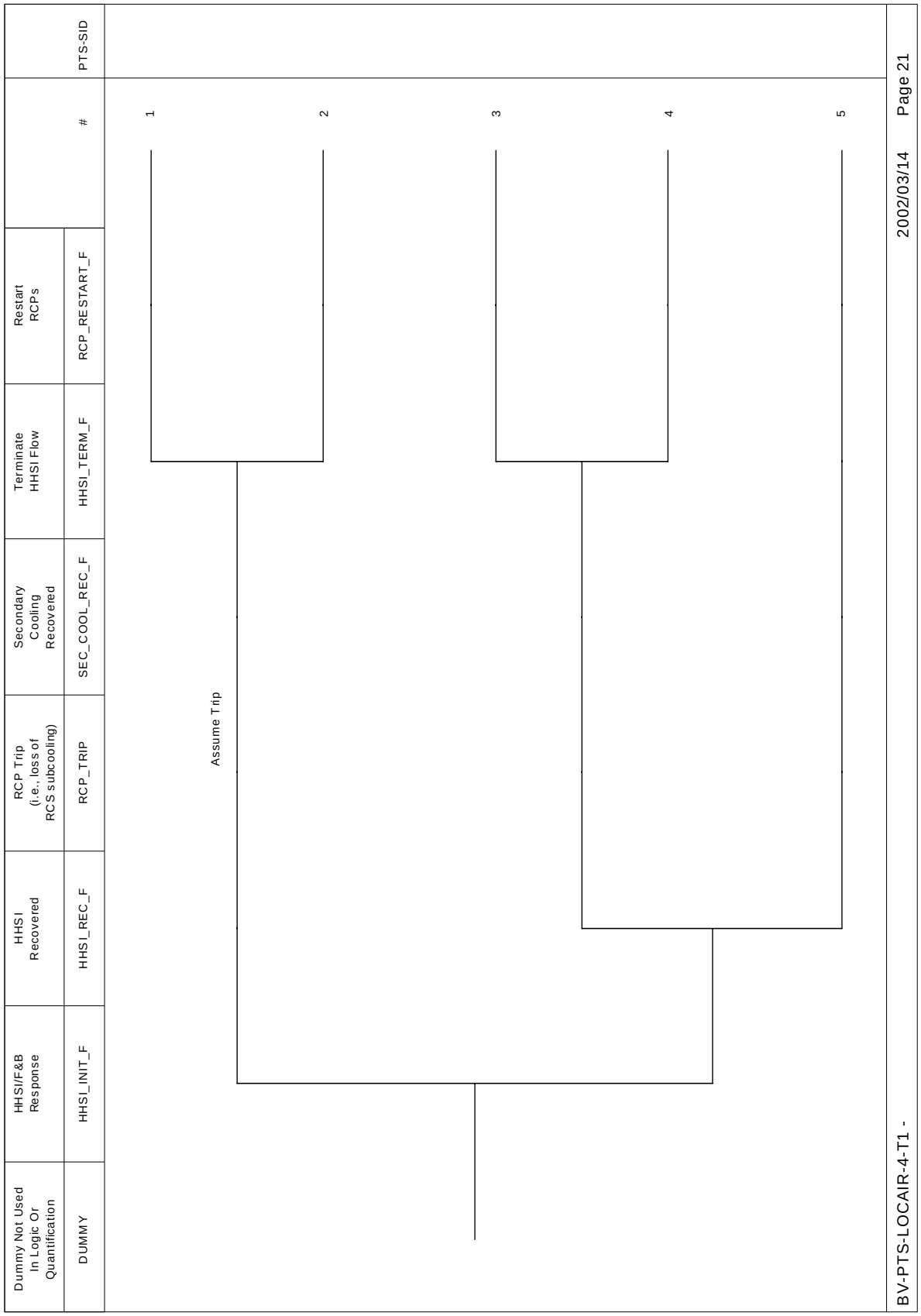

Figure 4.22. Beaver Valley LOCAIR-4-T1: Loss of containment air–at least one SRV initially open (HHSI not F&B).

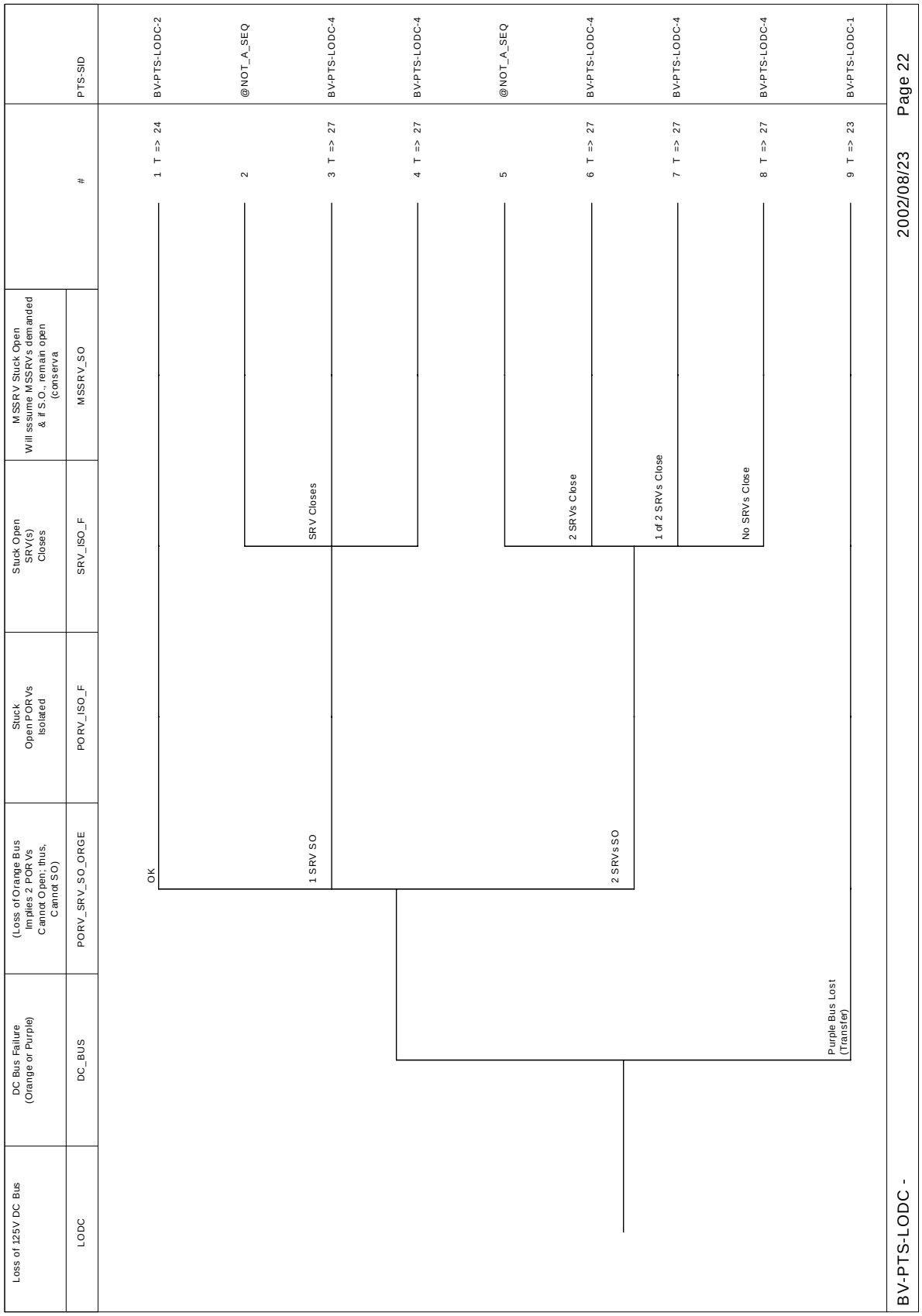

Figure 4.23. Beaver Valley LODC: Loss of 125V DC bus (orange bus lost).

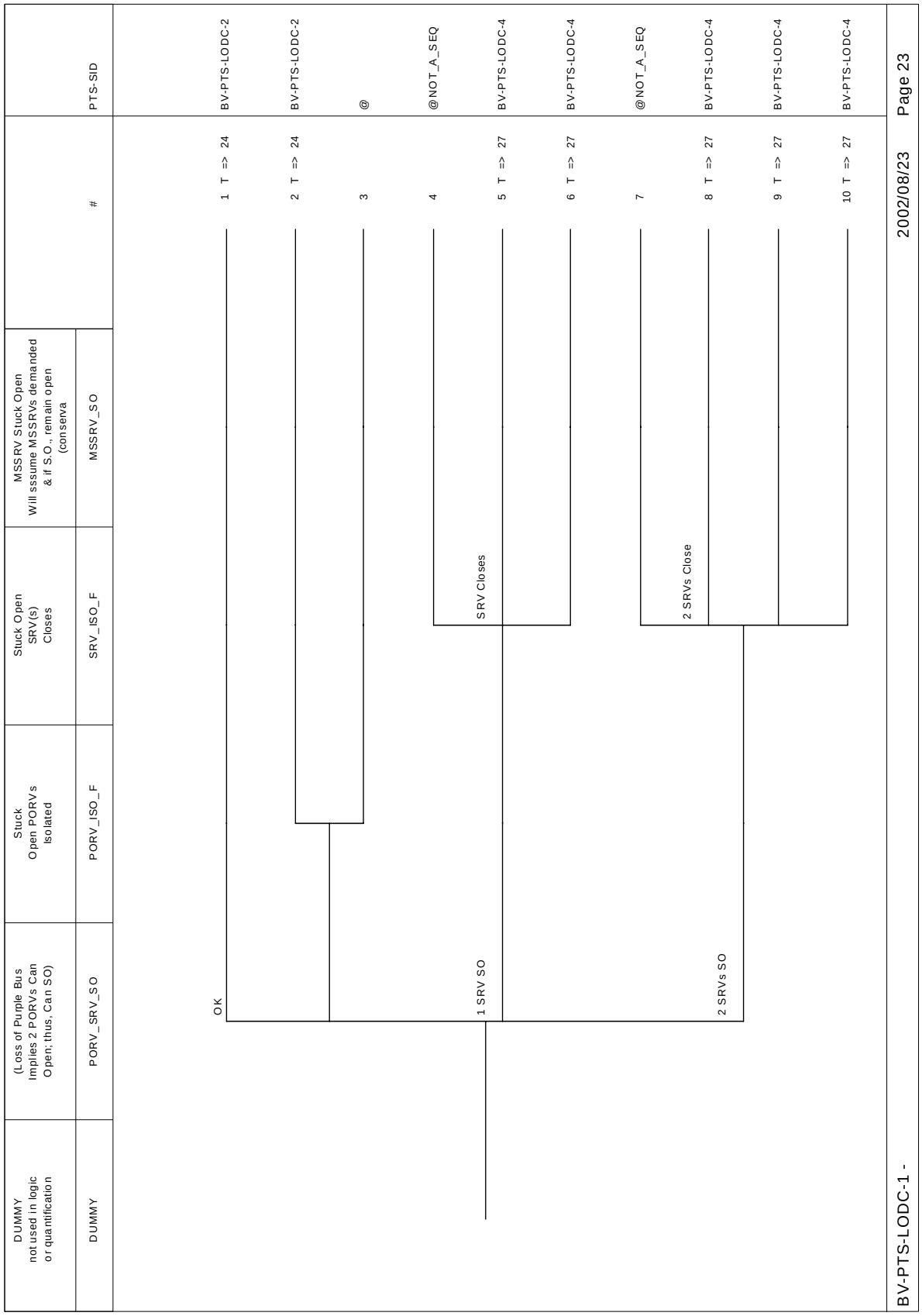

Figure 4.24. Beaver Valley LODC-1: Loss of 125V DC bus (purple bus lost).

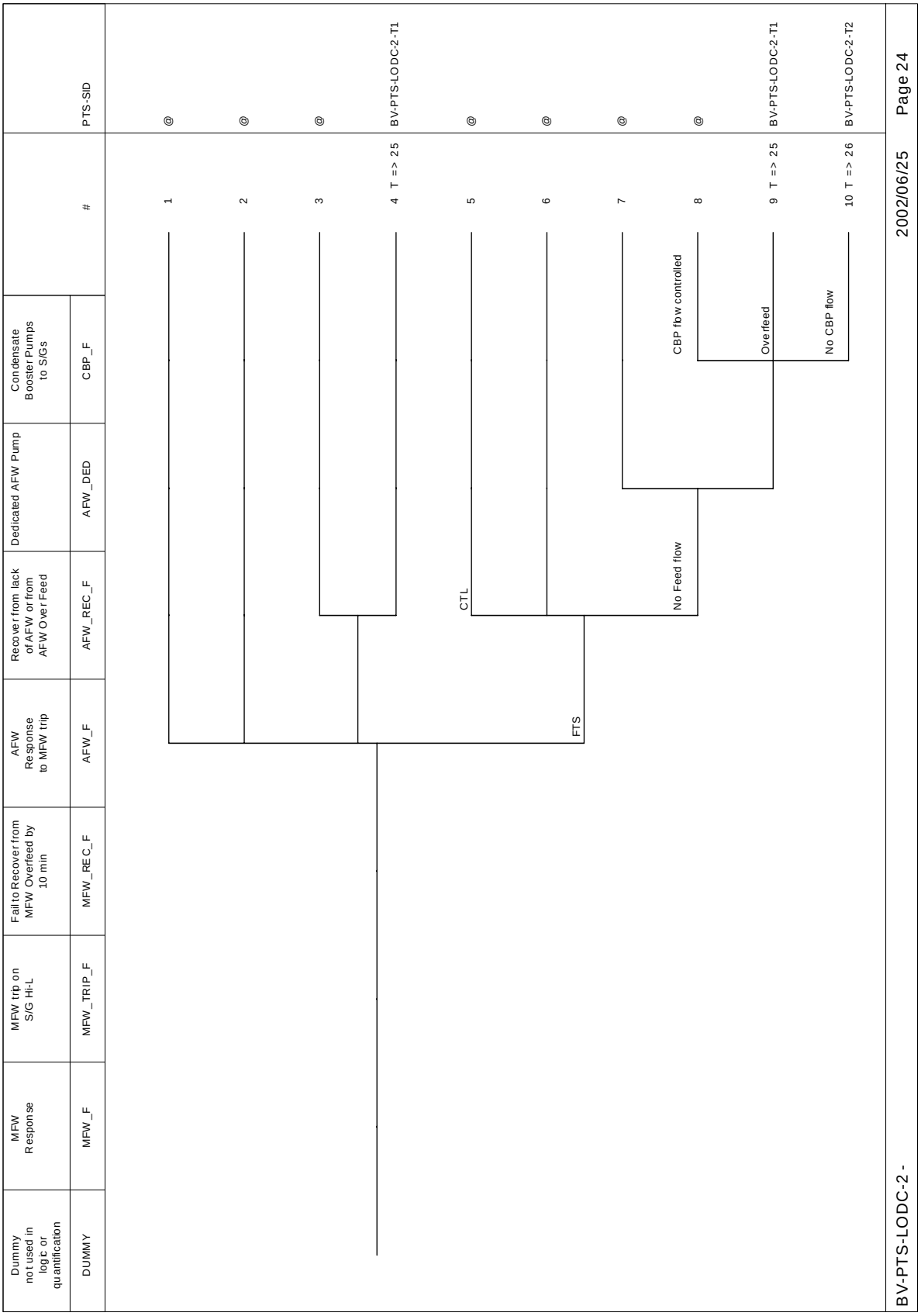

Figure 4.25. Beaver Valley LODC-2: Loss of 125V DC orange or purple bus (primary system intact).

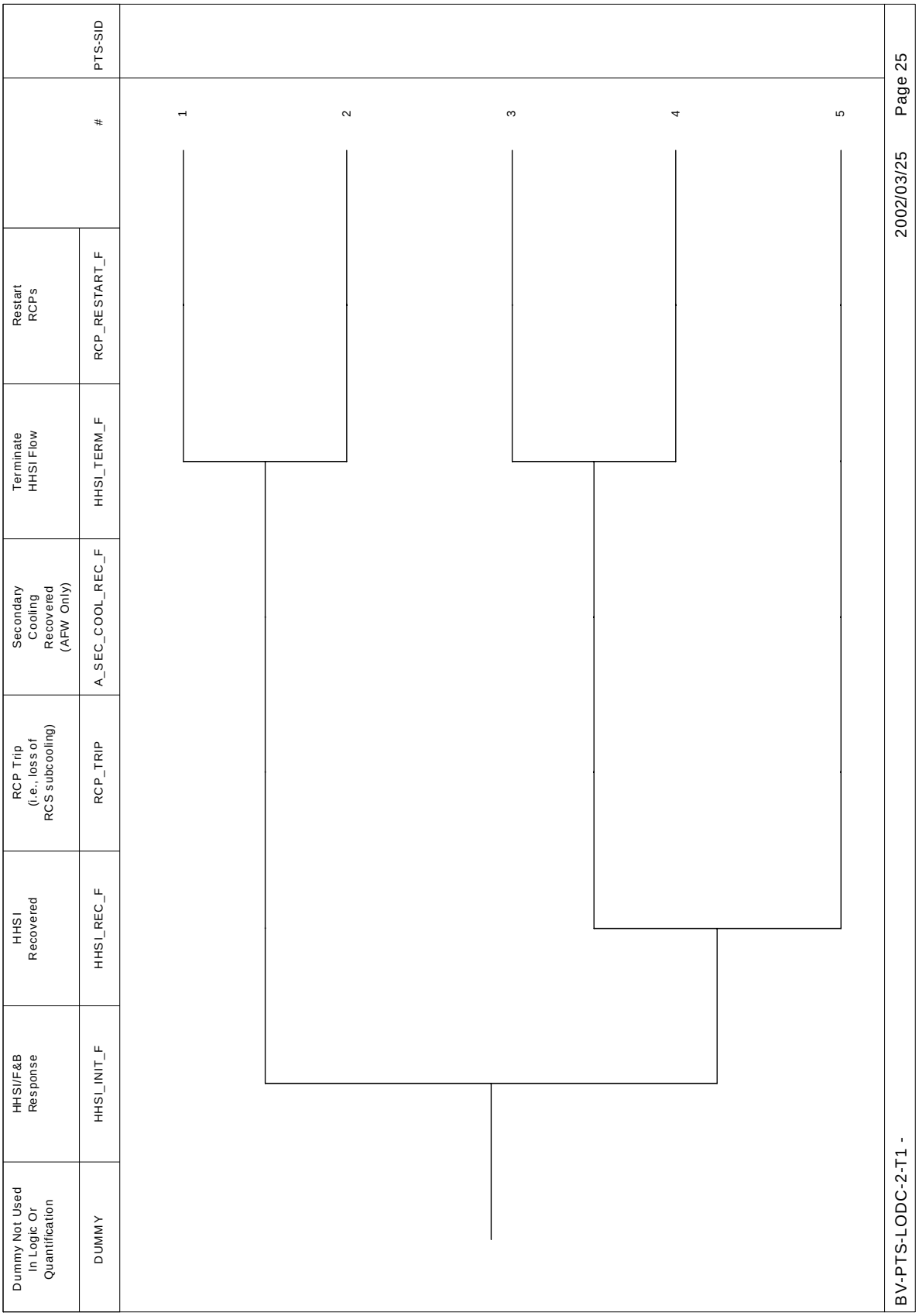

Figure 4.26. Beaver Valley LODC-2-T1: Loss of 125V DC orange or purple bus–primary system intact (HHSI not F&B).

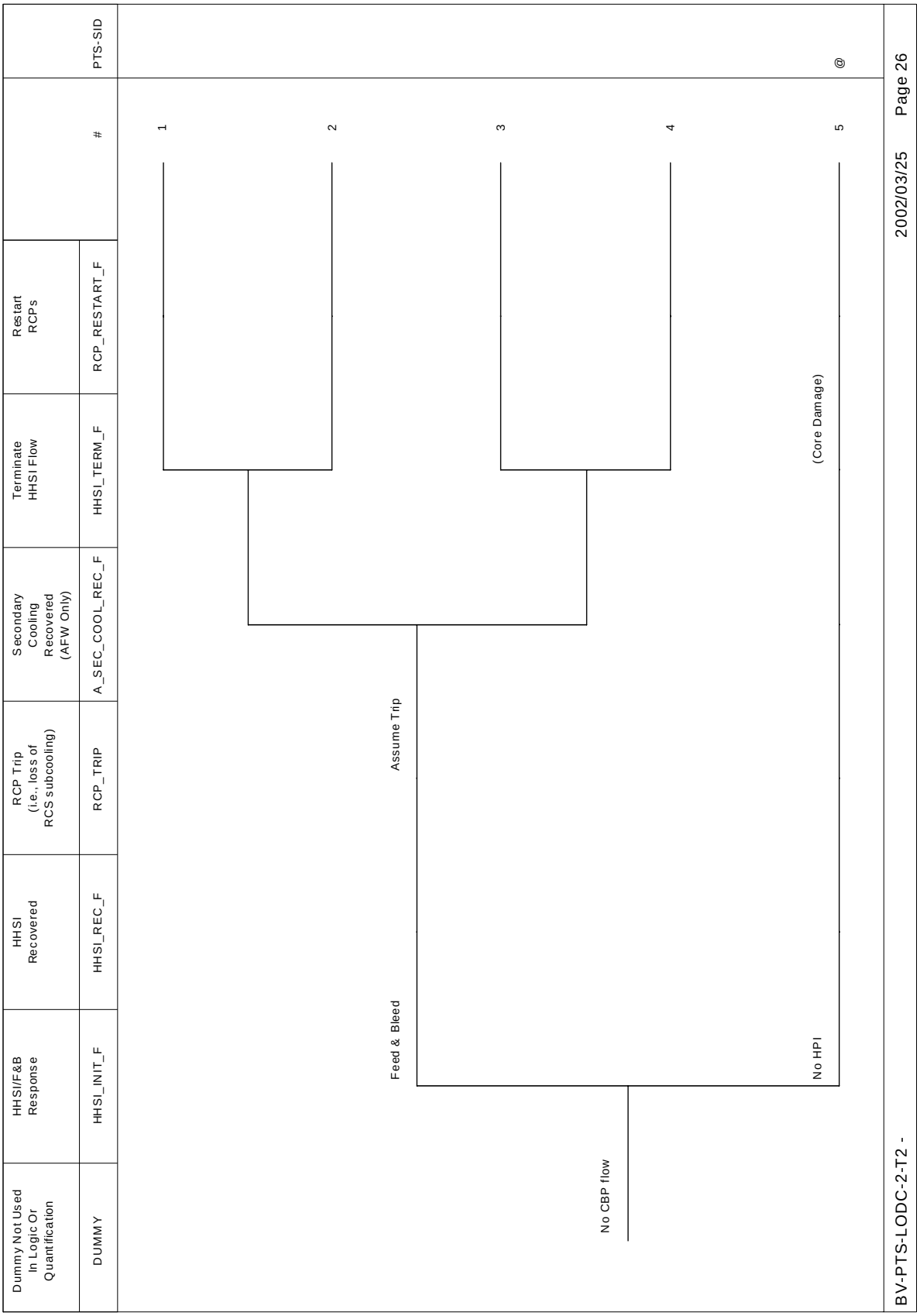

Figure 4.27. Beaver Valley LODC-2-T2: Loss of 125V DC orange or purple bus–primary system intact (HHSI F&B).

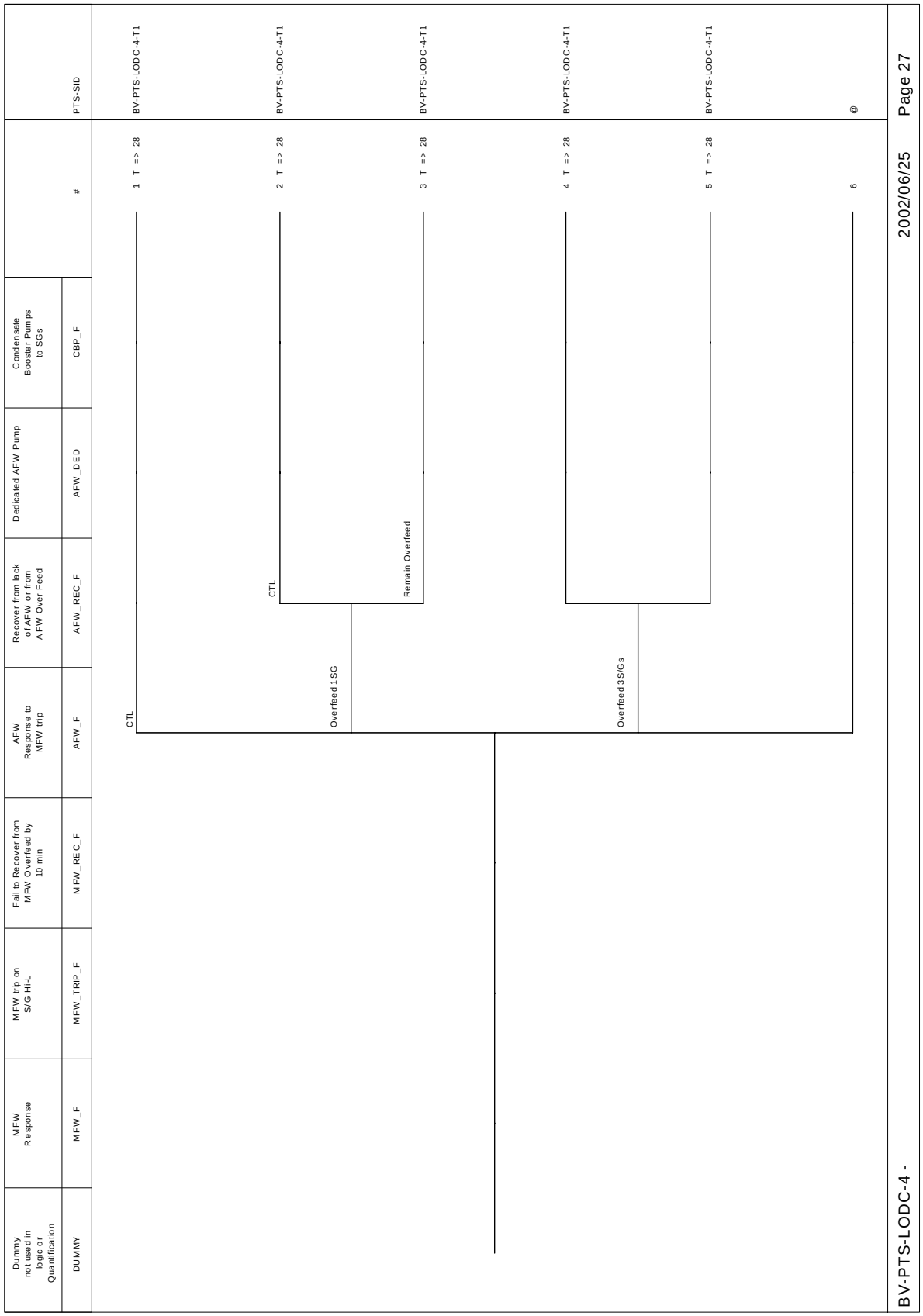

Figure 4.28. Beaver Valley LODC-4: Loss of 125V DC orange or purple bus (at least one SRV initially open).

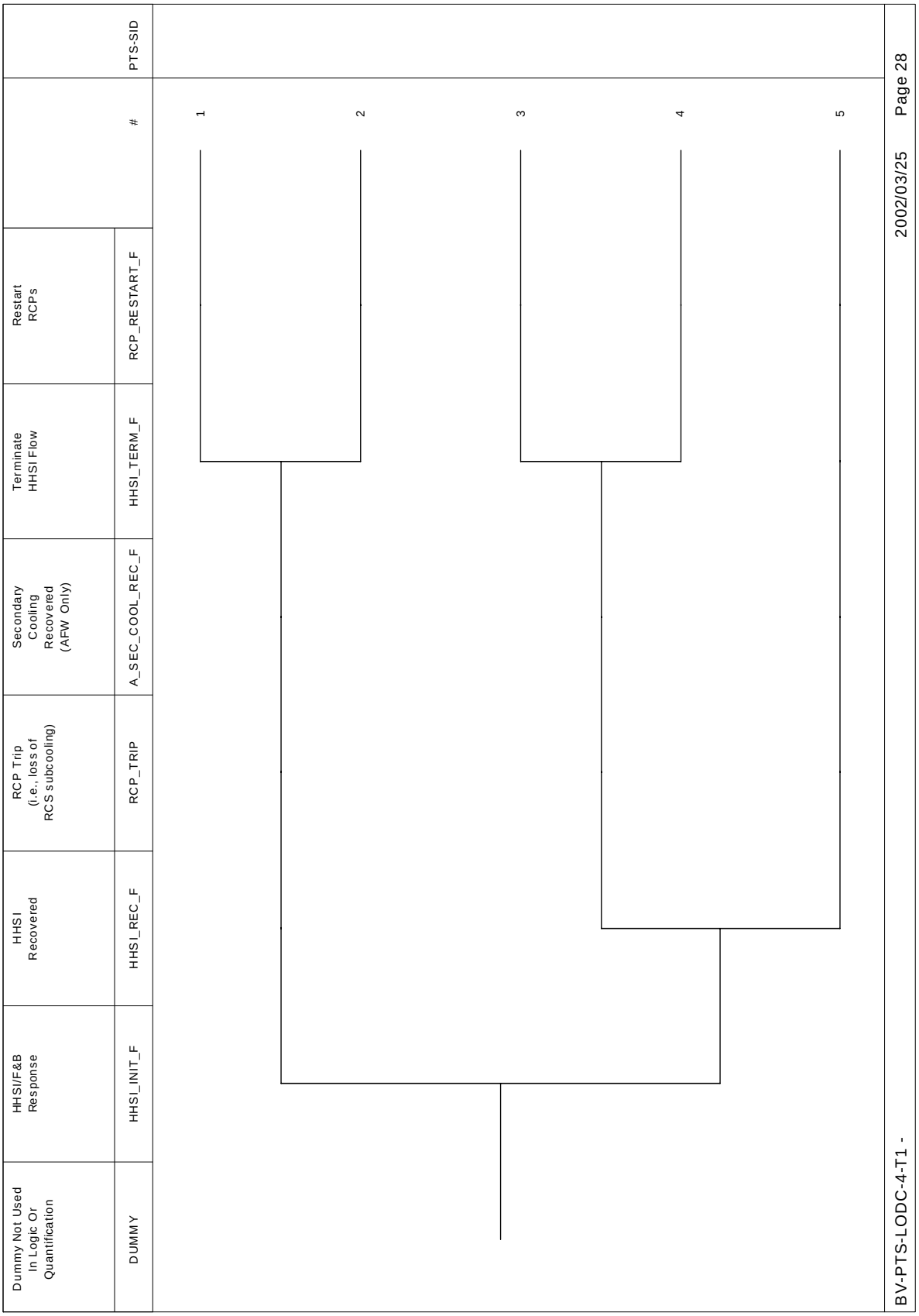

Figure 4.29. Beaver Valley LODC-4-T1: Loss of 125V DC orange or purple bus–at least one SRV initially open (HHSI not F&B).

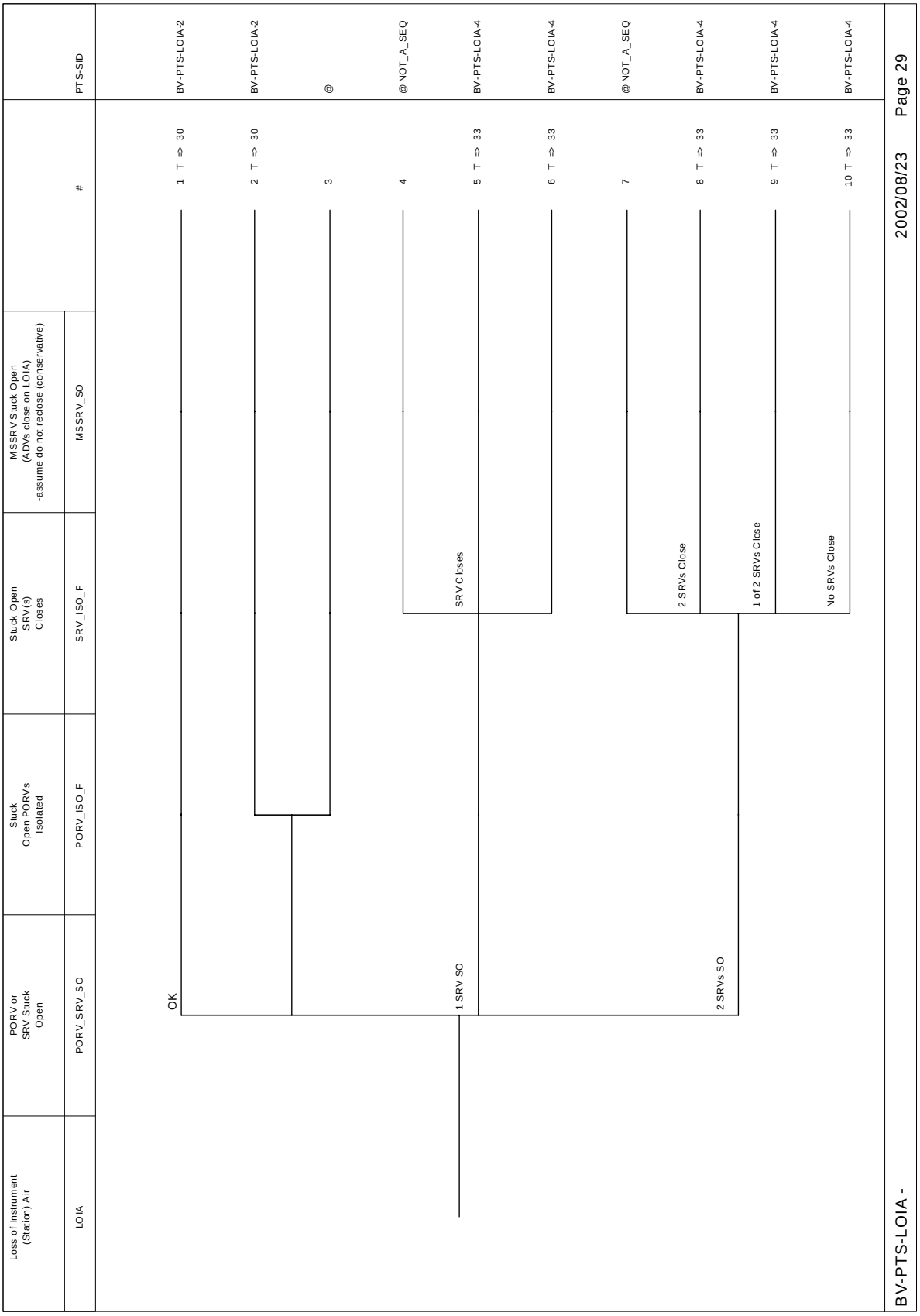

Figure 4.30. Beaver Valley LOIA: Loss of instrument (station) air.

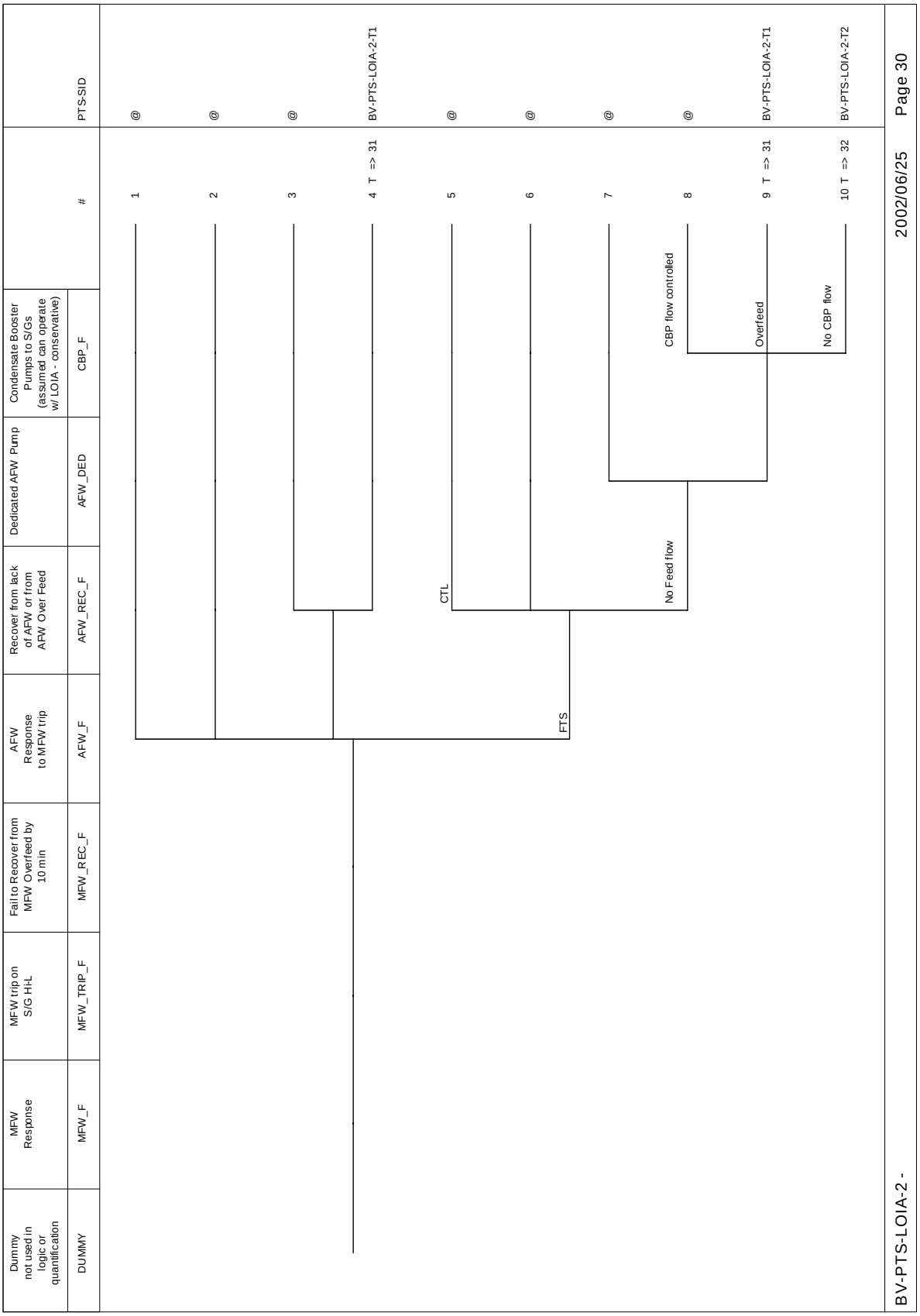

Figure 4.31. Beaver Valley LOIA-2: Loss of instrument (station) air (primary system intact).

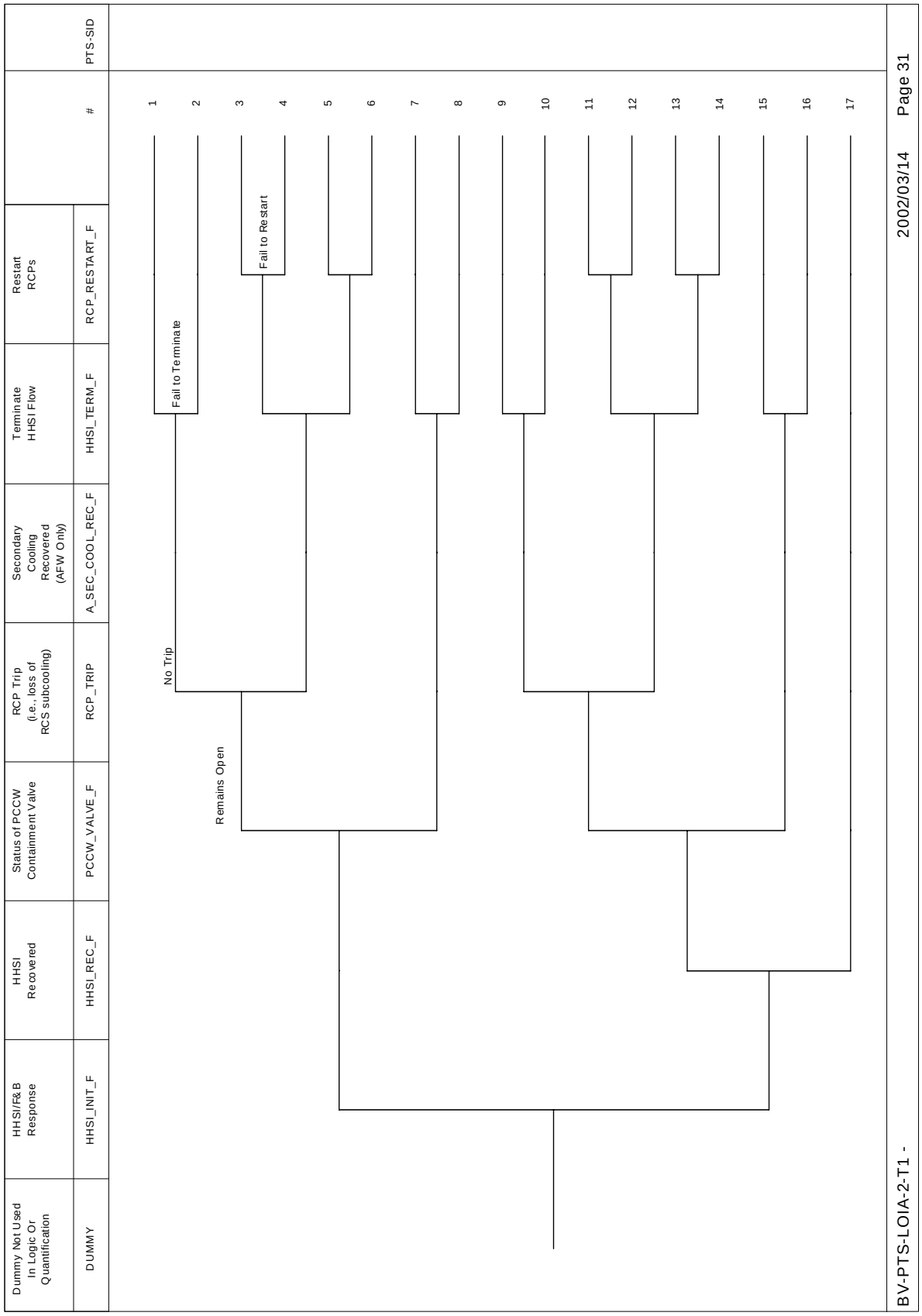

Figure 4.32. Beaver Valley LOIA-2-T1: Loss of instrument (station) air–primary system intact (HHSI not F&B).

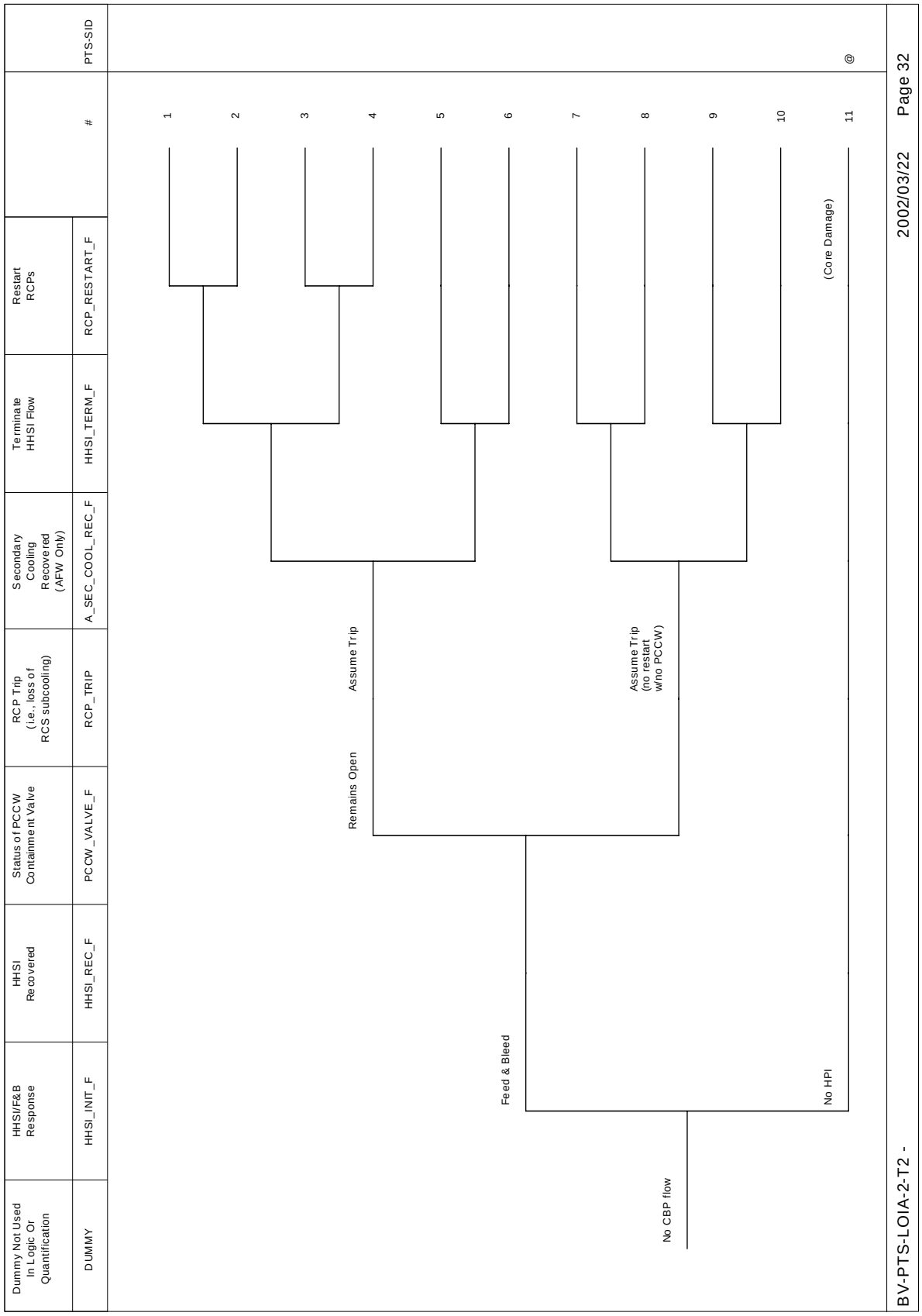

Figure 4.33. Beaver Valley LOIA-2-T2: Loss of instrument (station) air–primary system intact (HHSI F&B).

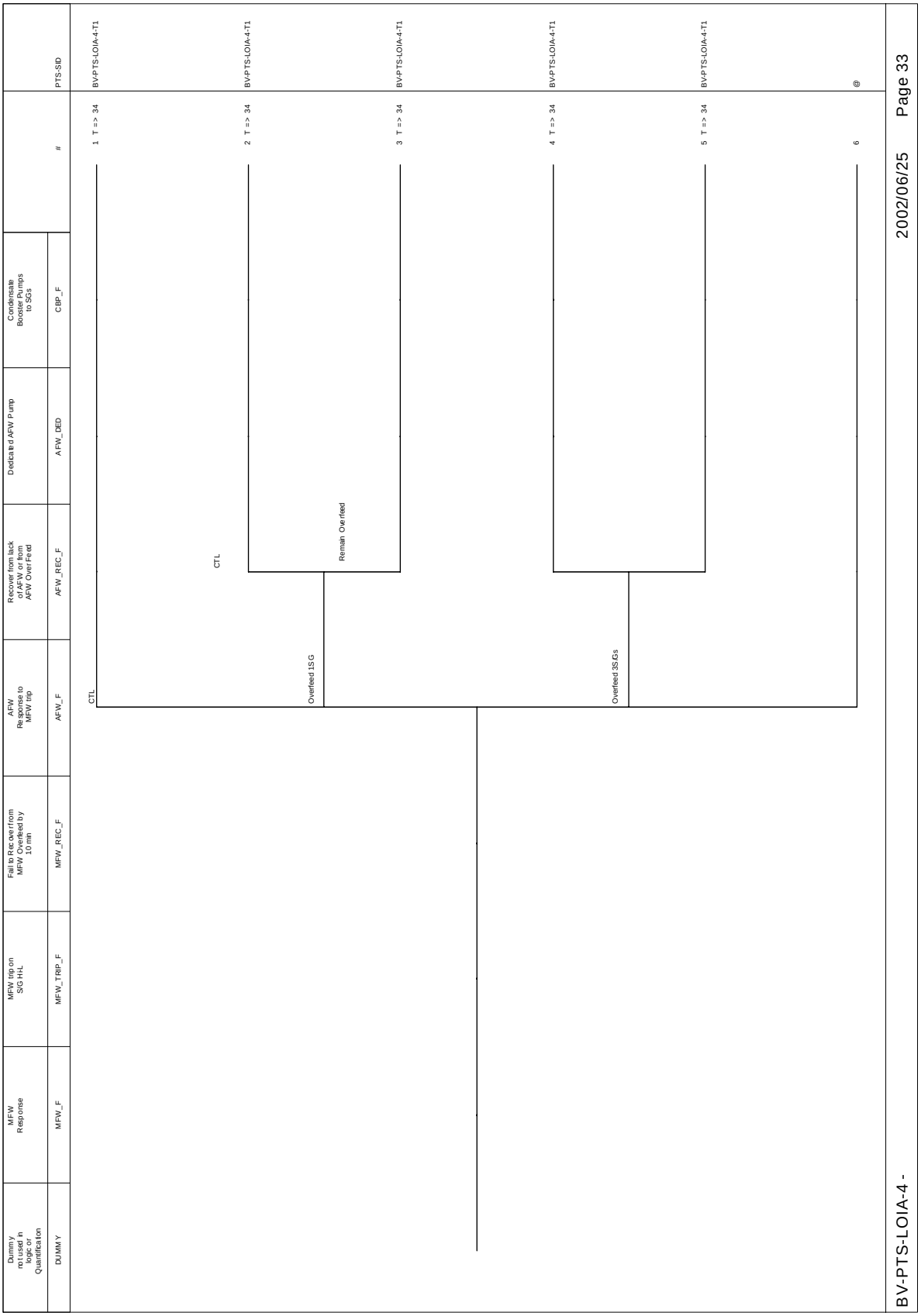

Figure 4.34. Beaver Valley LOIA-4: Loss of instrument (station) air (at least one SRV initially open).

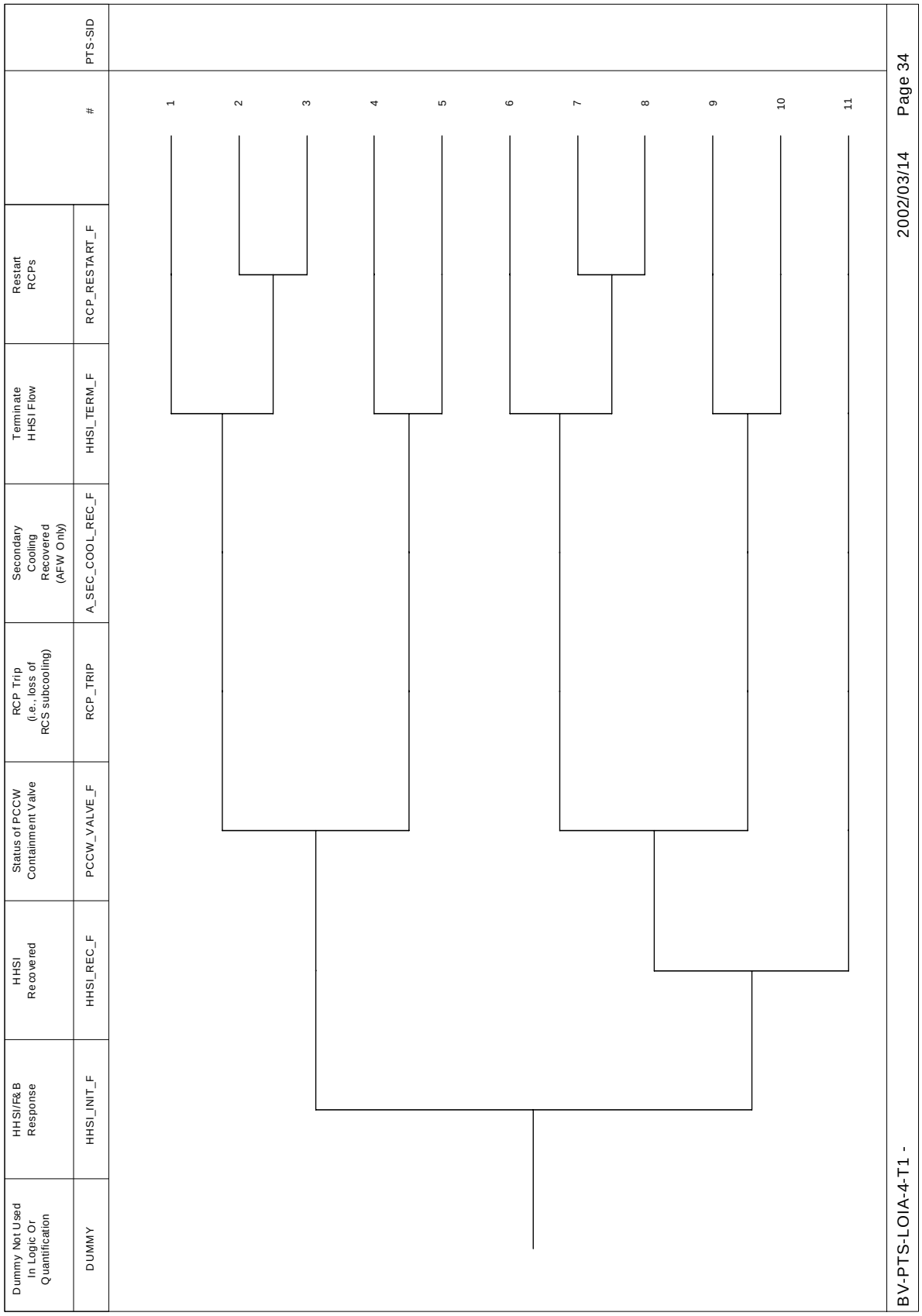

Figure 4.35. Beaver Valley LOIA-4-T1: Loss of instrument (station) air–at least one SRV initially open (HHSI not F&B).

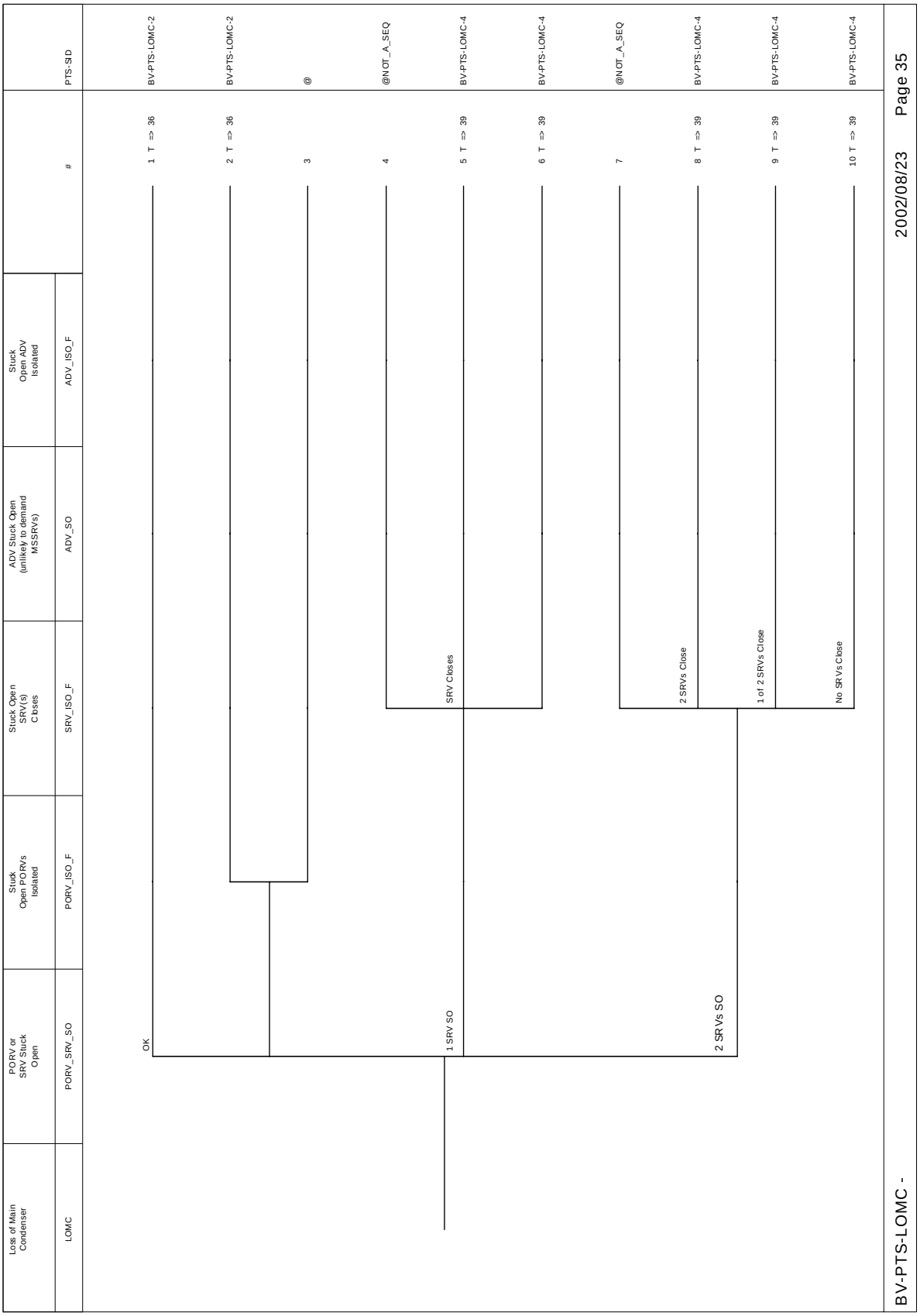

Figure 4.36. Beaver Valley LOMC: Loss of main condenser.

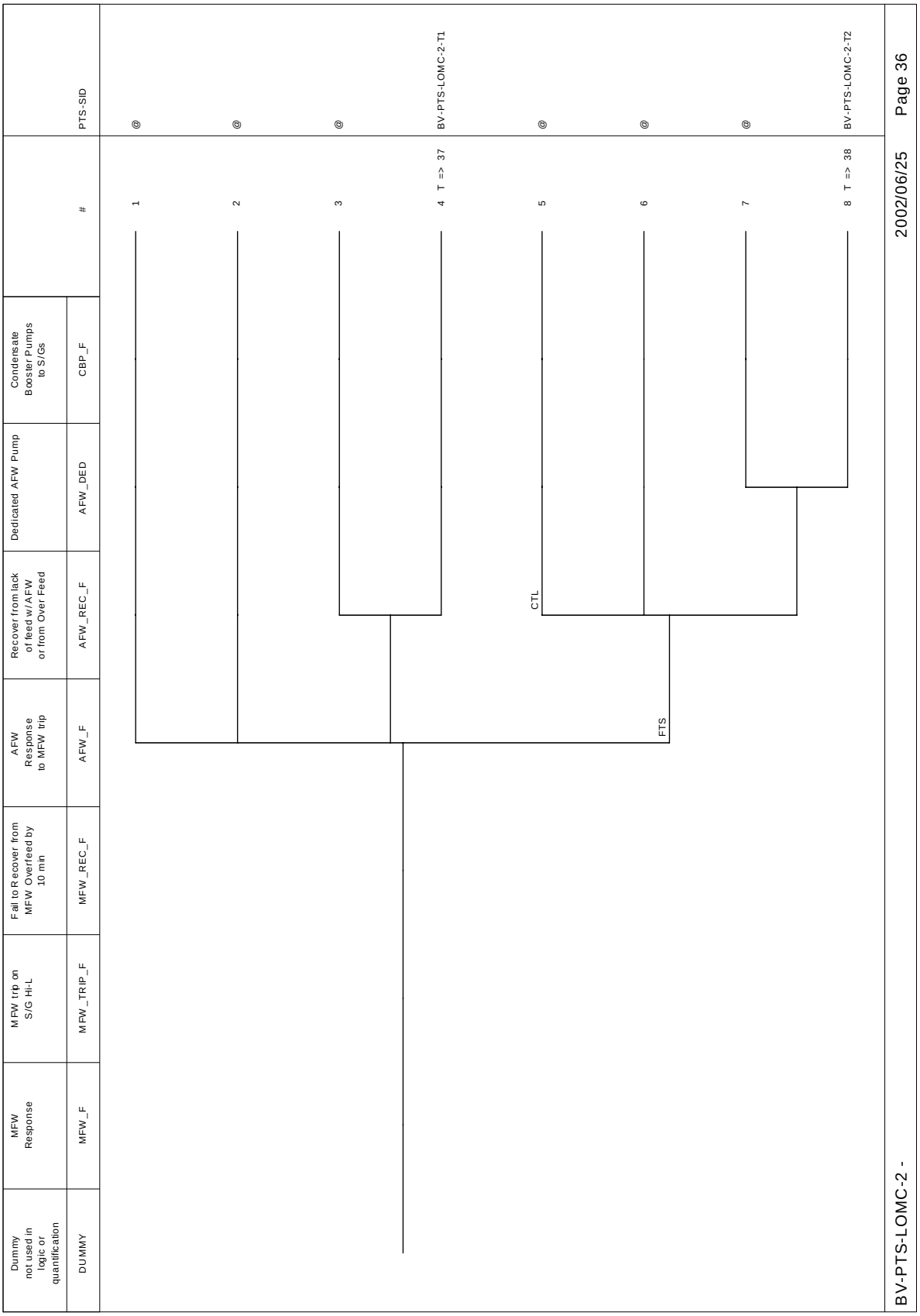

Figure 4.37. Beaver Valley LOMC-2: Loss of main condenser (primary system intact).

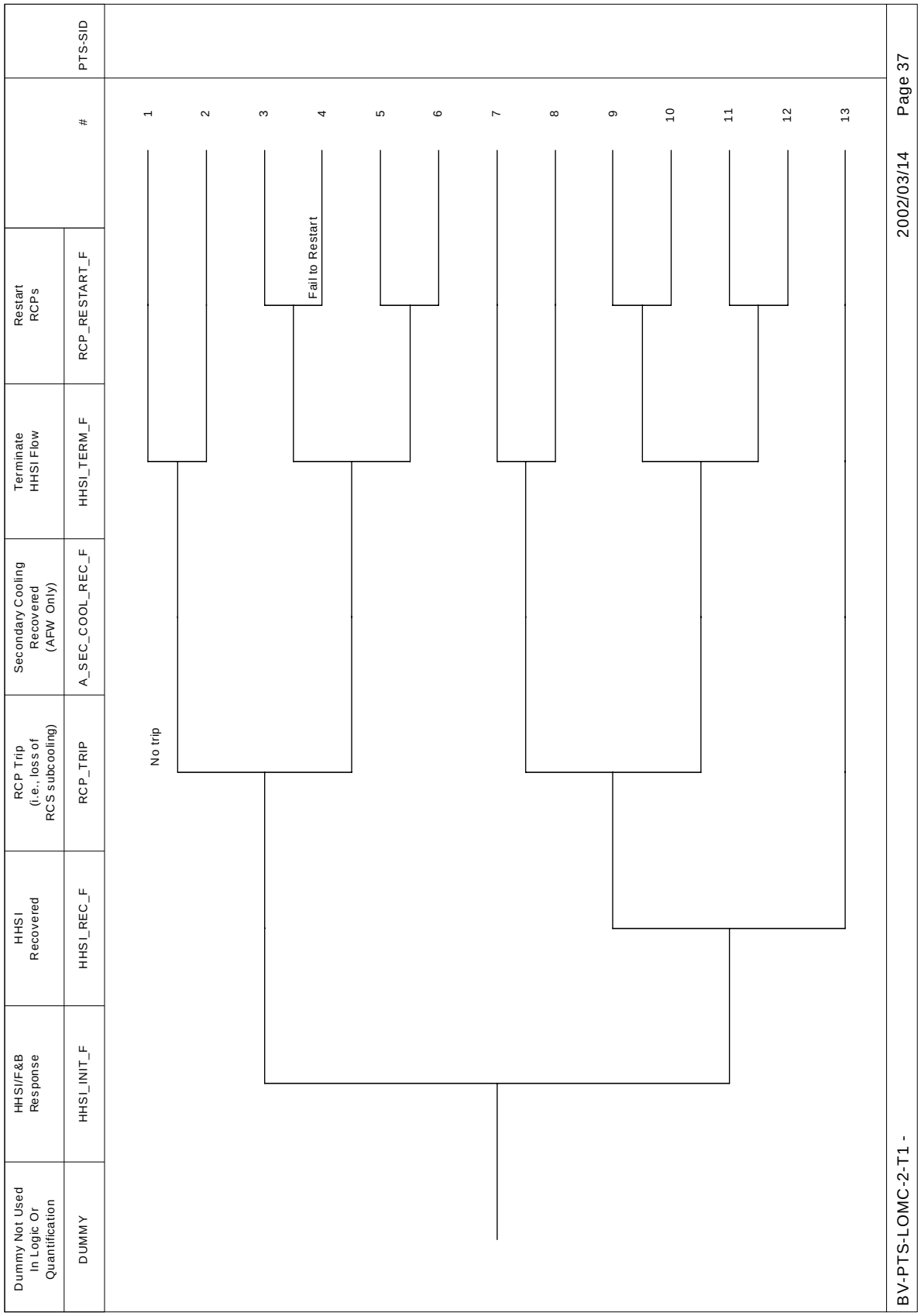

Figure 4.38. Beaver Valley LOMC-2-T1: Loss of main condenser–primary system intact (HHSI not F&B).

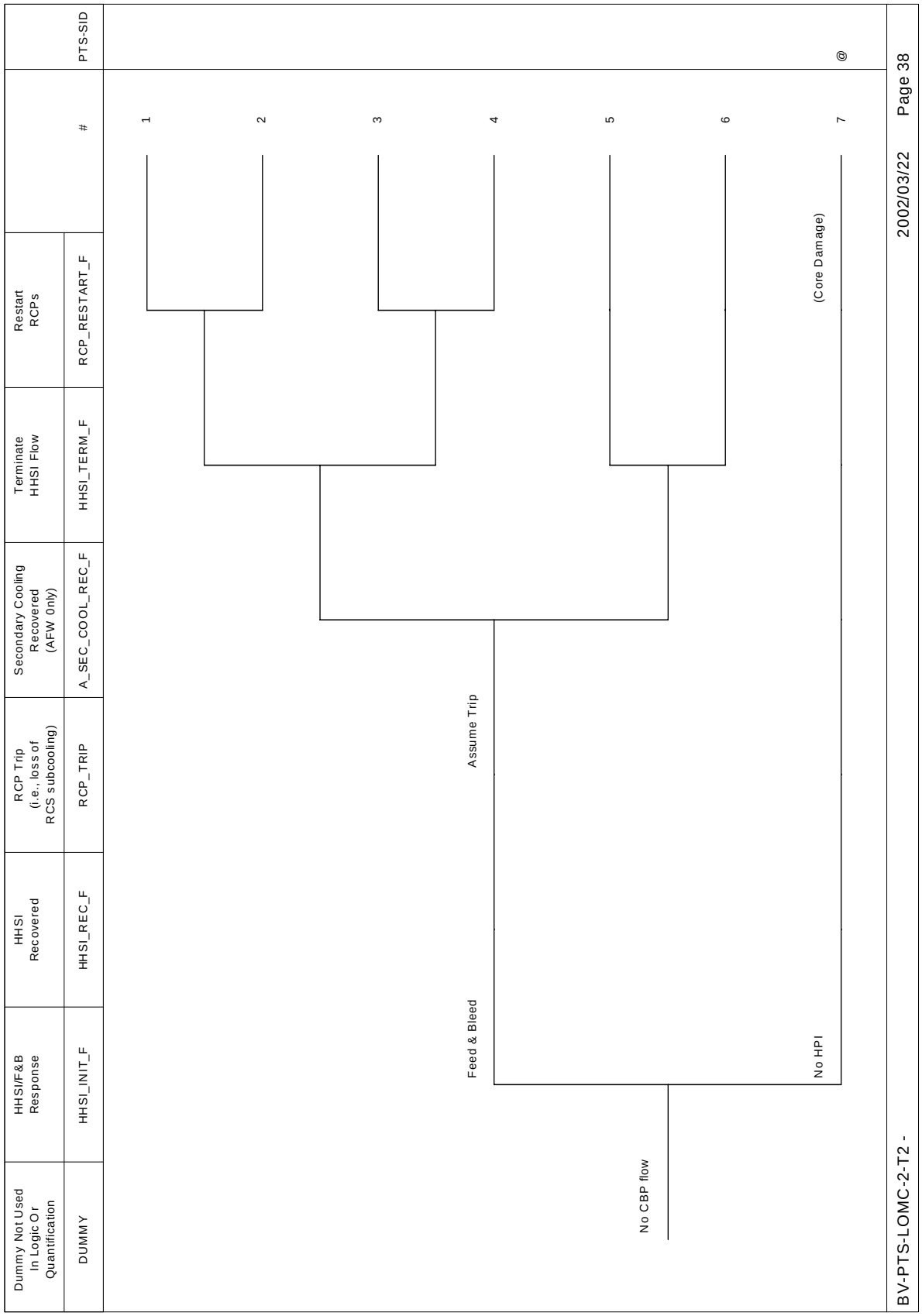

Figure 4.39. Beaver Valley LOMC-2-T2: Loss of main condenser–primary system intact (HHSI F&B).

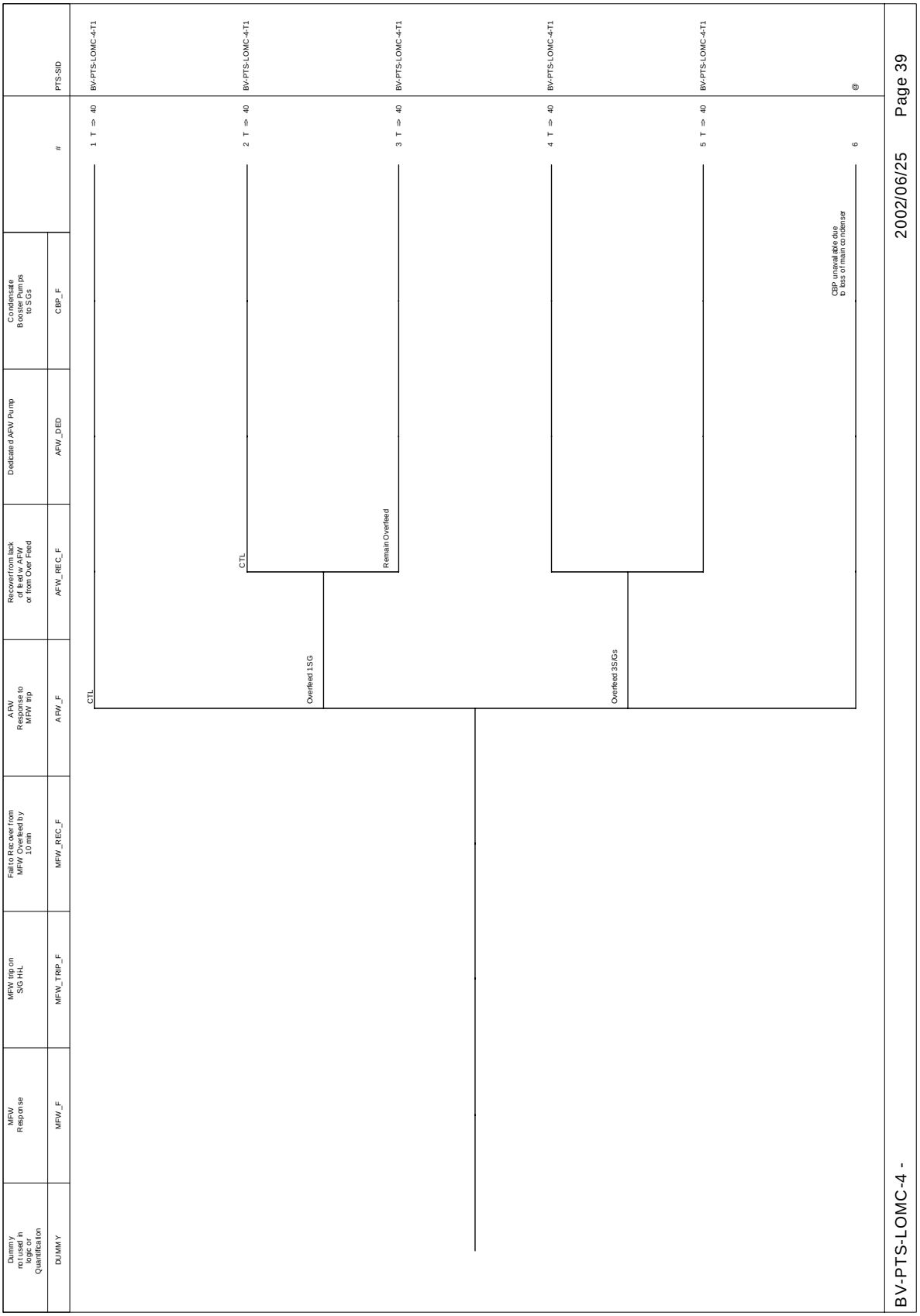

Figure 4.40. Beaver Valley LOMC-4: Loss of main condenser (at least one SRV initially open).

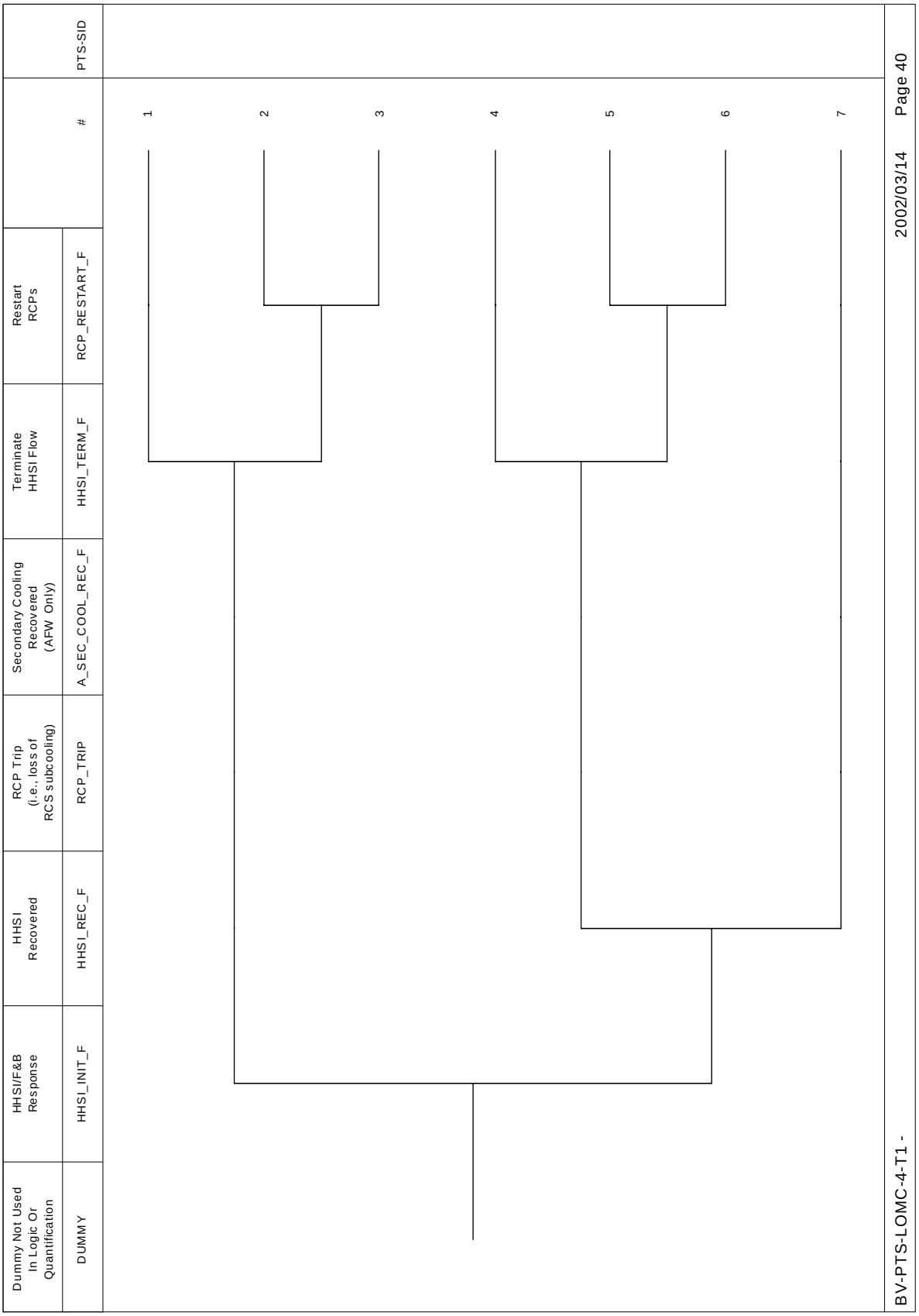

Figure 4.41. Beaver Valley LOMC-4-T1: Loss of main condenser–at least one SRV initially open (HHSI not F&B).

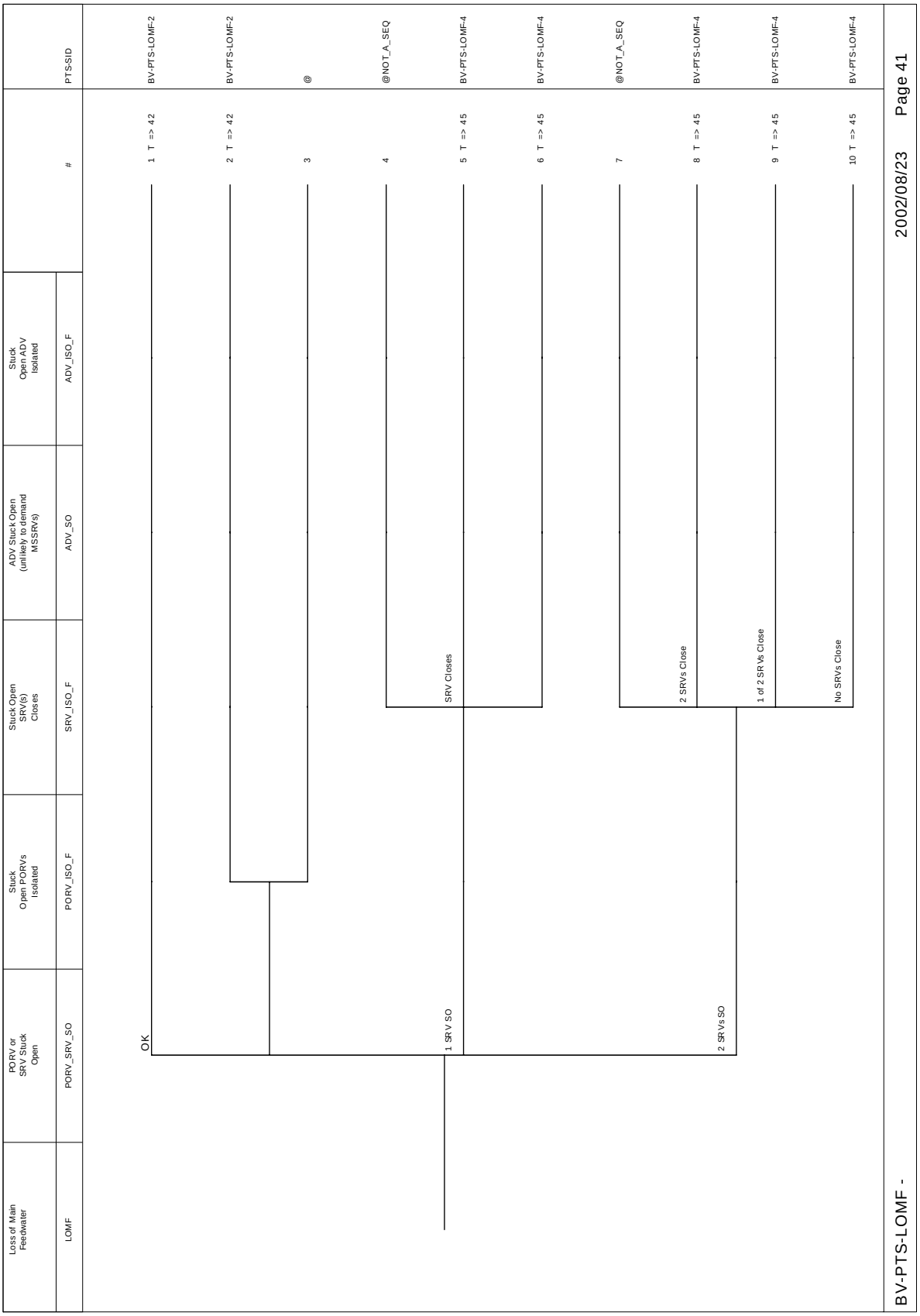

Figure 4.42. Beaver Valley LOMF: Loss of main feedwater.

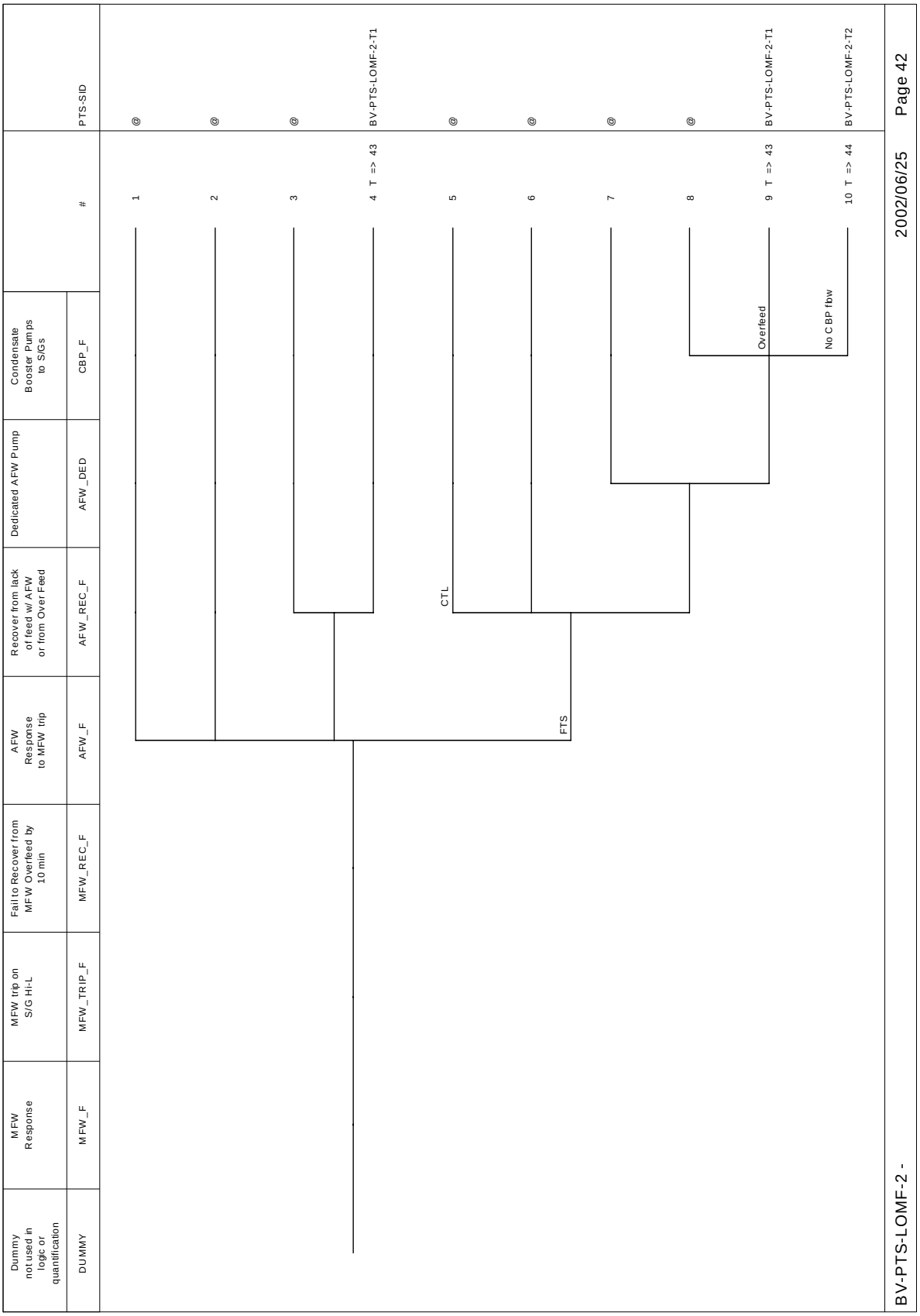

Figure 4.43. Beaver Valley LOMF-2: Loss of main feedwater (primary system intact).

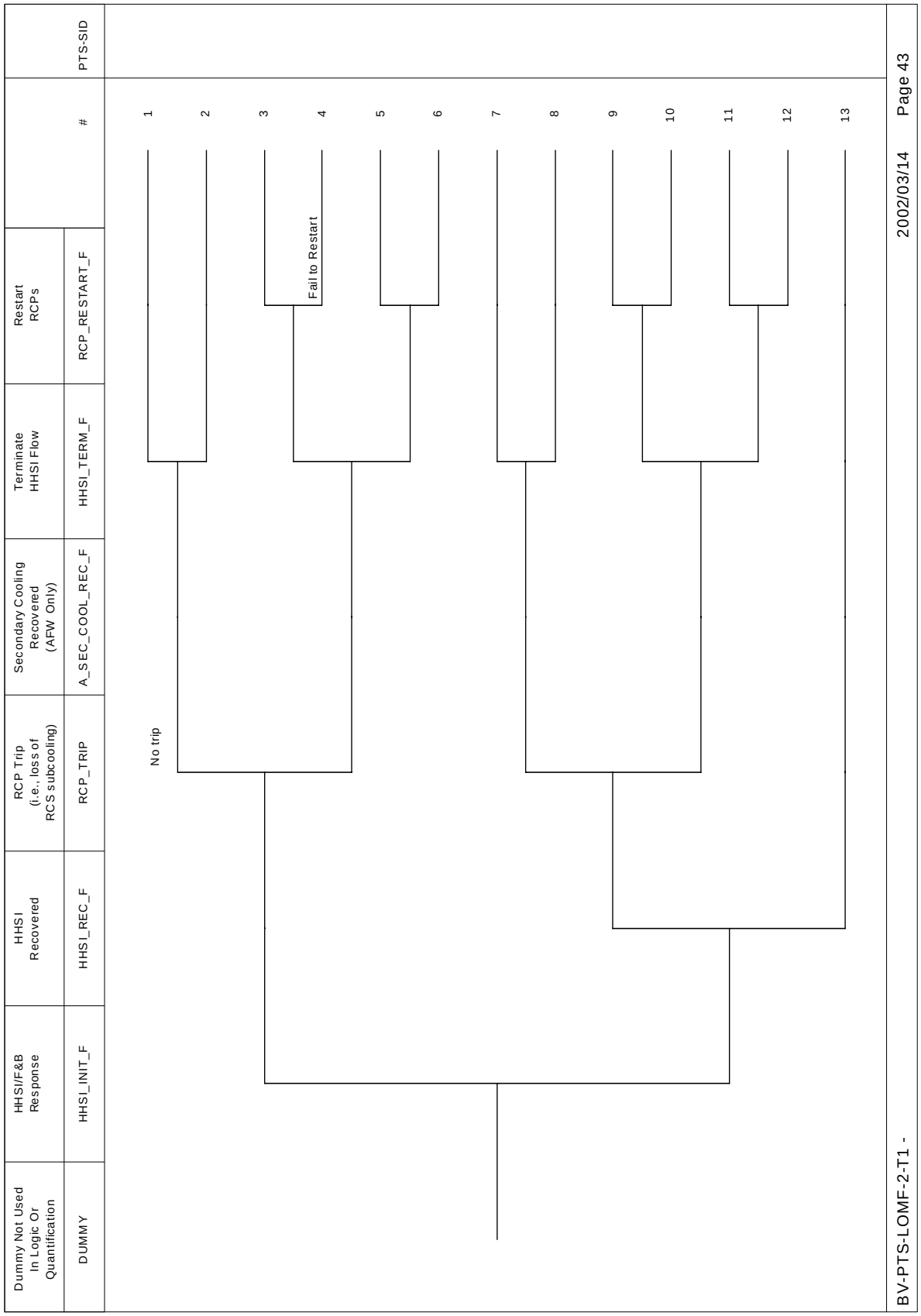

Figure 4.44. Beaver Valley LOMF-2-T1: Loss of main feedwater–primary system intact (HHSI not F&B).

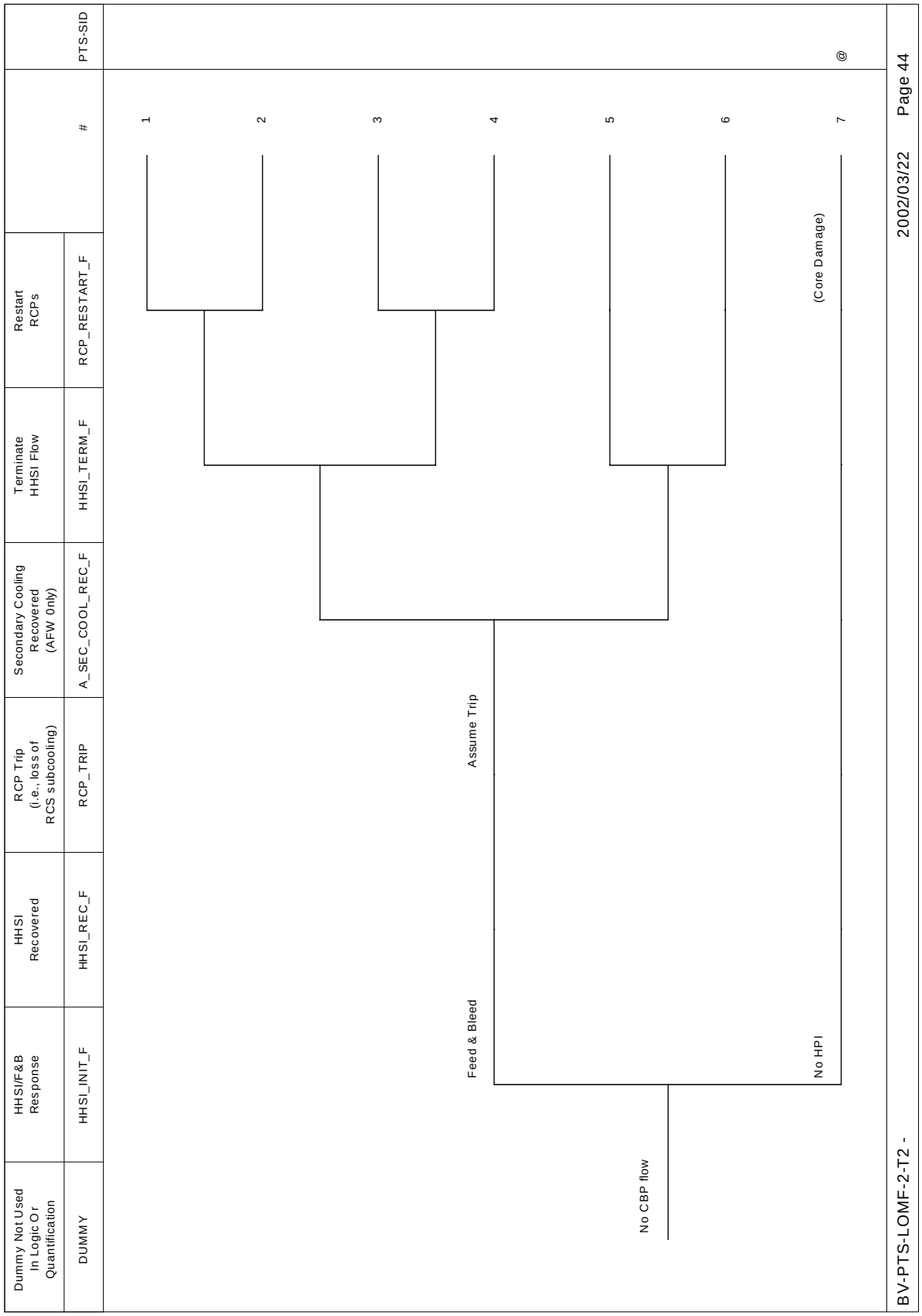

Figure 4.45. Beaver Valley LOMF-2-T2: Loss of main feedwater–primary system intact (HHSI F&B).

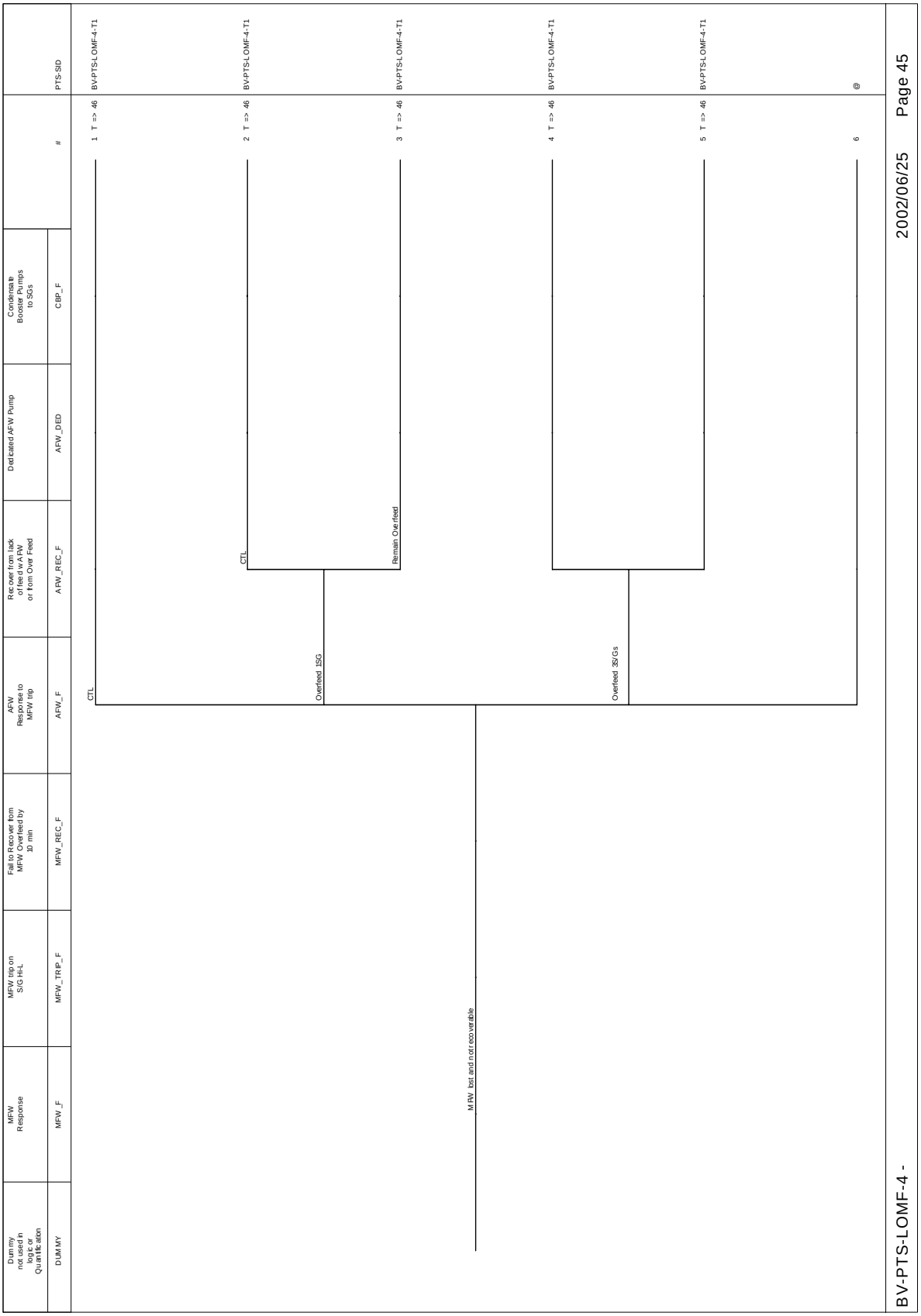

Figure 4.46. Beaver Valley LOMF-4: Loss of main feedwater (at least one SRV initially open).

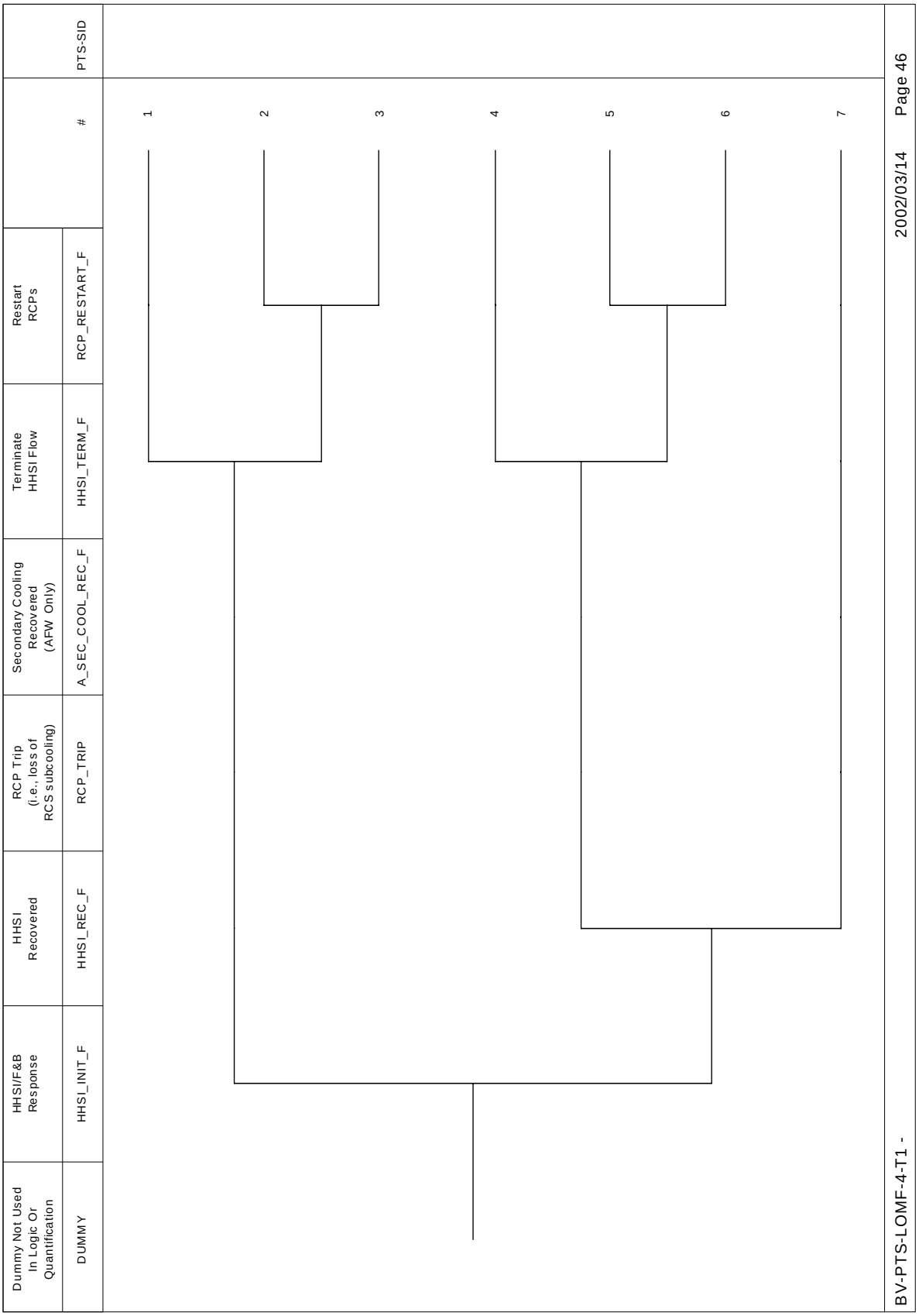

Figure 4.47. Beaver Valley LOMF-4-T1: Loss of main feedwater–at least one SRV initially open (HHSI not F&B).

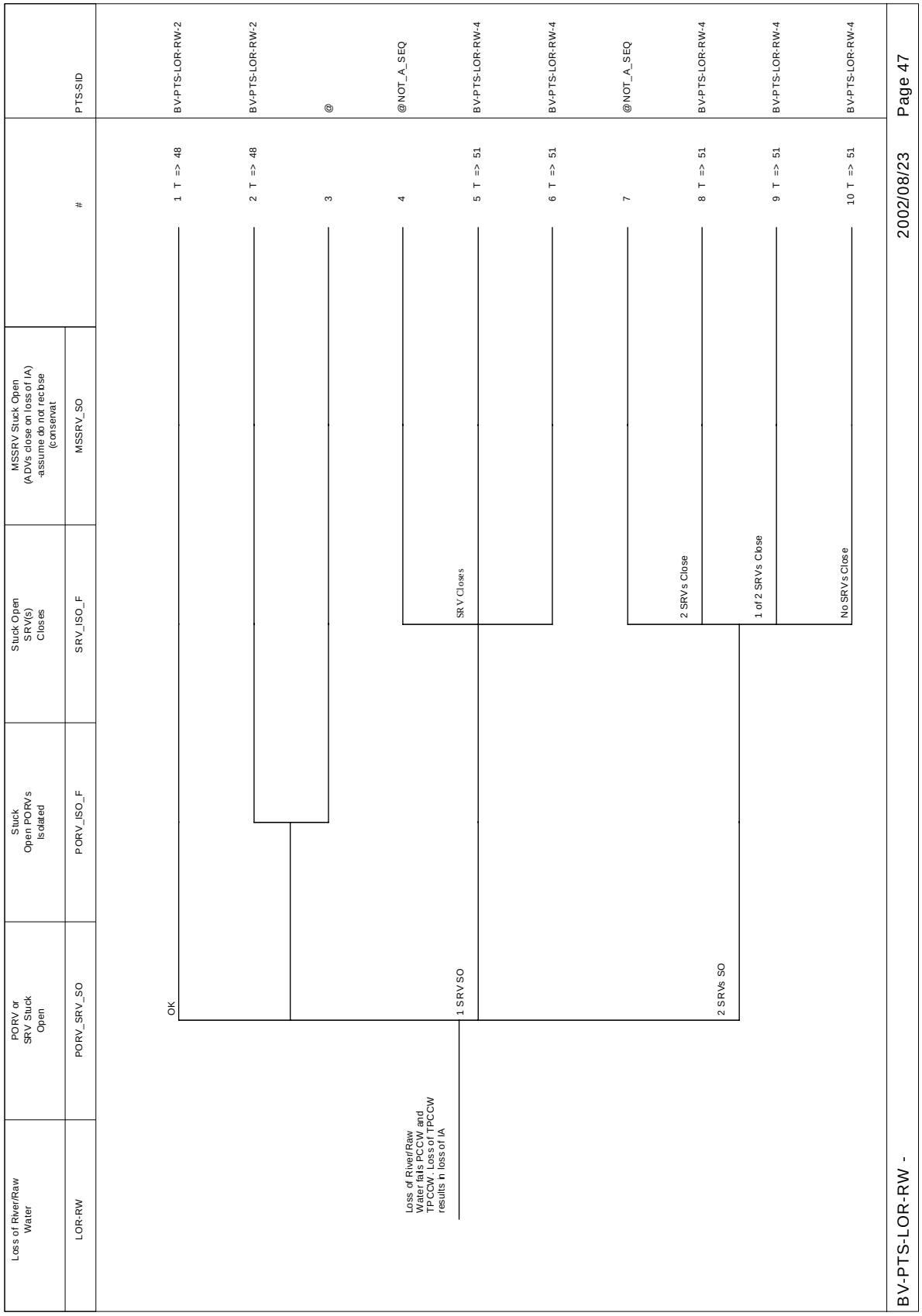

Figure 4.48. Beaver Valley LOR-RW: Loss of river/raw water.

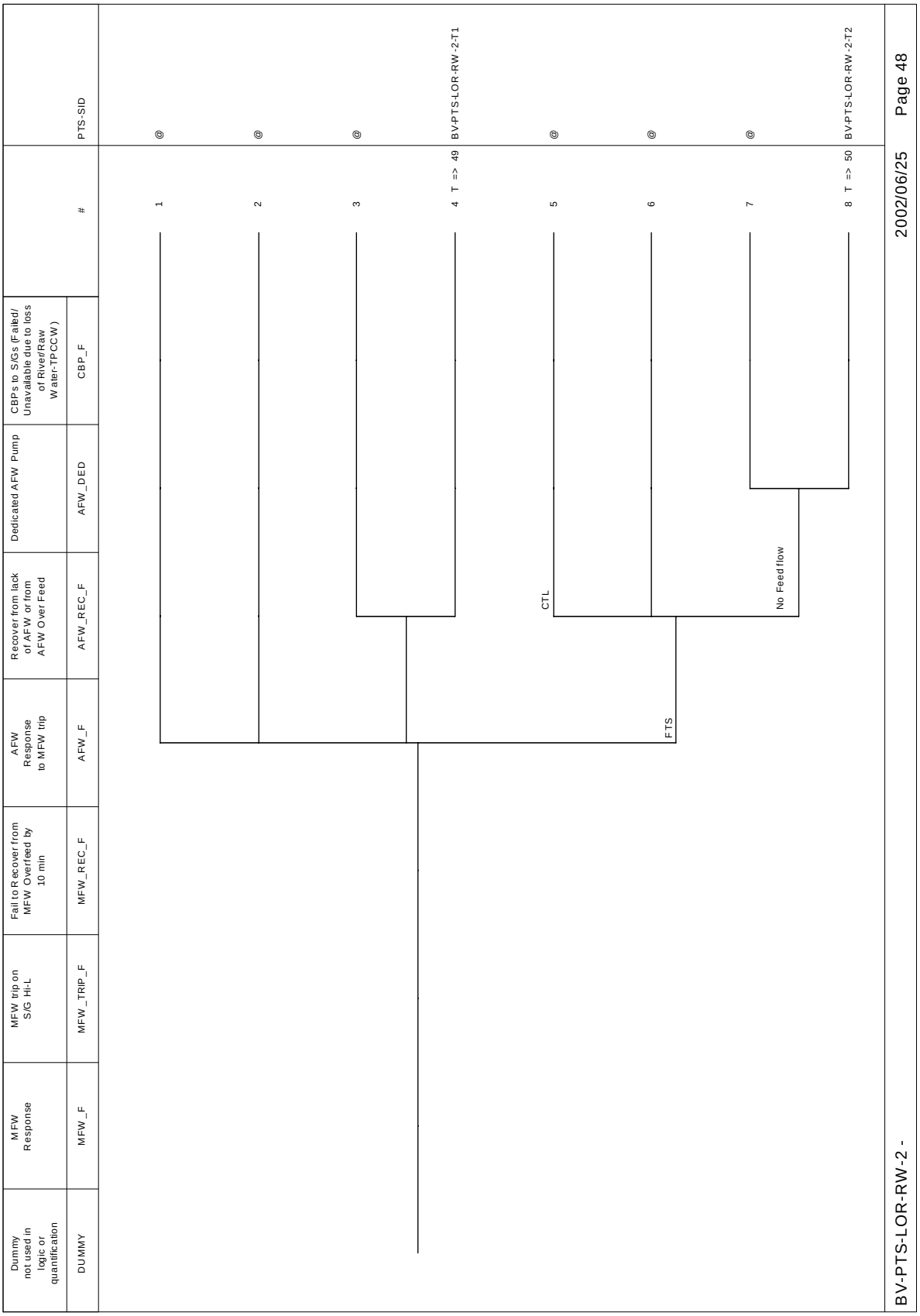

Figure 4.49. Beaver Valley LOR-RW-2: Loss of river/raw water (primary system intact).

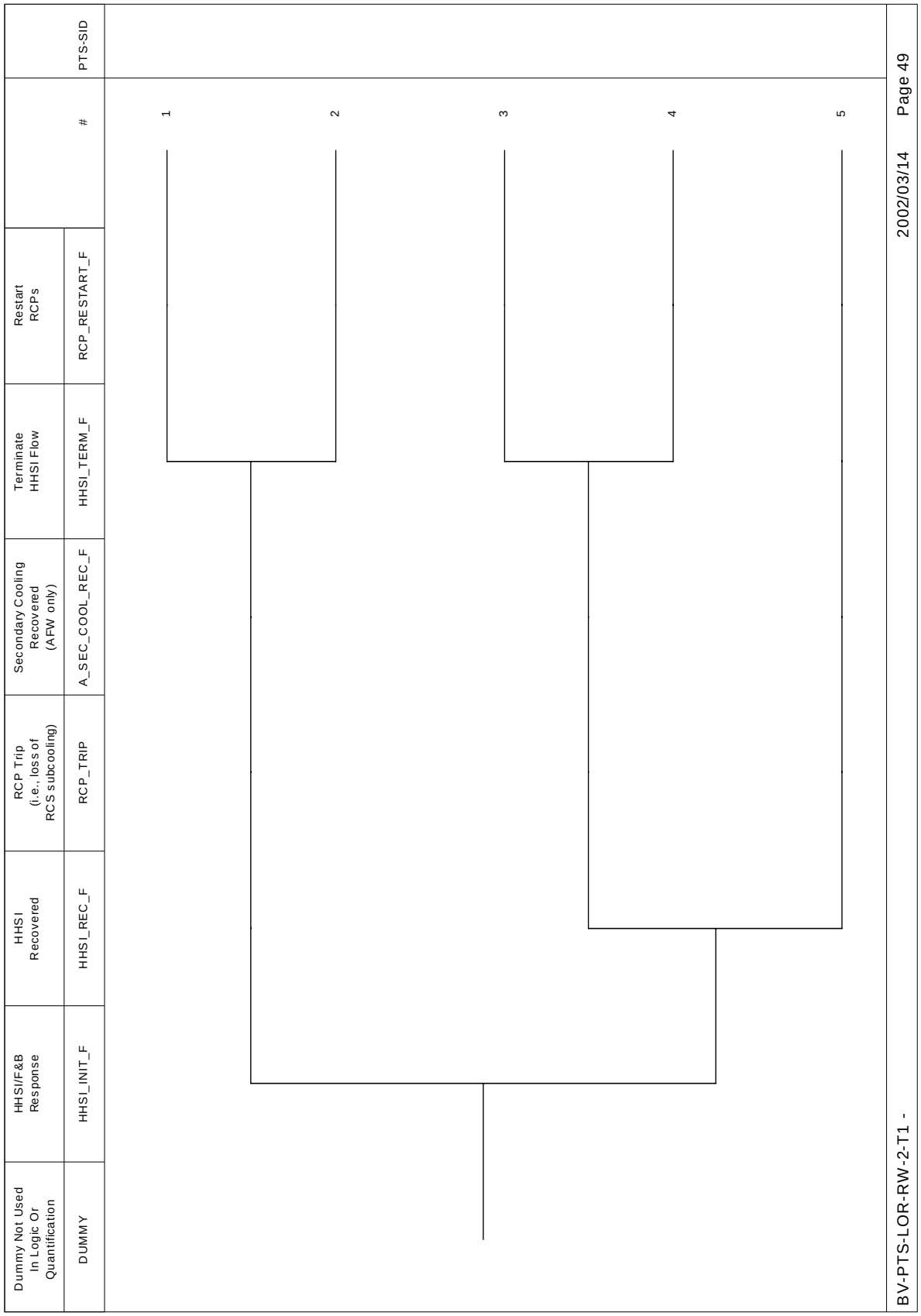

Figure 4.50. Beaver Valley LOR-RW-2-T1: Loss of river/raw water–primary system intact (HHSI not F&B).

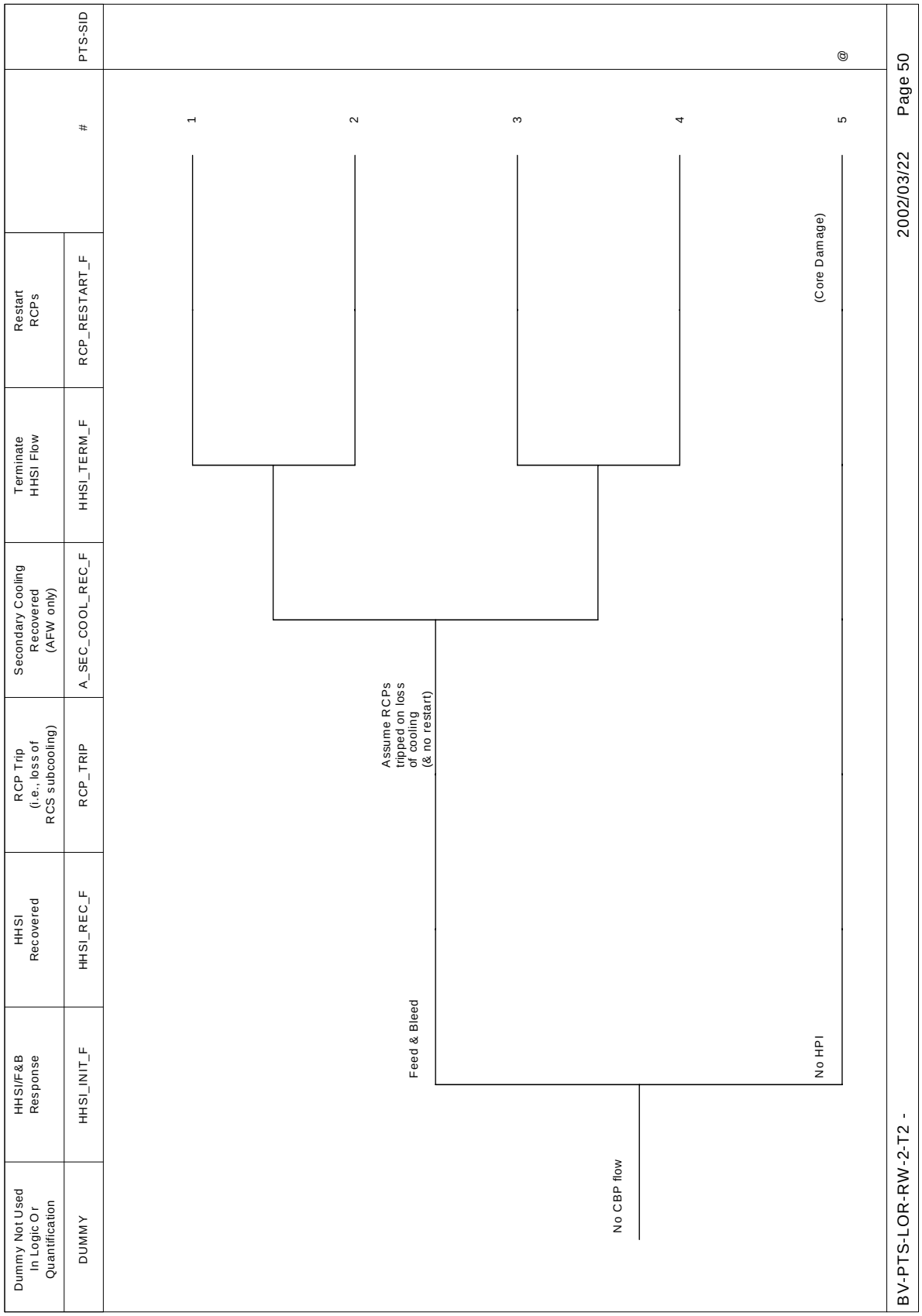

Figure 4.51. Beaver Valley LOR-RW-2-T2: Loss of river/raw water–primary system intact (HHSI F&B).

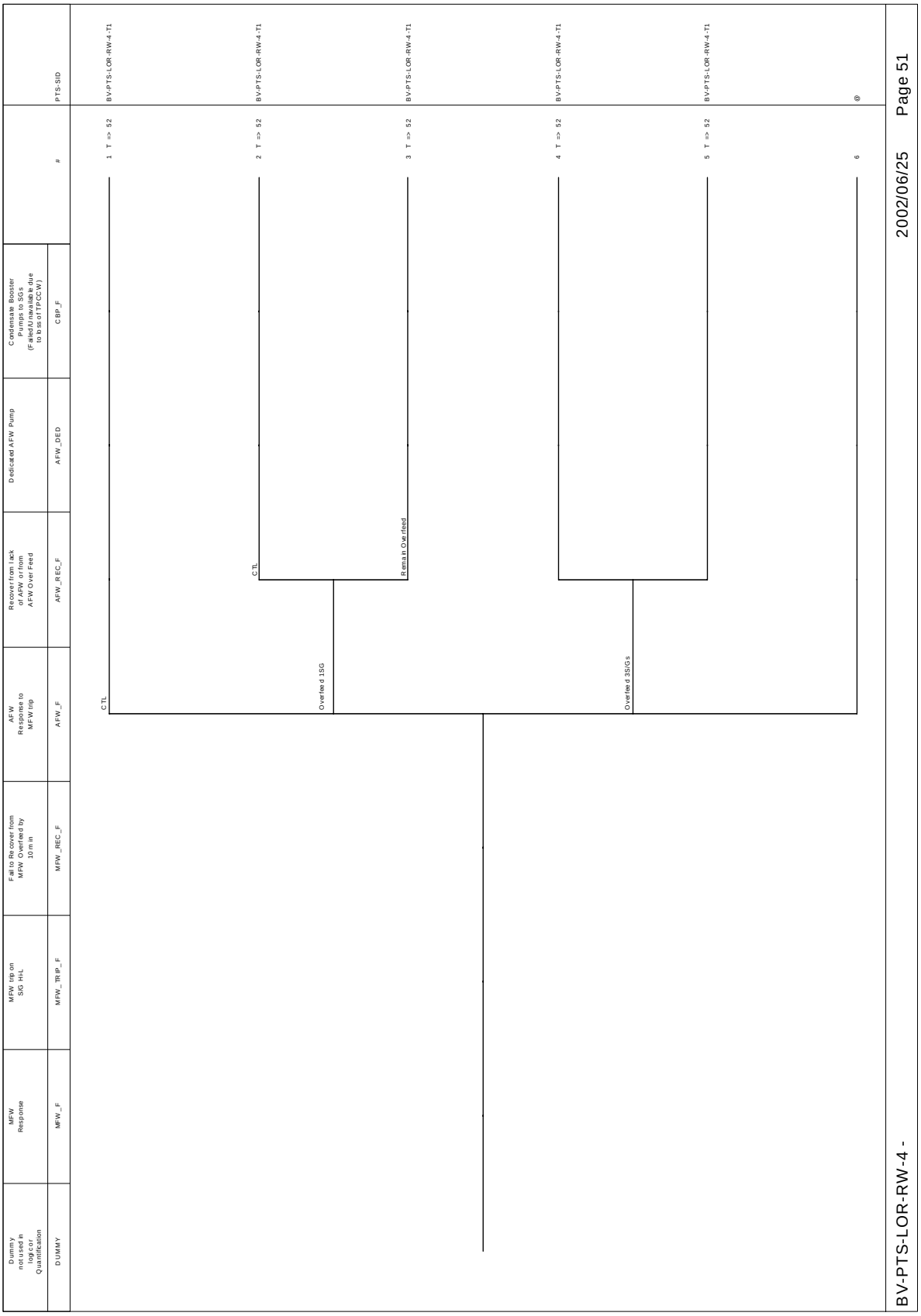

Figure 4.52. Beaver Valley LOR-RW-4: Loss of river/raw water (at least one SRV initially open).

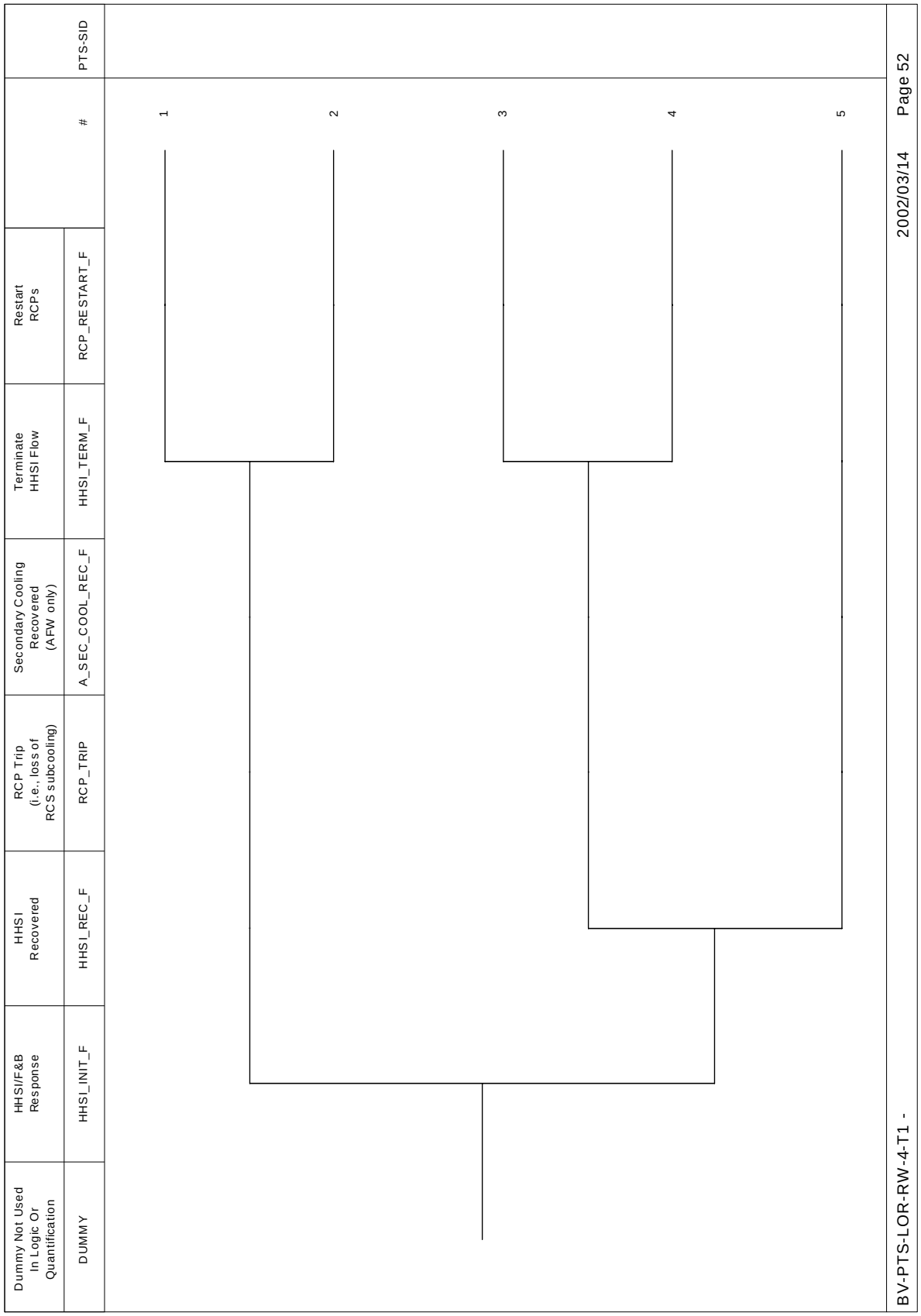

Figure 4.53. Beaver Valley LOR-RW-4-T1: Loss of river/raw water–at least one SRV initially open (HHSI not F&B).

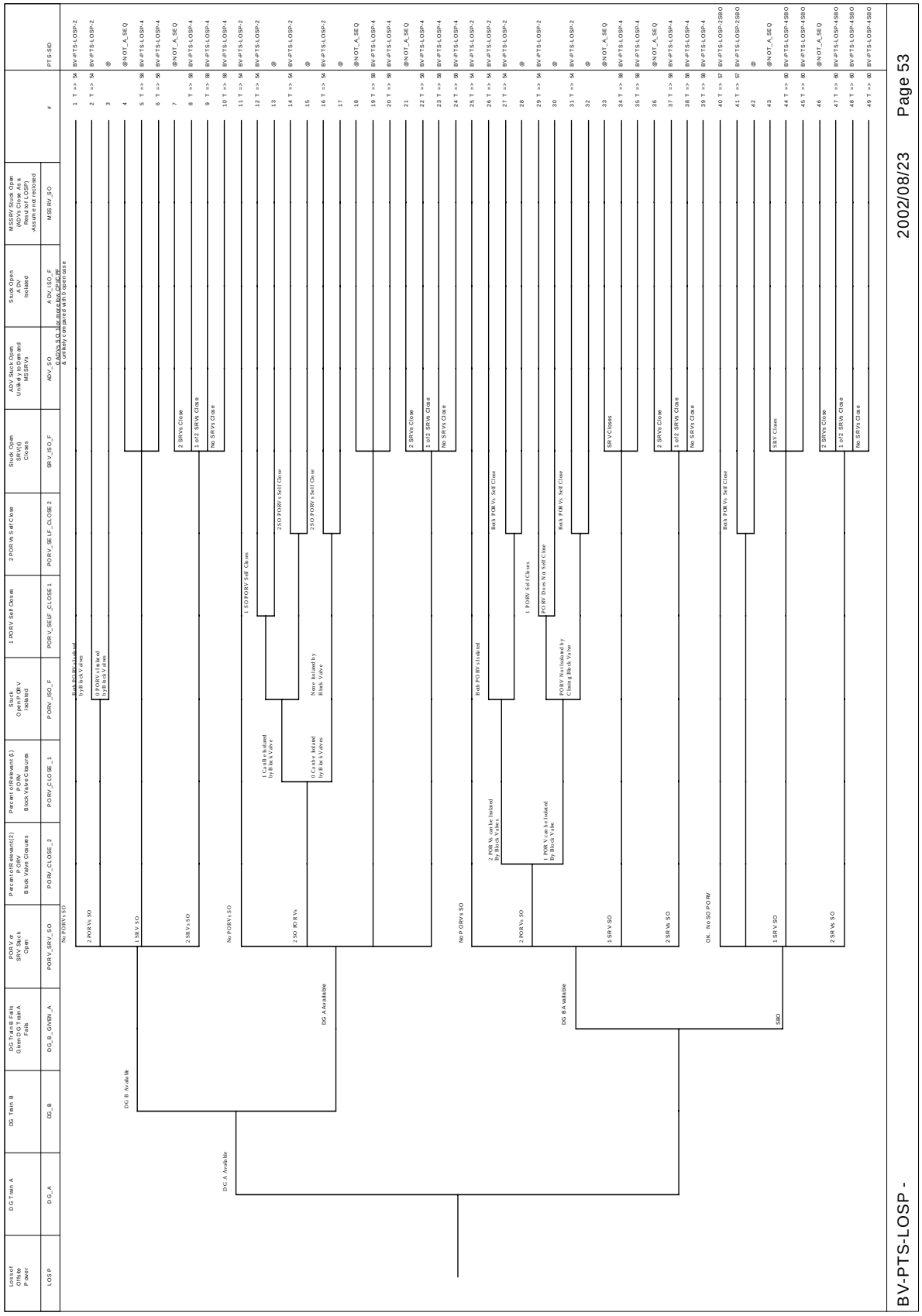

Figure 4.54. Beaver Valley LOSP: Loss of offsite power.

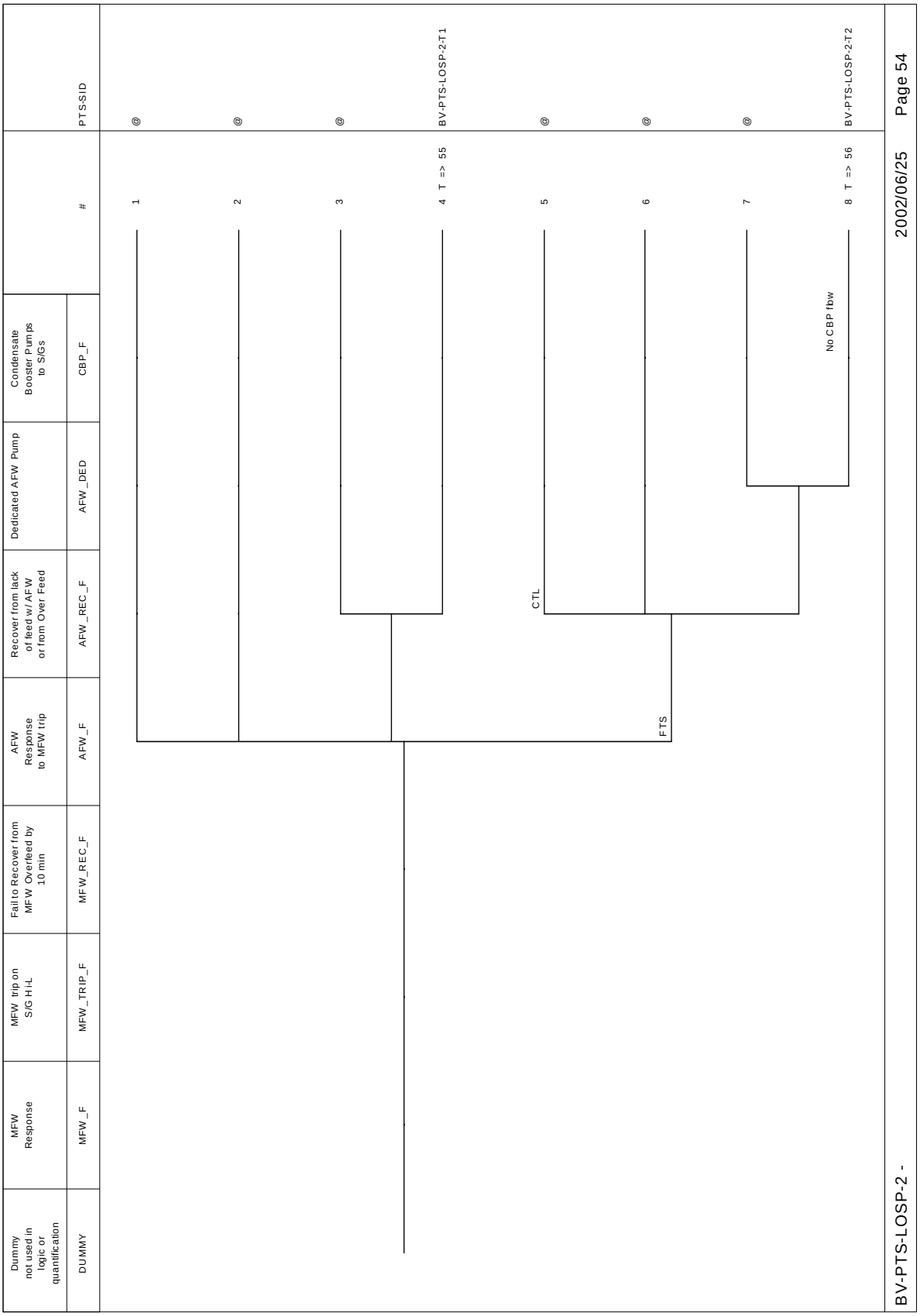

Figure 4.55. Beaver Valley LOSP-2: Loss of offsite power (primary system intact).

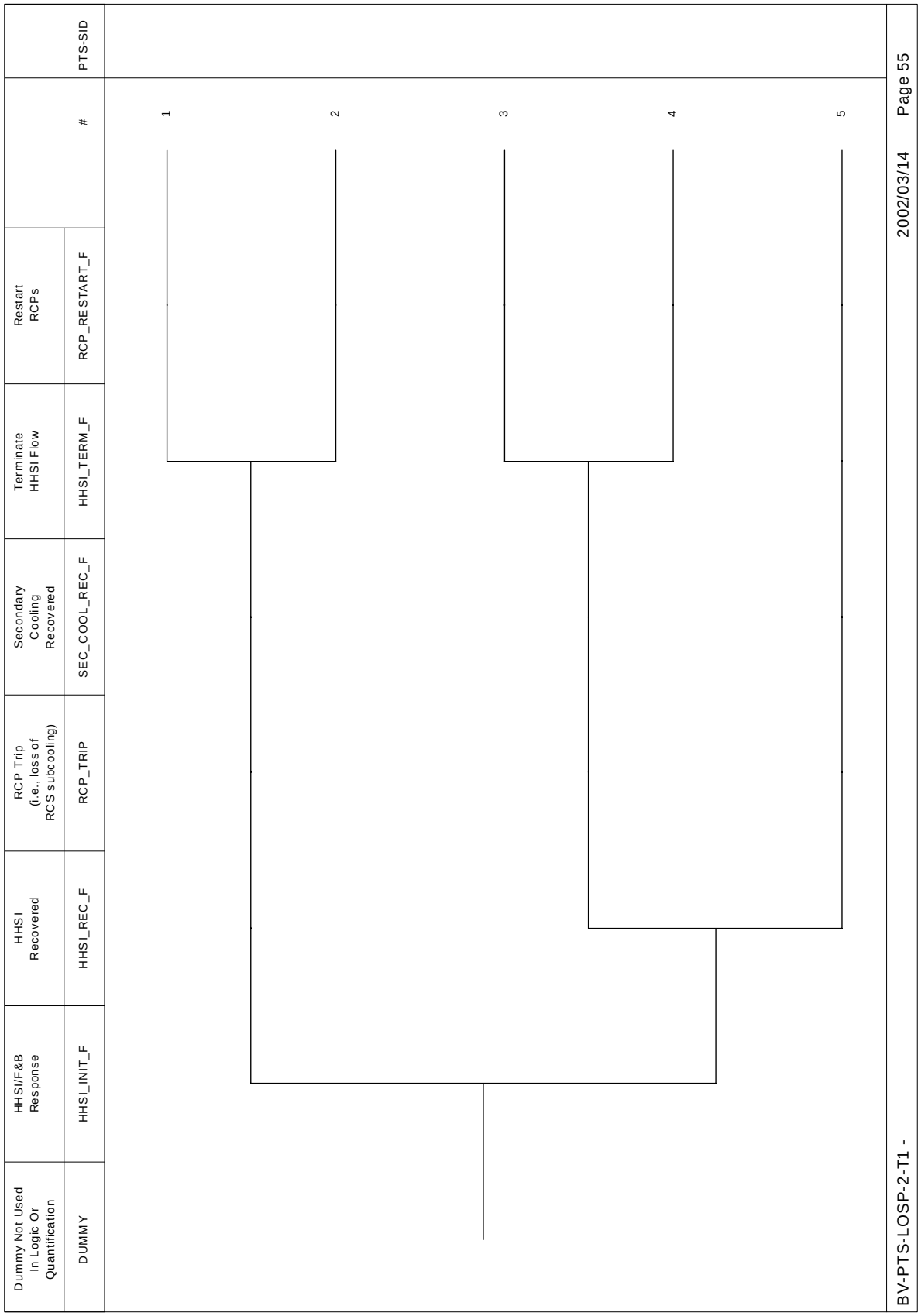

Figure 4.56. Beaver Valley LOSP-2-T1: Loss of offsite power–primary system intact (HHSI not F&B).

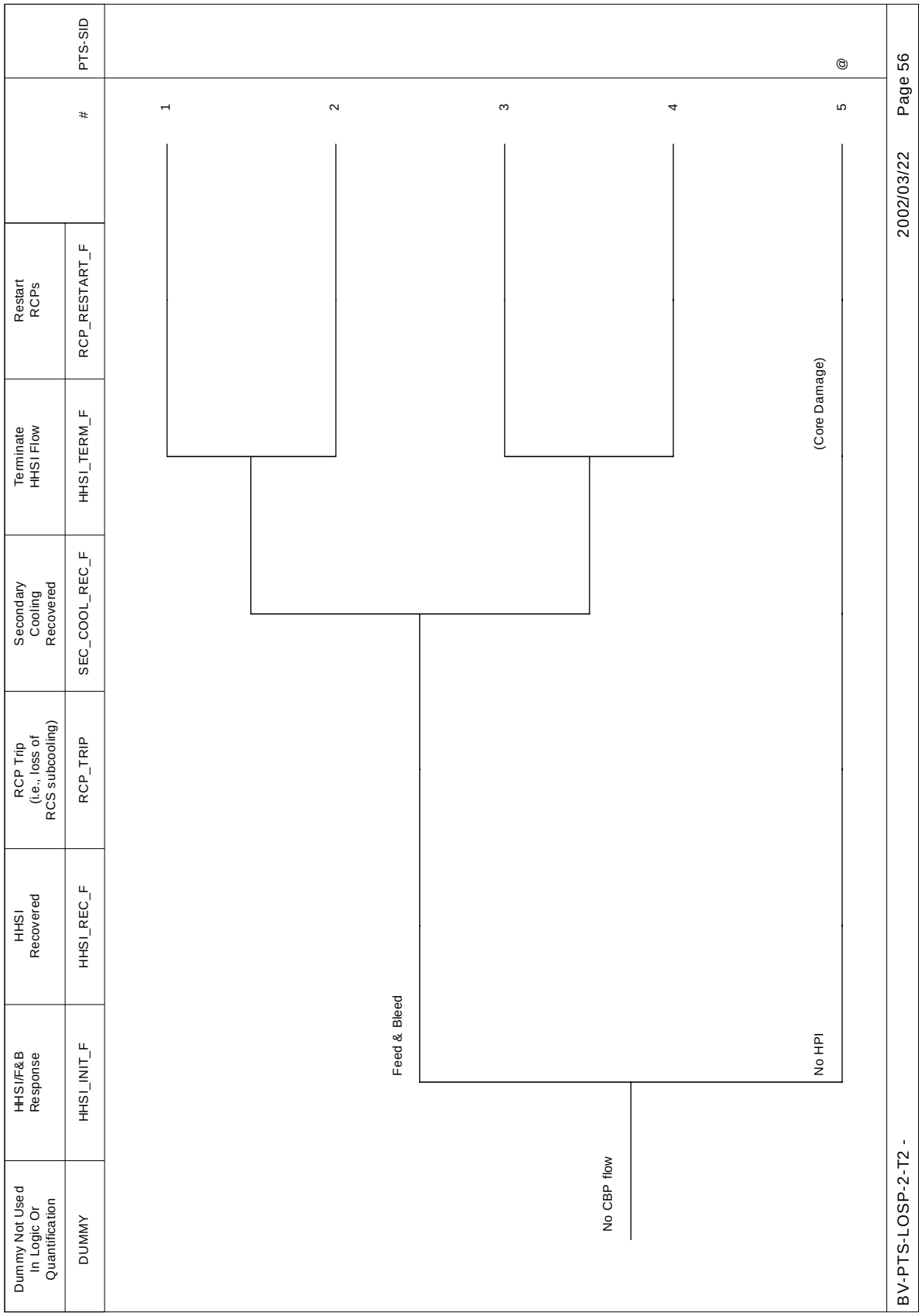

Figure 4.57. Beaver Valley LOSP-2-T2: Loss of offsite power–primary system intact (HHSI F&B).

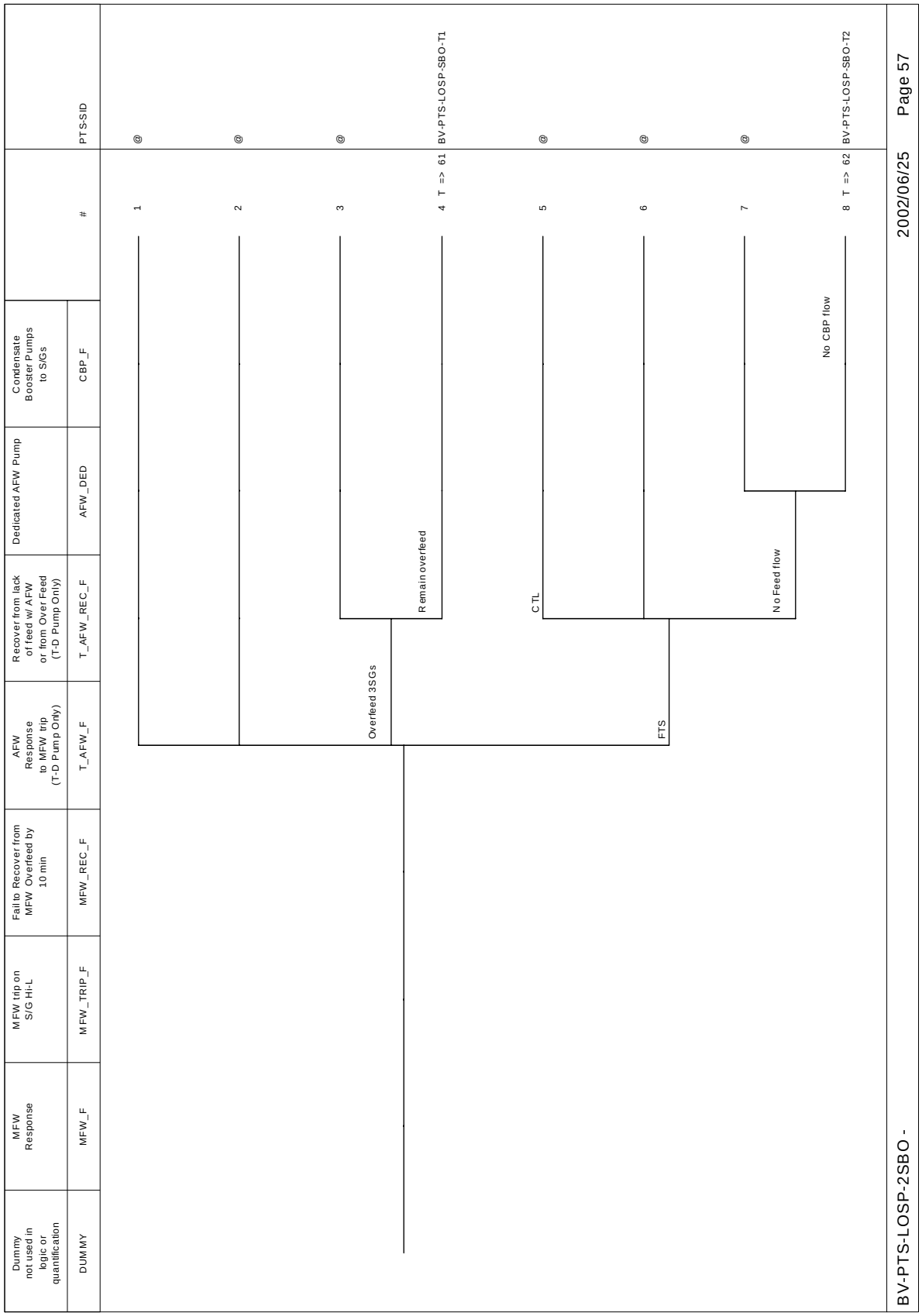

Figure 4.58. Beaver Valley LOSP-2SBO: Loss of offsite power (station blackout)–primary system intact.

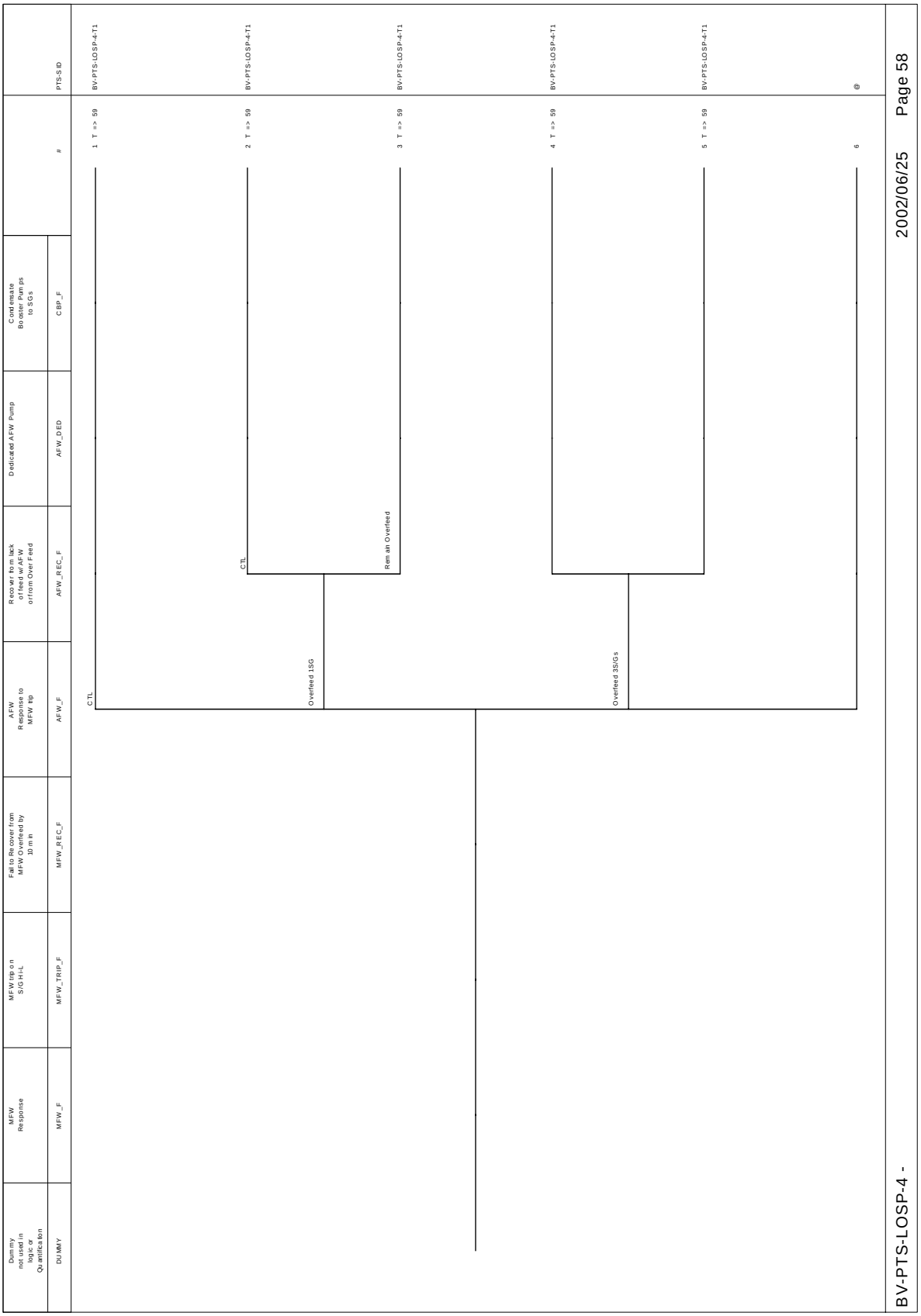

Figure 4.59. Beaver Valley LOSP-4: Loss of offsite power (at least one SRV initially open).

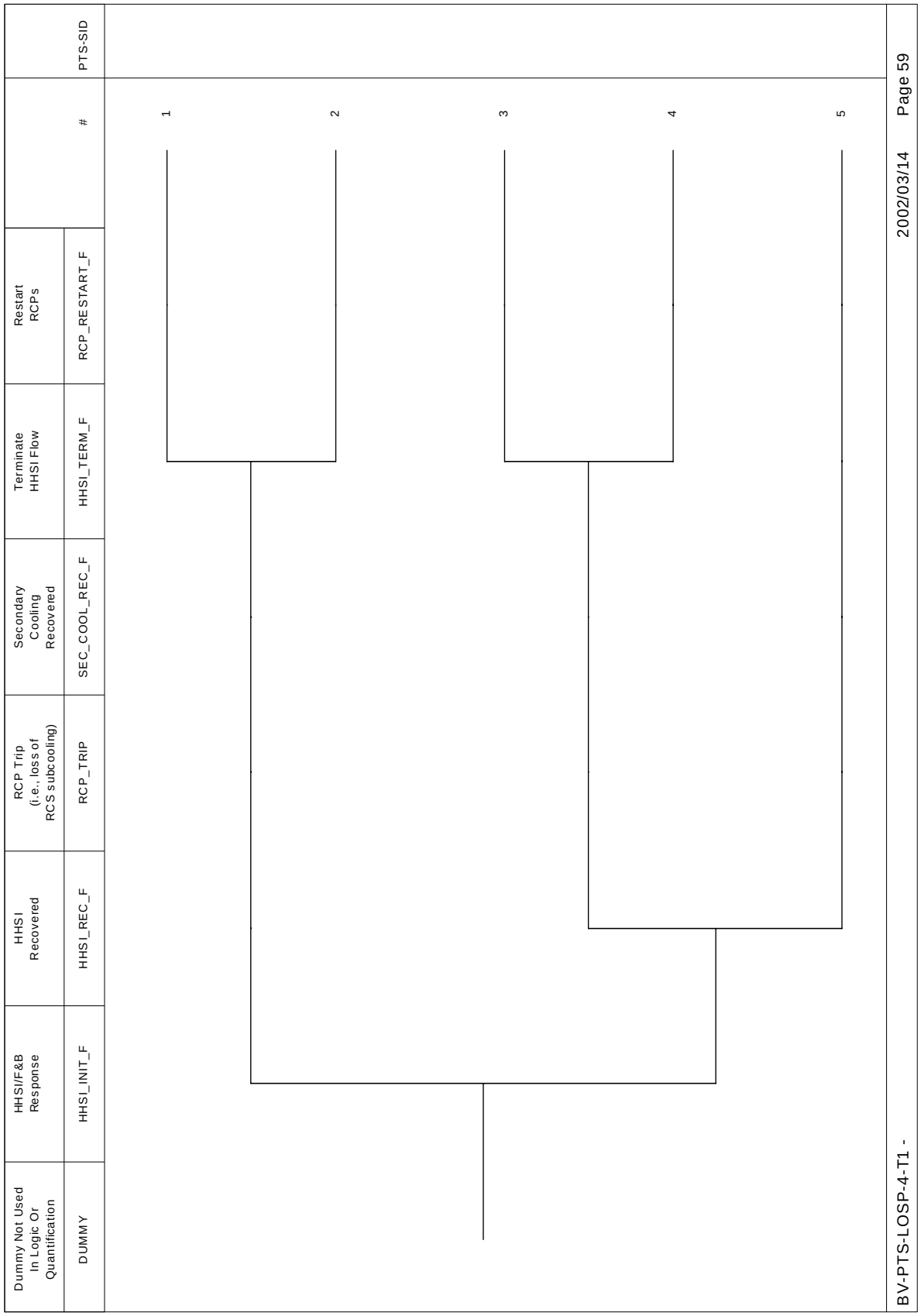

Figure 4.60. Beaver Valley LOSP-4-T1: Loss of offsite power–at least one SRV initially open (HHSI not F&B).

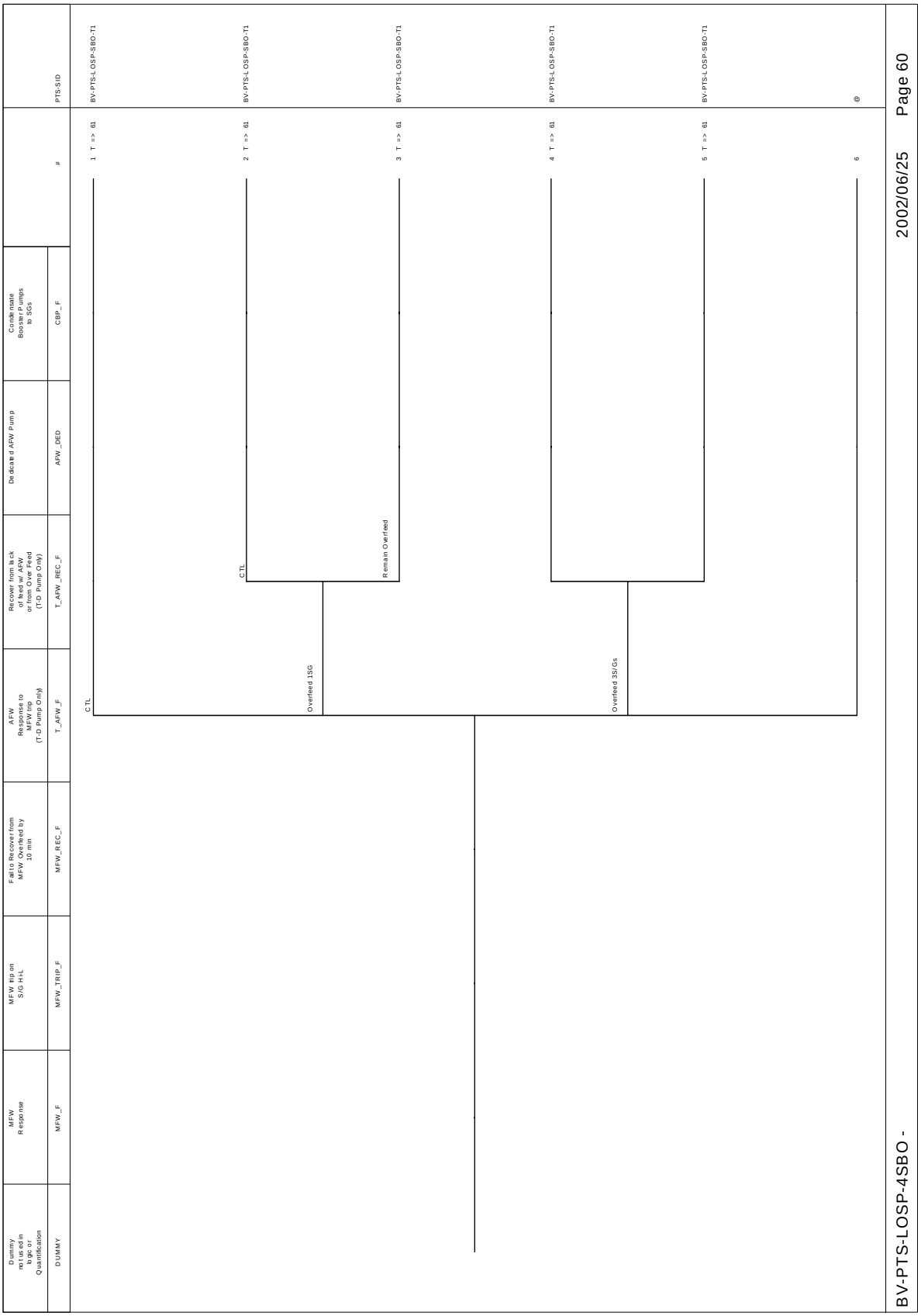

Figure 4.61. Beaver Valley LOSP-4SBO: Loss of offsite power (station blackout)–at least one SRV initially open.

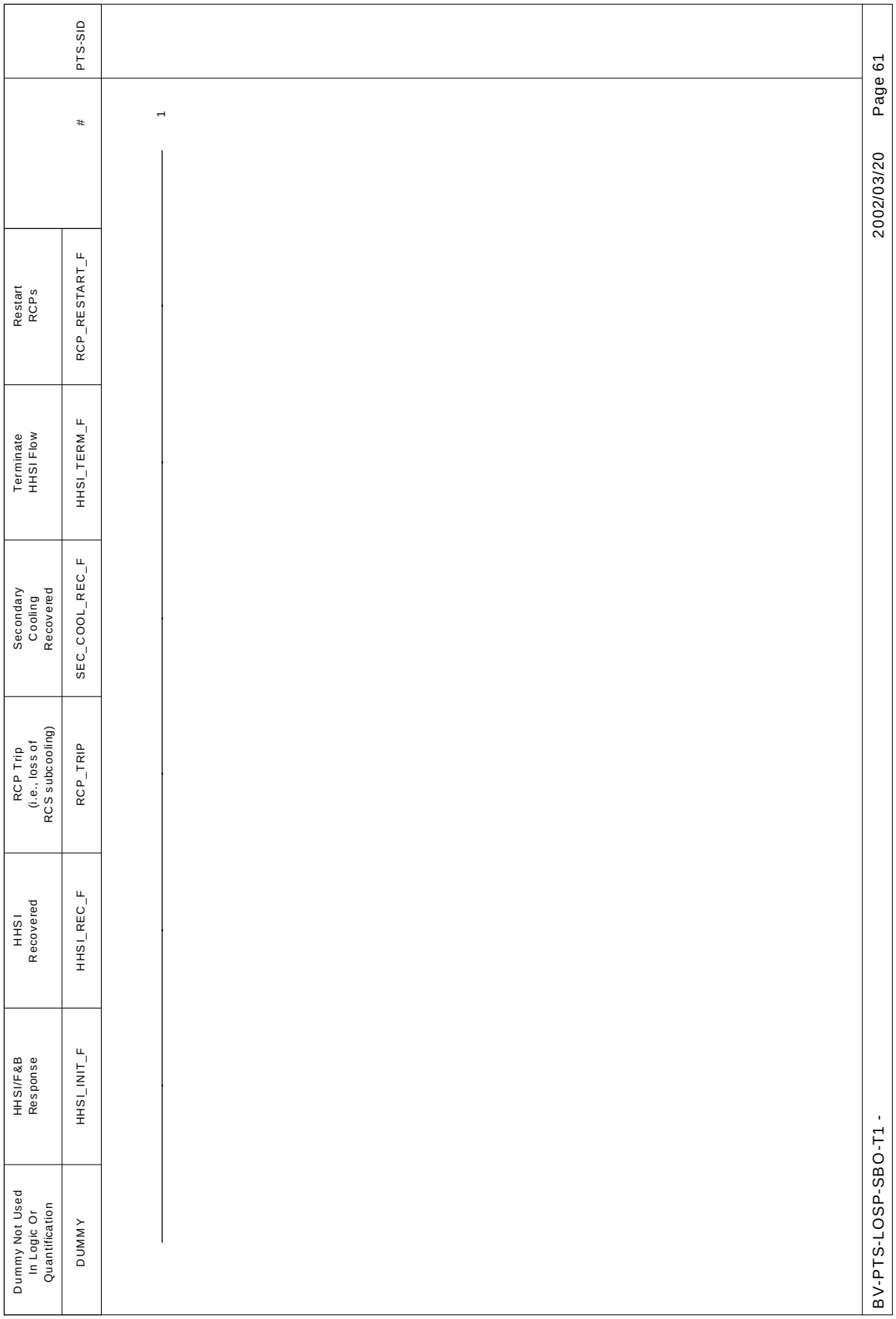

Figure 4.62. Beaver Valley LOSP-SBO-T1: Loss of offsite power (station blackout)–primary system intact or at least one SRV initially open (HHSI not F&B).

Dummy Not Used In Logic Or Quantification	HHSI/F&B Response	HHSI Recovered	RCP Trip (i.e., loss of RCS subcooling)	Secondary Cooling Recovered	Terminate HHSI Flow	Restart RCPs		
DUMMY	HHSI_INIT_F	HHSI_REC_F	RCP_TRIP	SEC_COOL_REC_F	HHSI_TERM_F	RCP_RESTART_F	#	PTS-SID
No CBP flow	No HPI					(Core Damage)	1	@

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Figure 4.63. Beaver Valley LOSP-SBO-T2: Loss of offsite power (station blackout)–primary system intact or at least one SRV initially open (HHSI F&B).

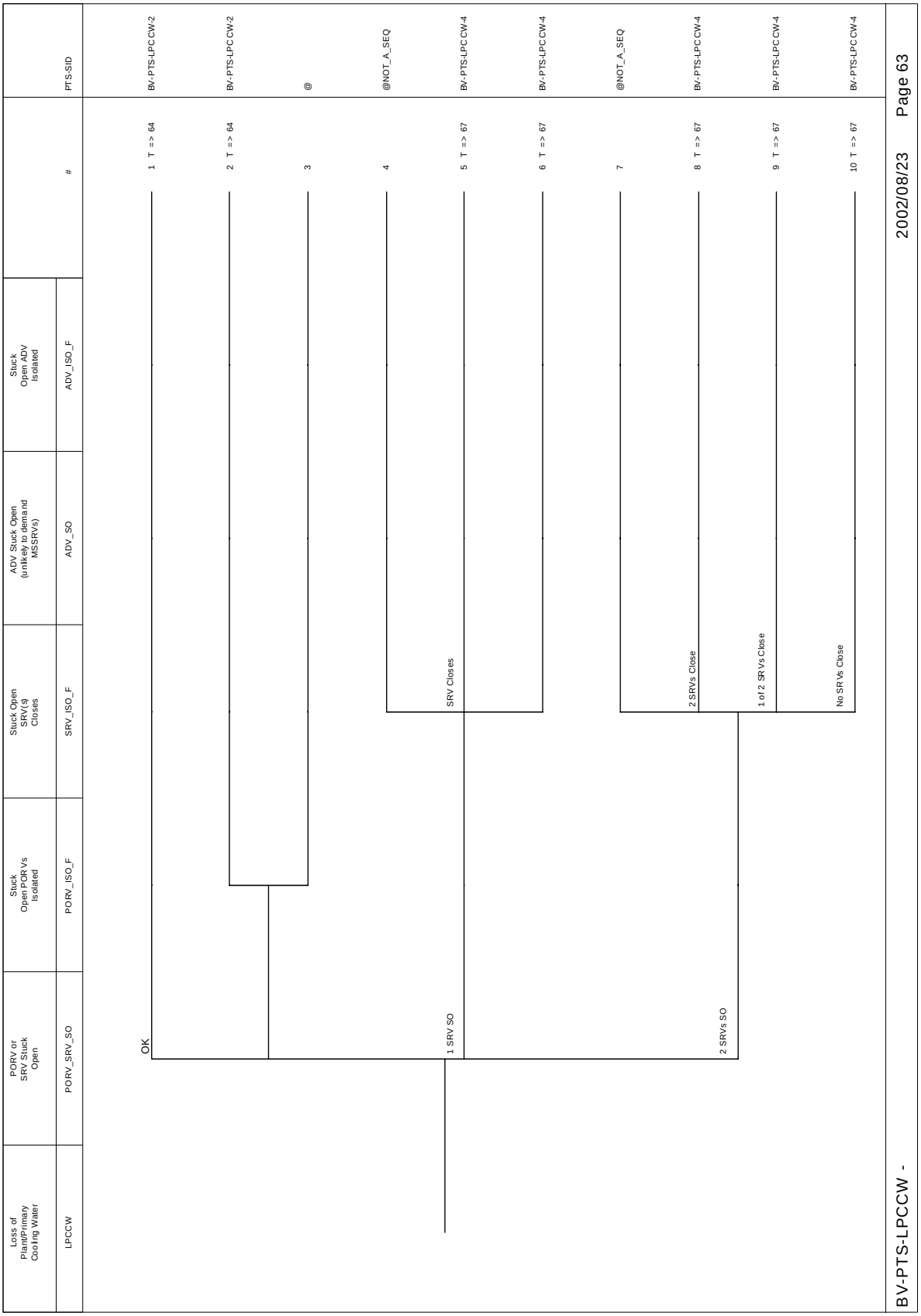

Figure 4.64. Beaver Valley LPCCW: Loss of (reactor) primary component cooling water.

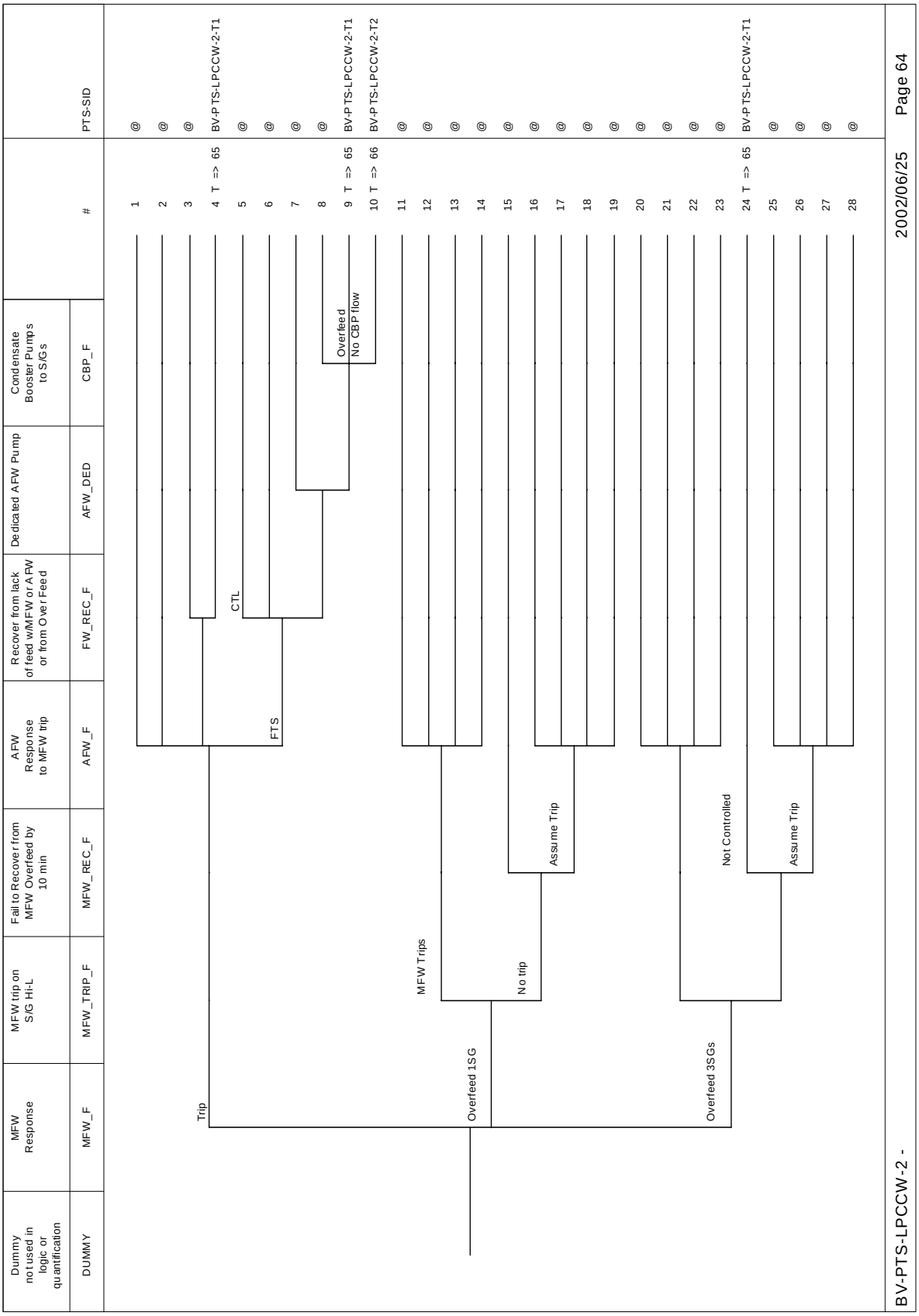

Figure 4.65. Beaver Valley LPCCW-2: Loss of (reactor) primary component cooling water (primary system intact).

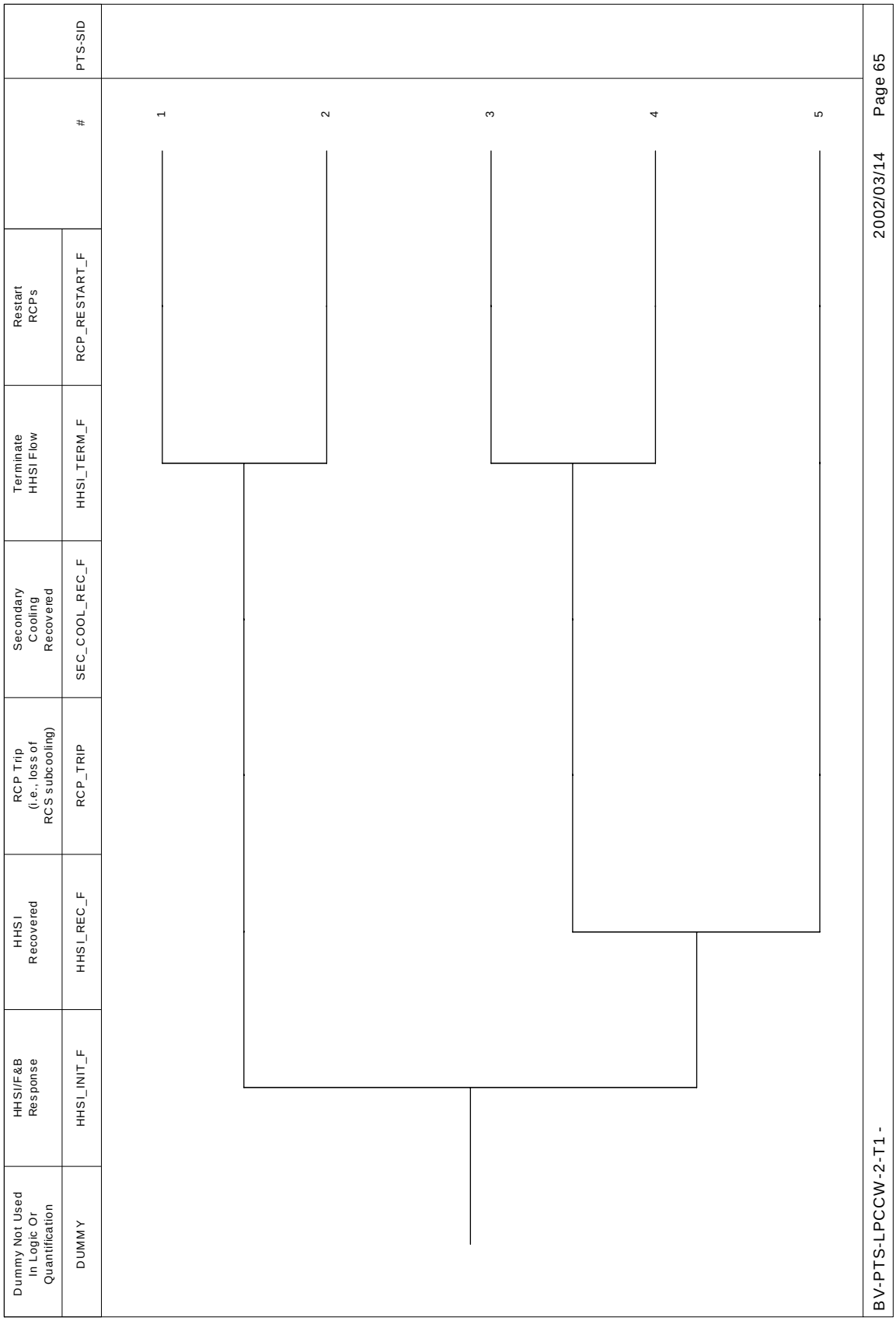

Figure 4.66. Beaver Valley LPCCW-2-T1: Loss of (reactor) primary component cooling water–primary system intact (HHSI not F&B).

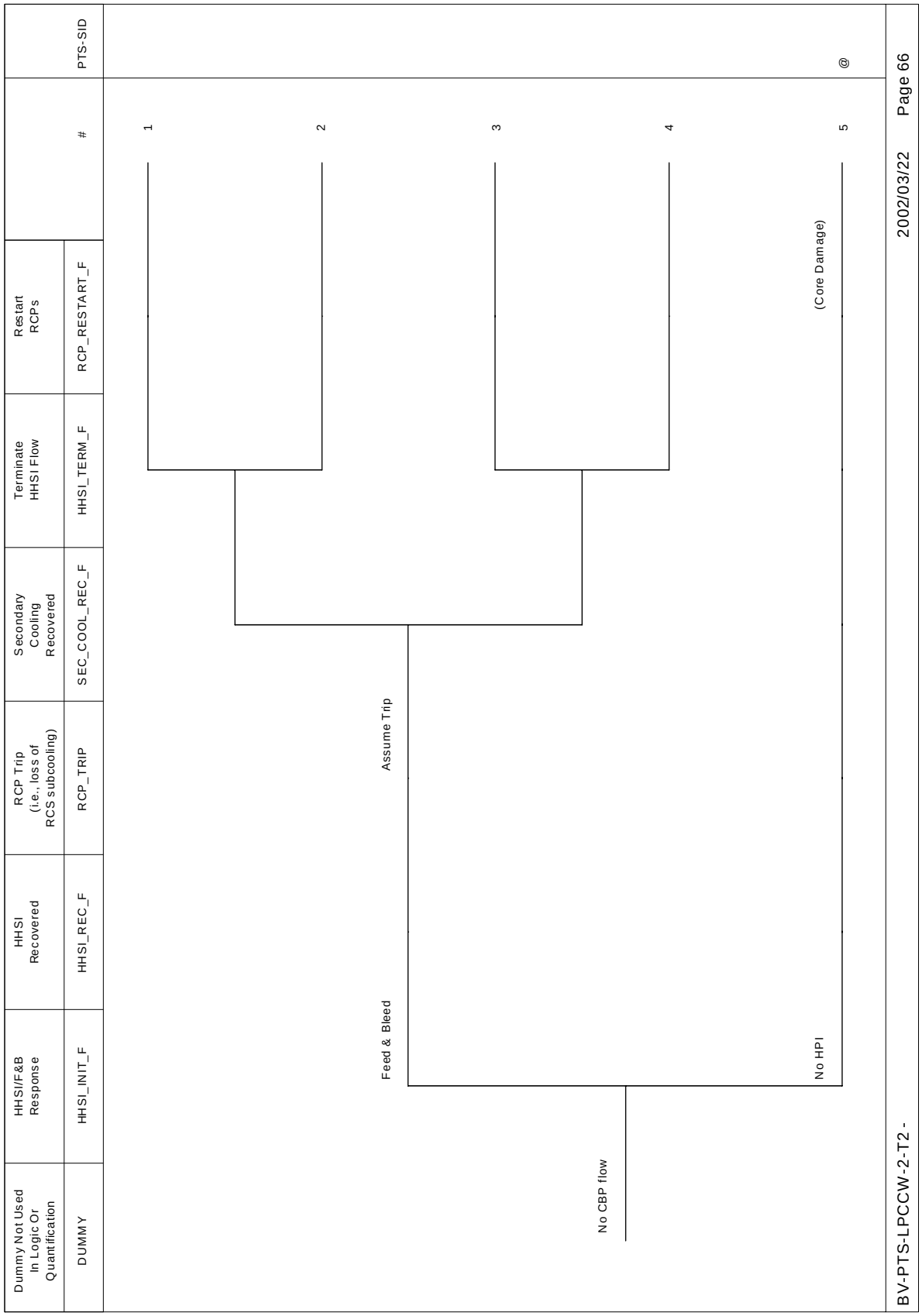

Figure 4.67. Beaver Valley LPCCW-2-T2: Loss of (reactor) primary component cooling water–primary system intact (HHSI F&B).

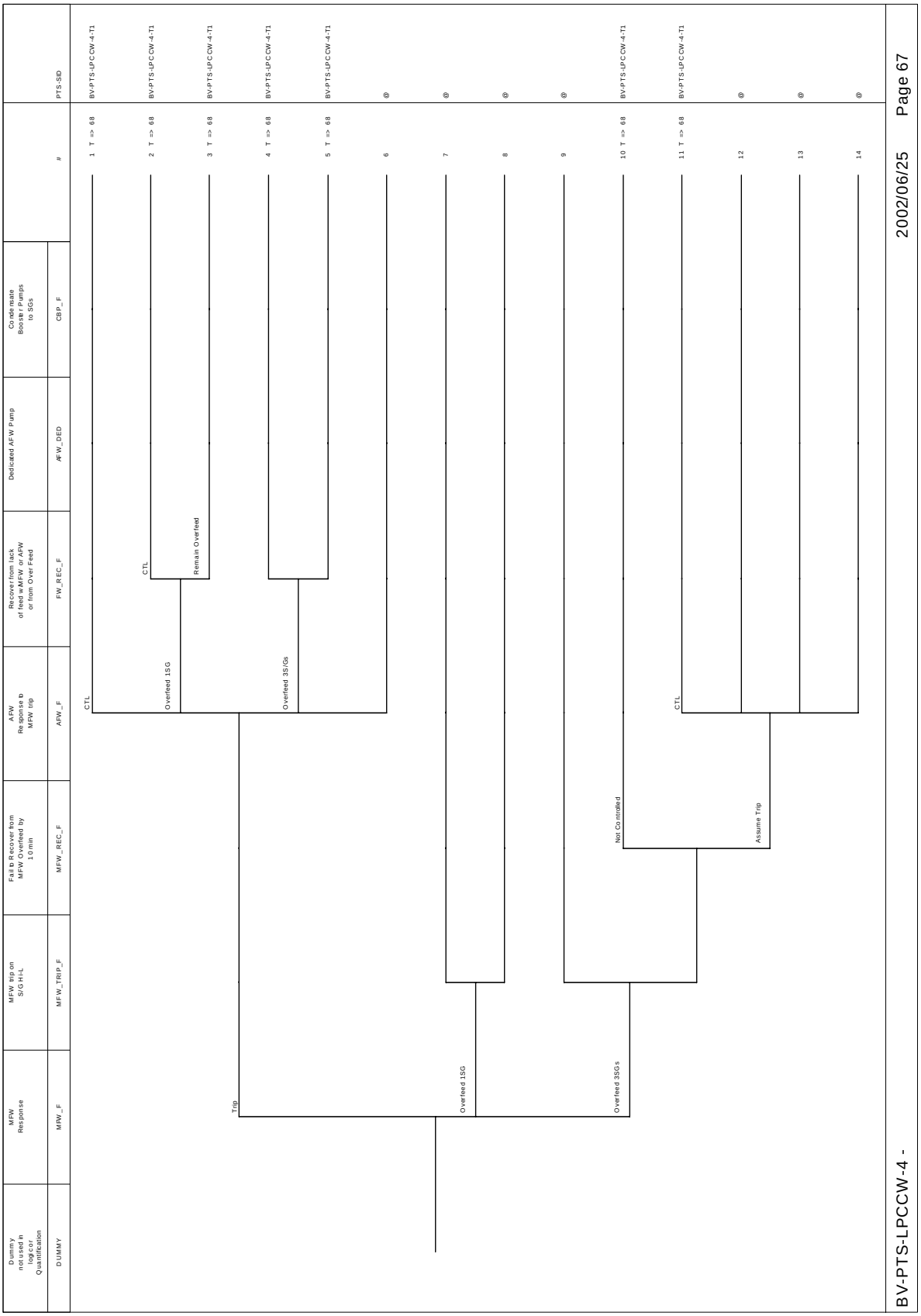

Figure 4.68. Beaver Valley LPCCW-4: Loss of (reactor) primary component cooling water (at least one SRV initially open).

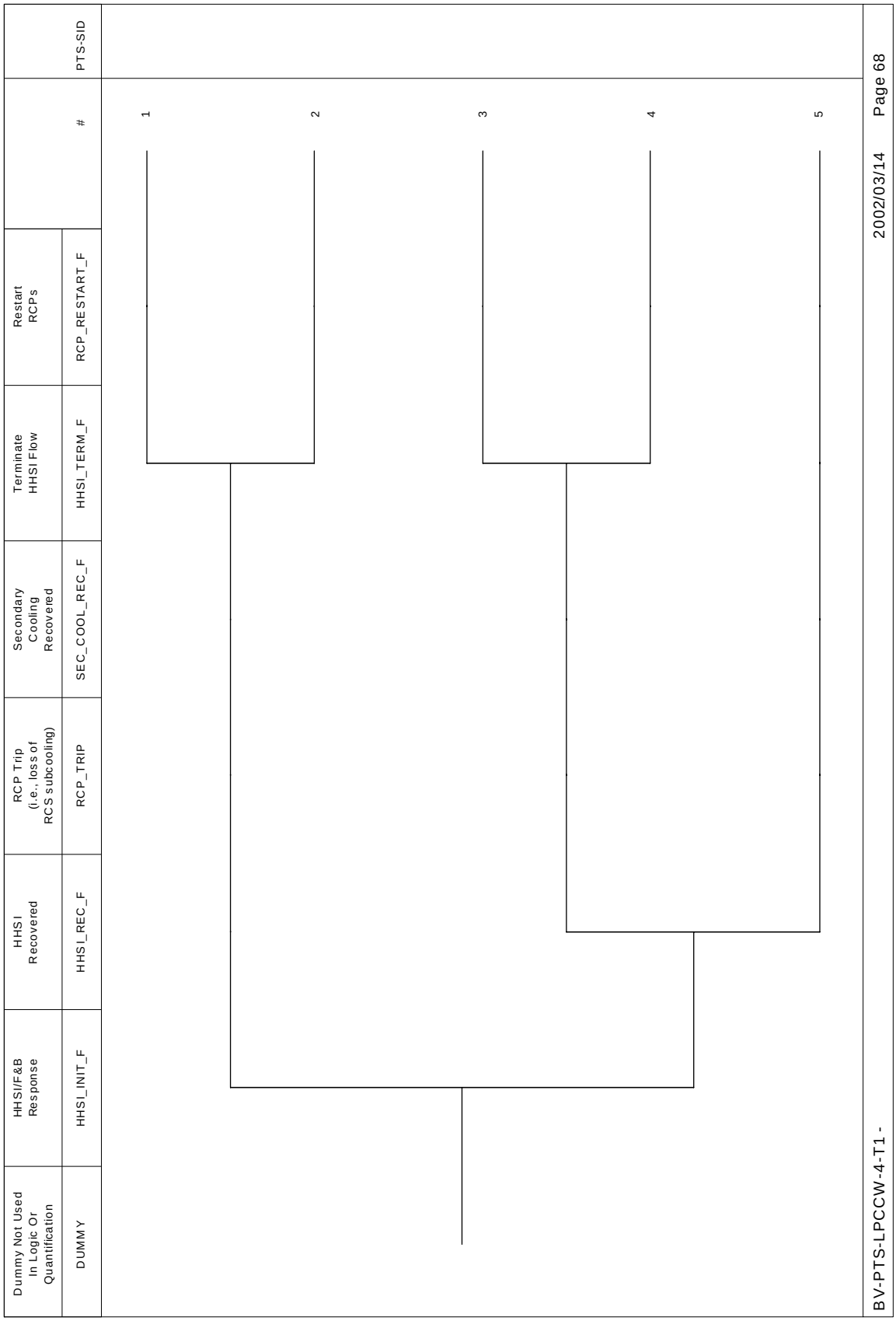

Figure 4.69. Beaver Valley LPCCW-4-T1: Loss of (reactor) primary component cooling water–at least one SRV initially open (HHSI not F&B).

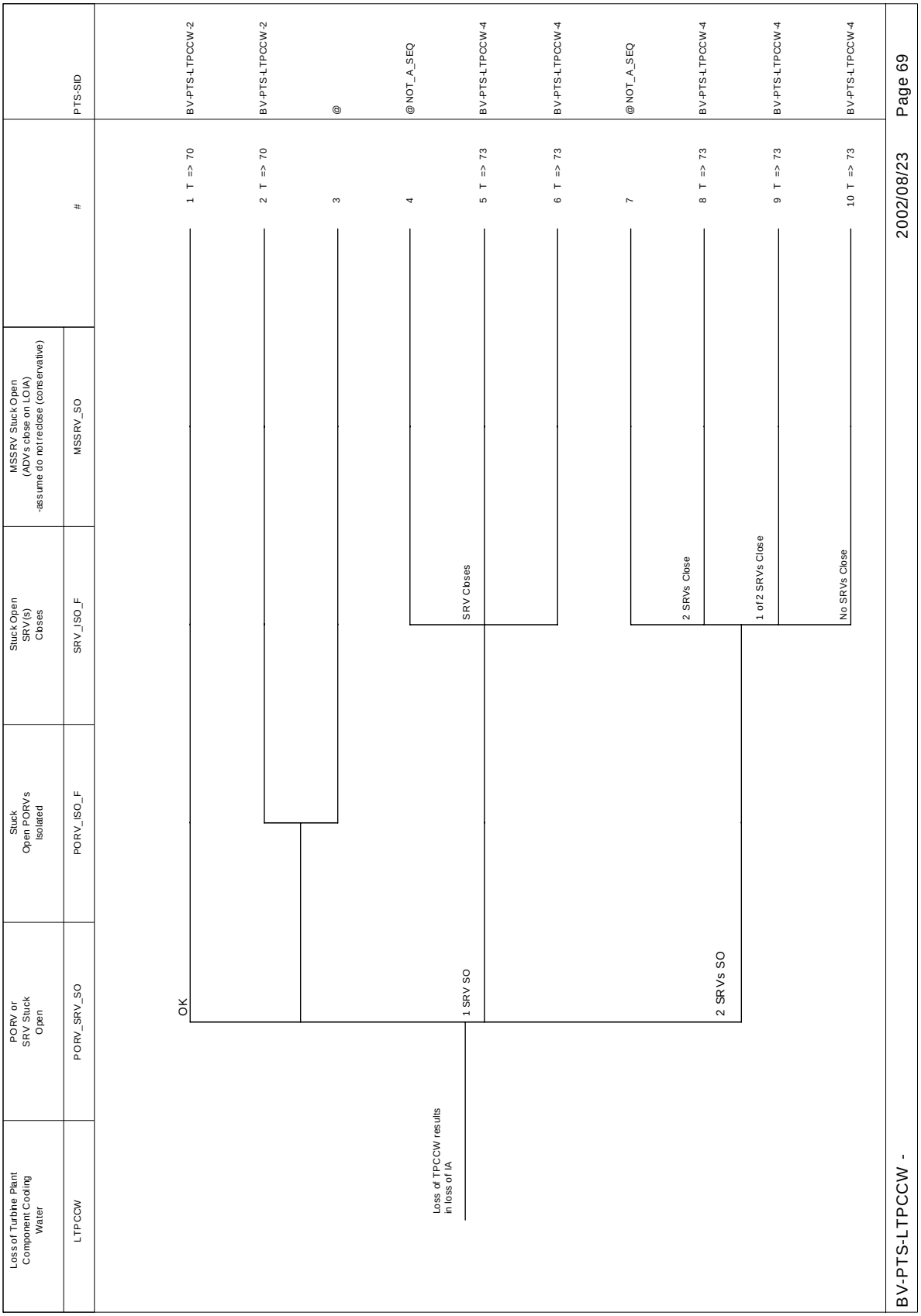

Figure 4.70. Beaver Valley LTPCCW: Loss of turbine plant component cooling water.

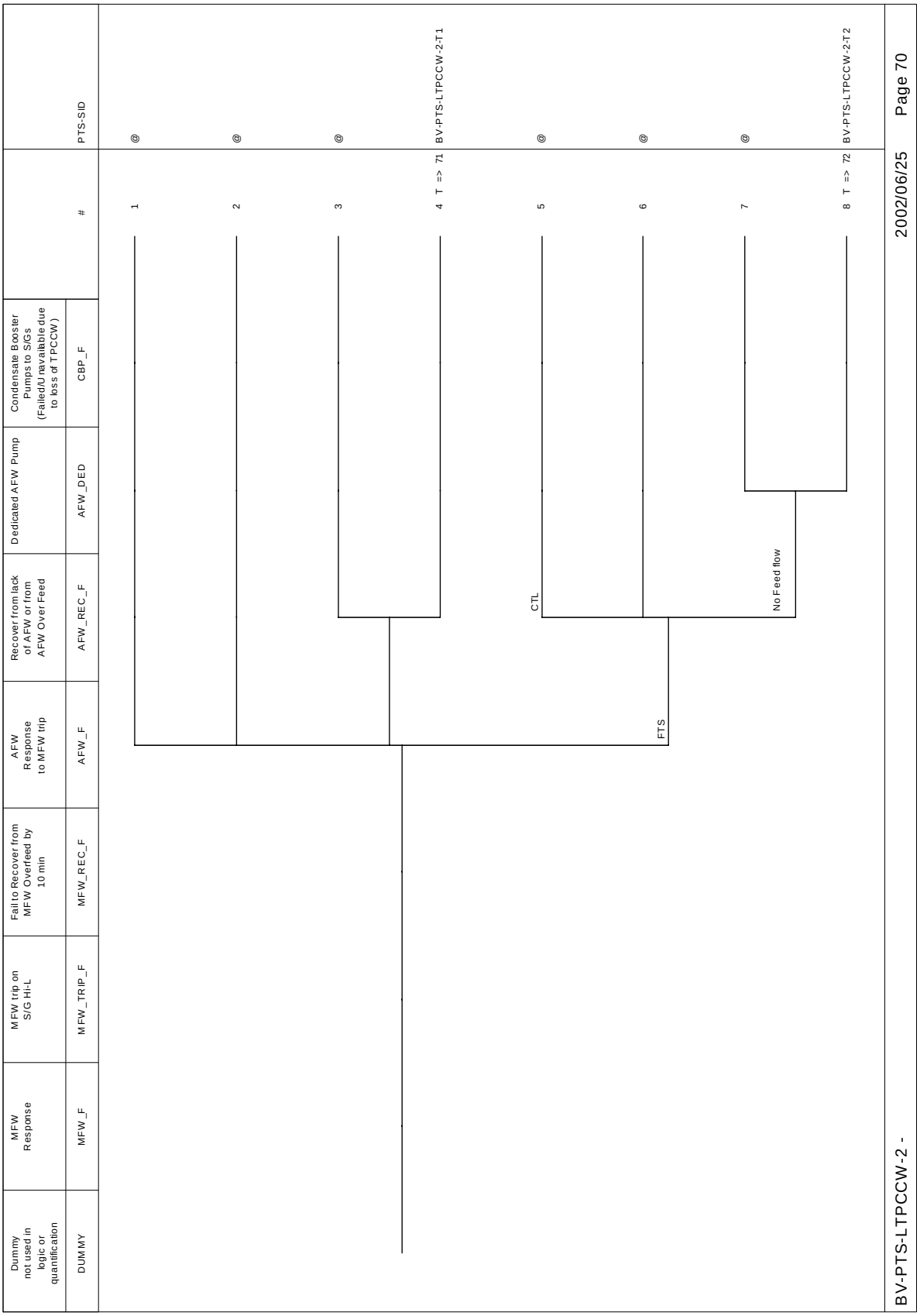

Figure 4.71. Beaver Valley LTPCCW-2: Loss of turbine plant component cooling water (primary system intact).

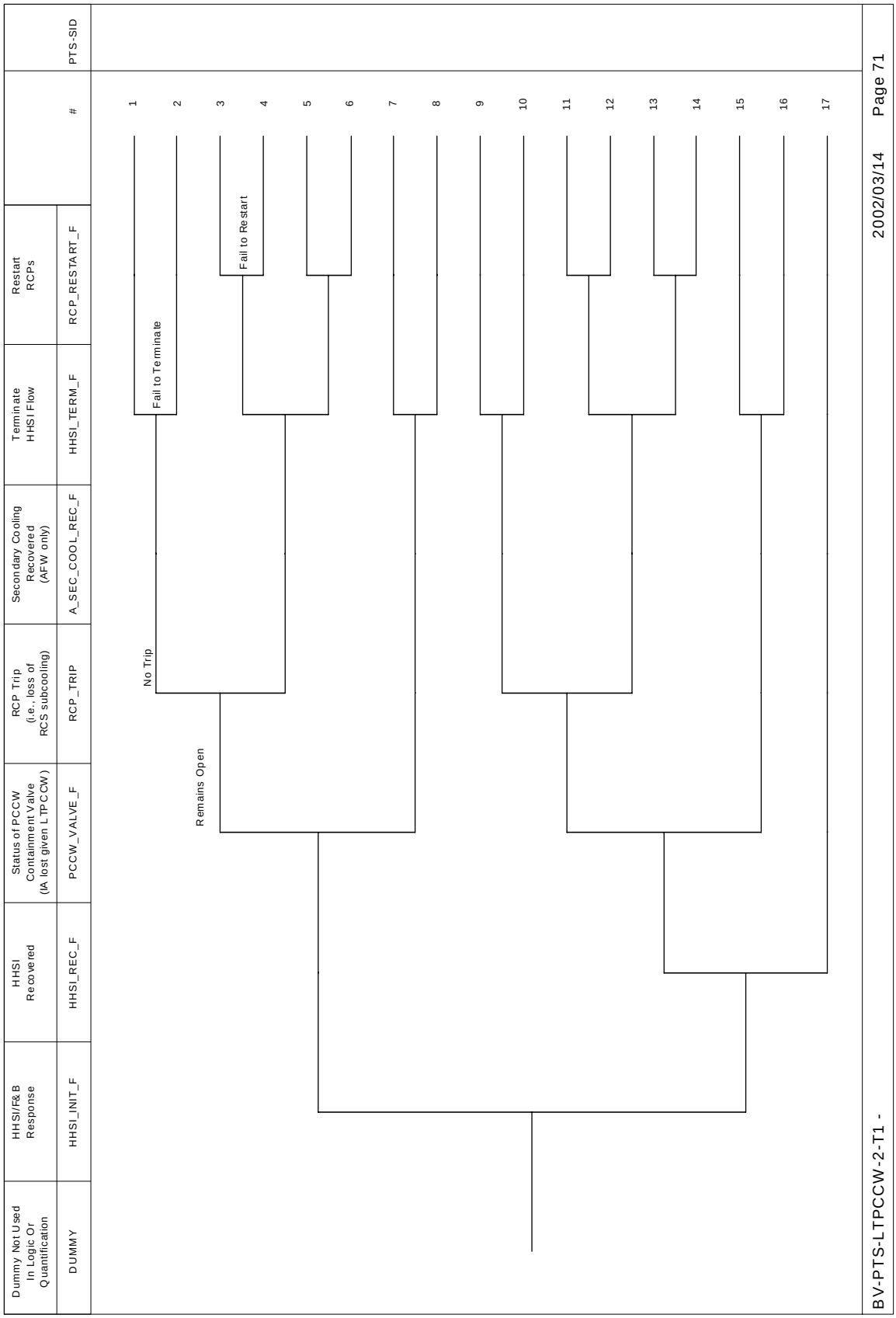

Figure 4.72. Beaver Valley LTPCCW-2-T1: Loss of turbine plant component cooling water–primary system intact (HHSI not F&B).

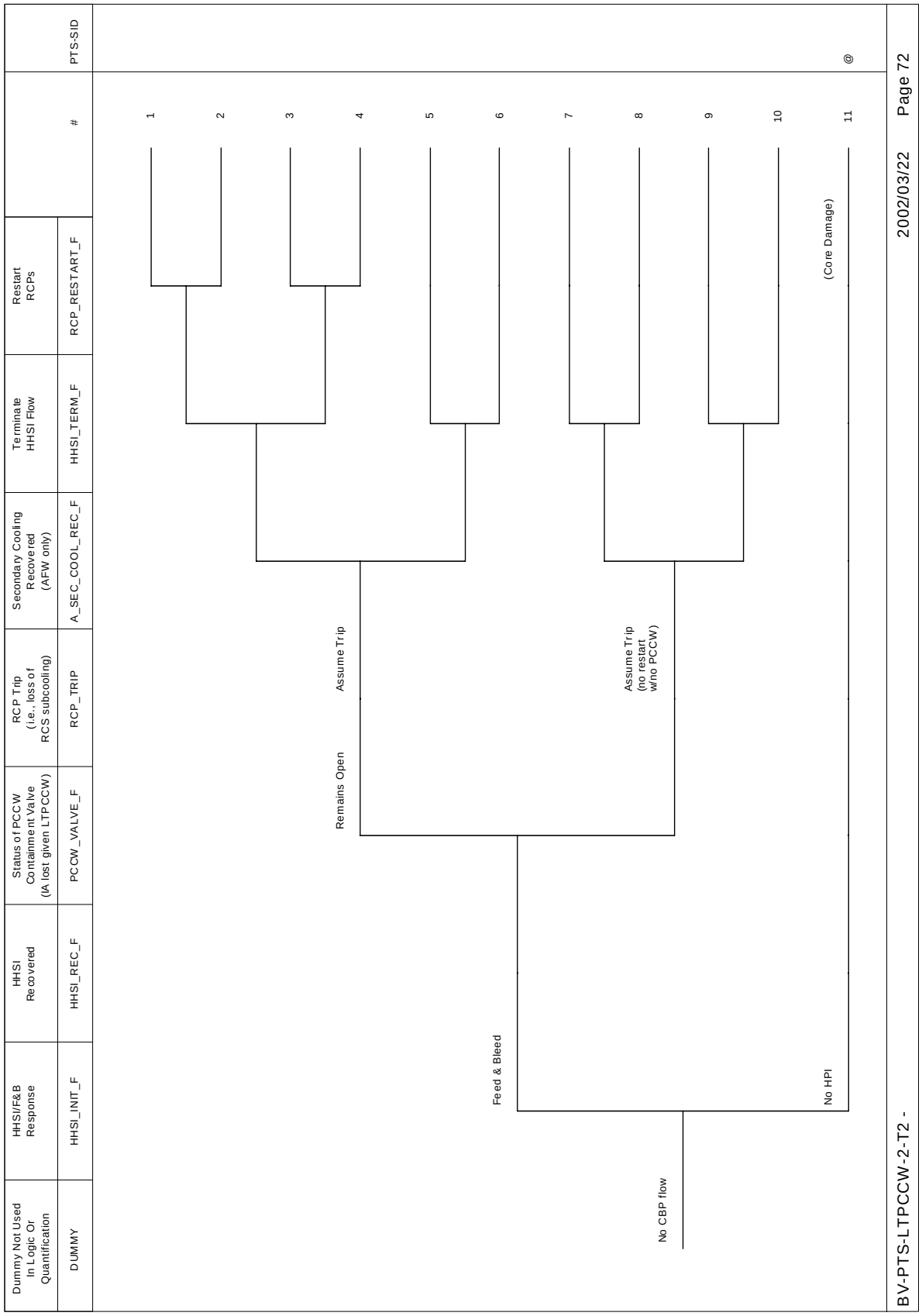

Figure 4.73. Beaver Valley LTPCCW-2-T2: Loss of turbine plant component cooling water–primary system intact (HHSI F&B).

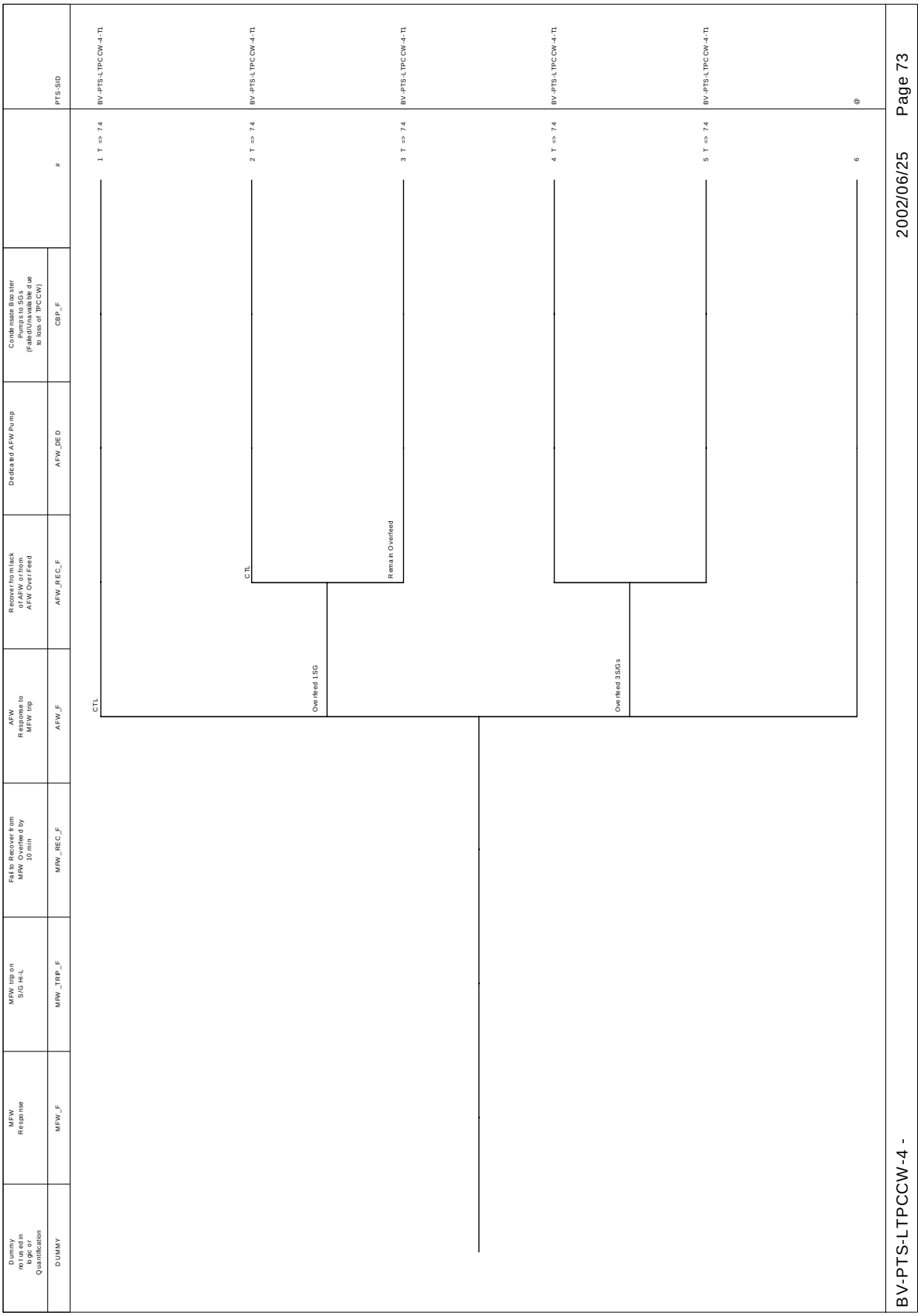

Figure 4.74. Beaver Valley LTPCCW-4: Loss of turbine plant component cooling water (at least one SRV initially open).

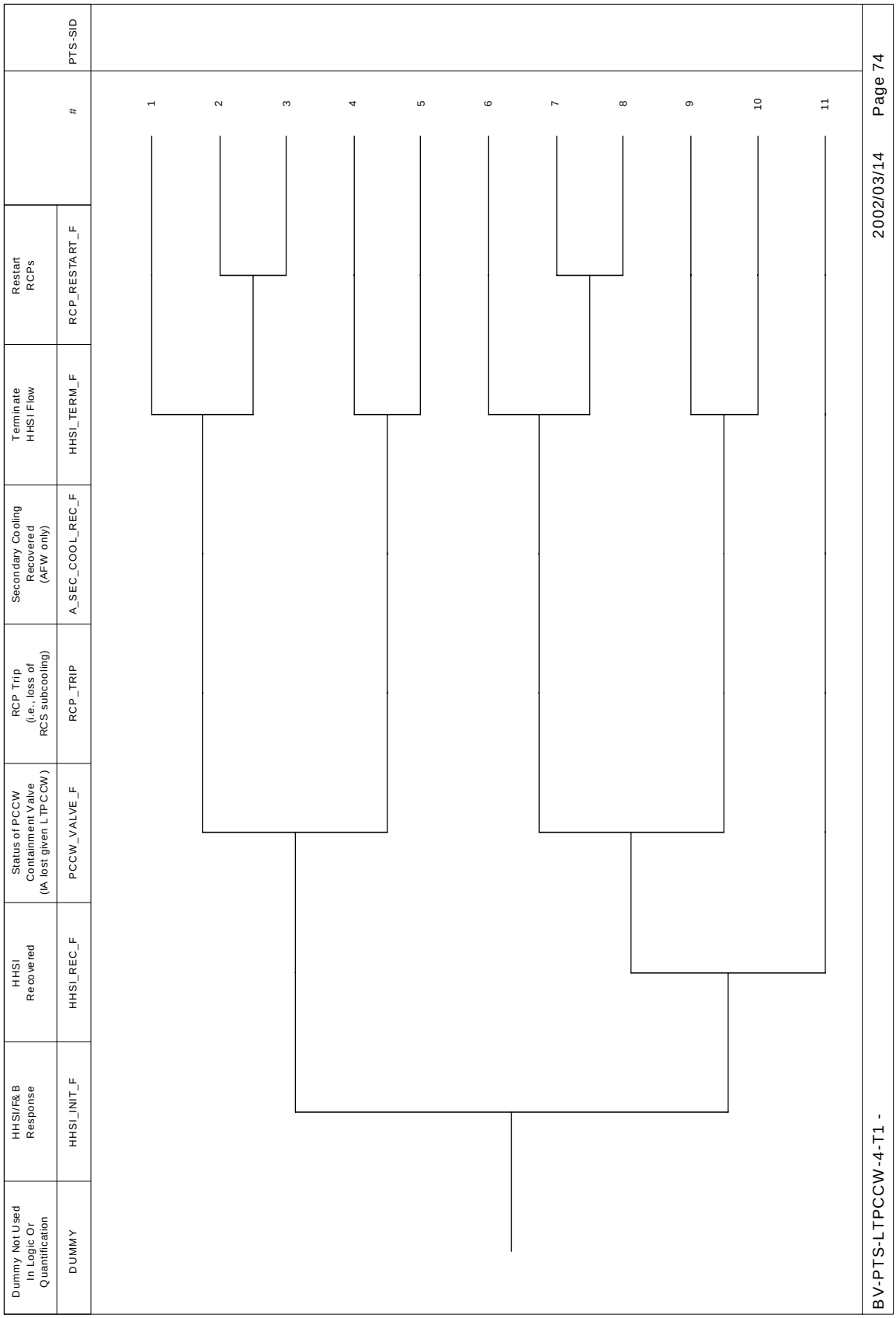

Figure 4.75. Beaver Valley LTPCCW-4-T1: Loss of turbine plant component cooling water–at least one SRV initially open (HHSI not F&B).

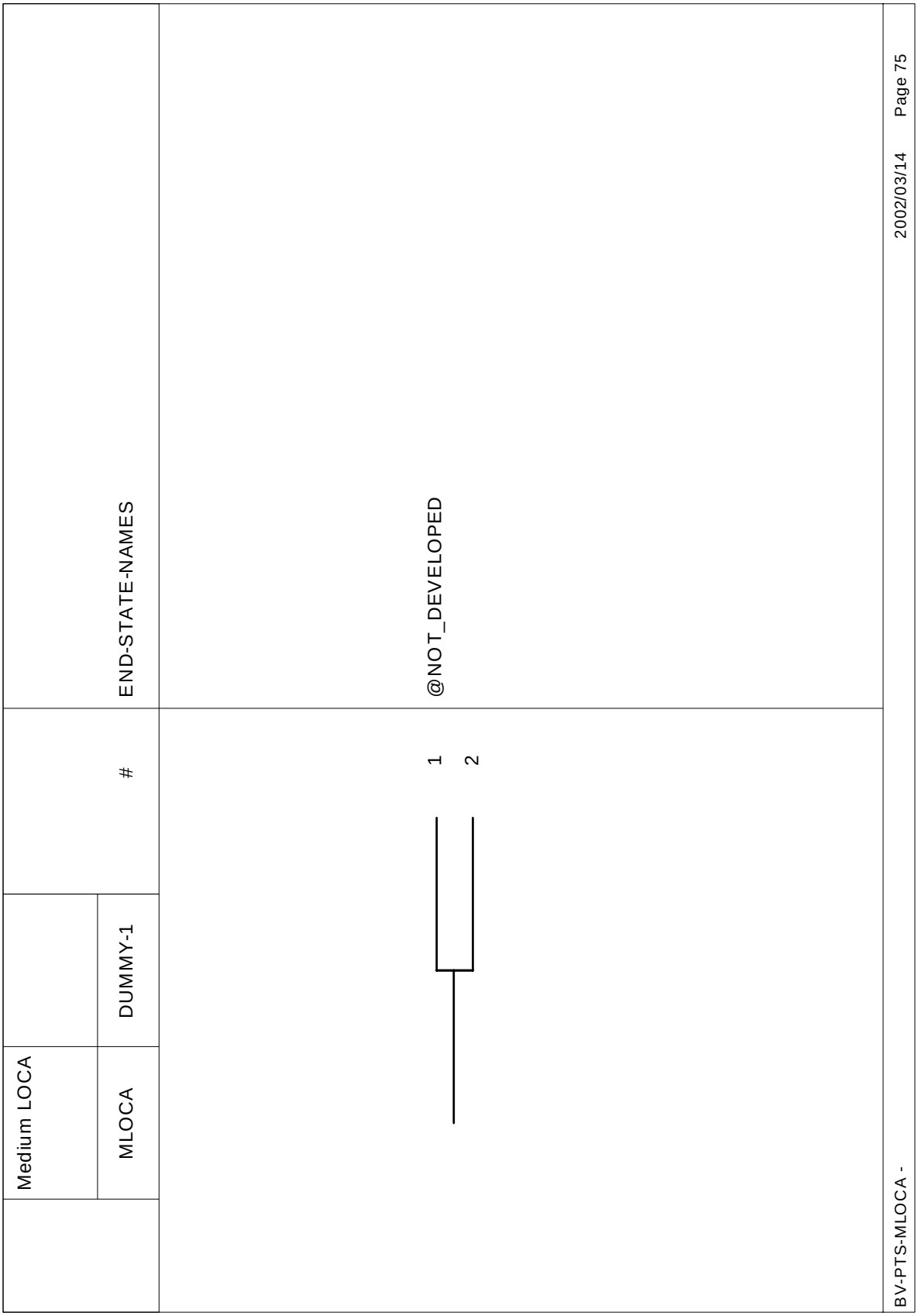

Figure 4.76. Beaver Valley MLOCA: Medium LOCA.

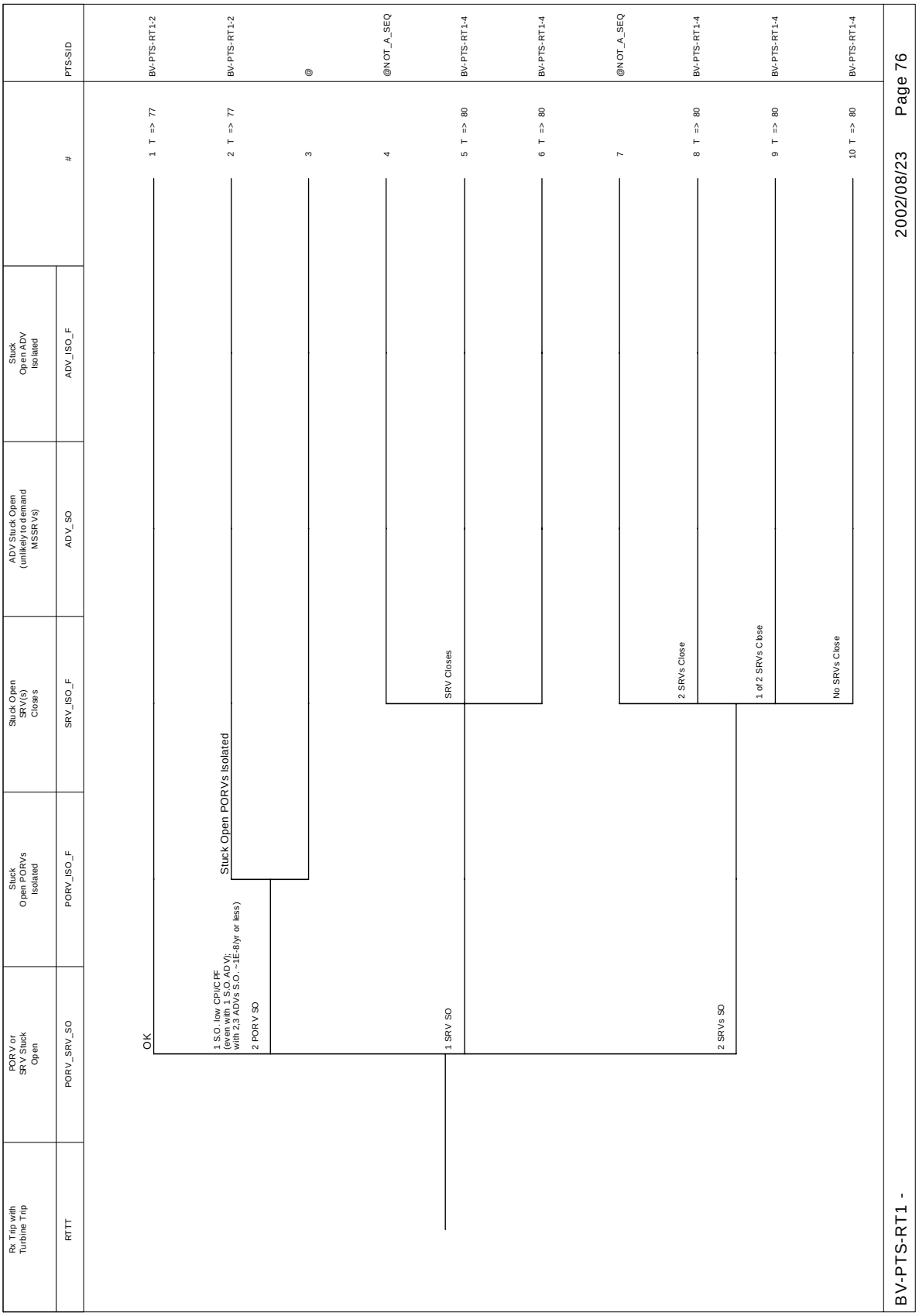

Figure 4.77. Beaver Valley RT1: Reactor trip with turbine trip.

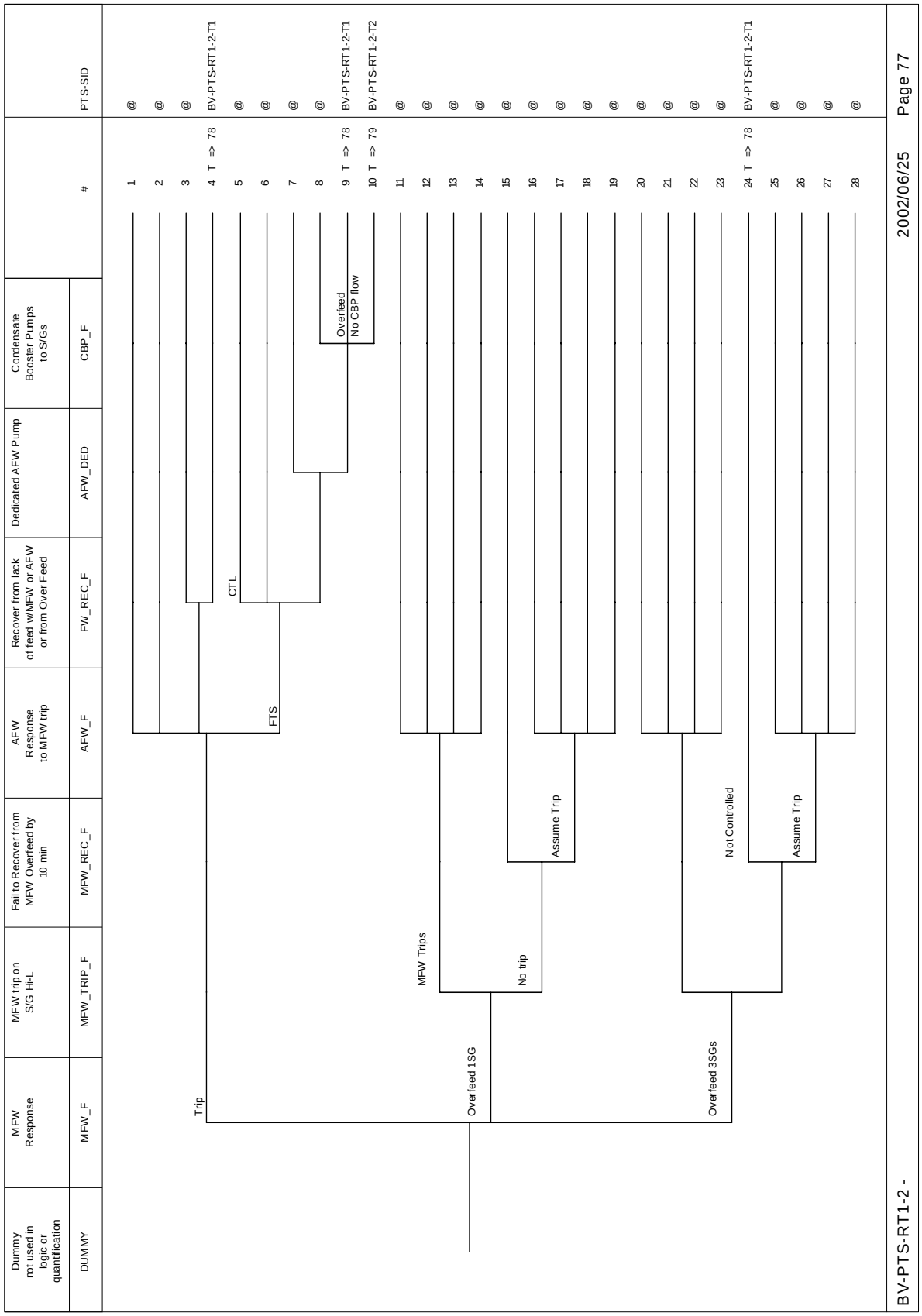

Figure 4.78. Beaver Valley RT1-2: Reactor trip with turbine trip (primary system intact).

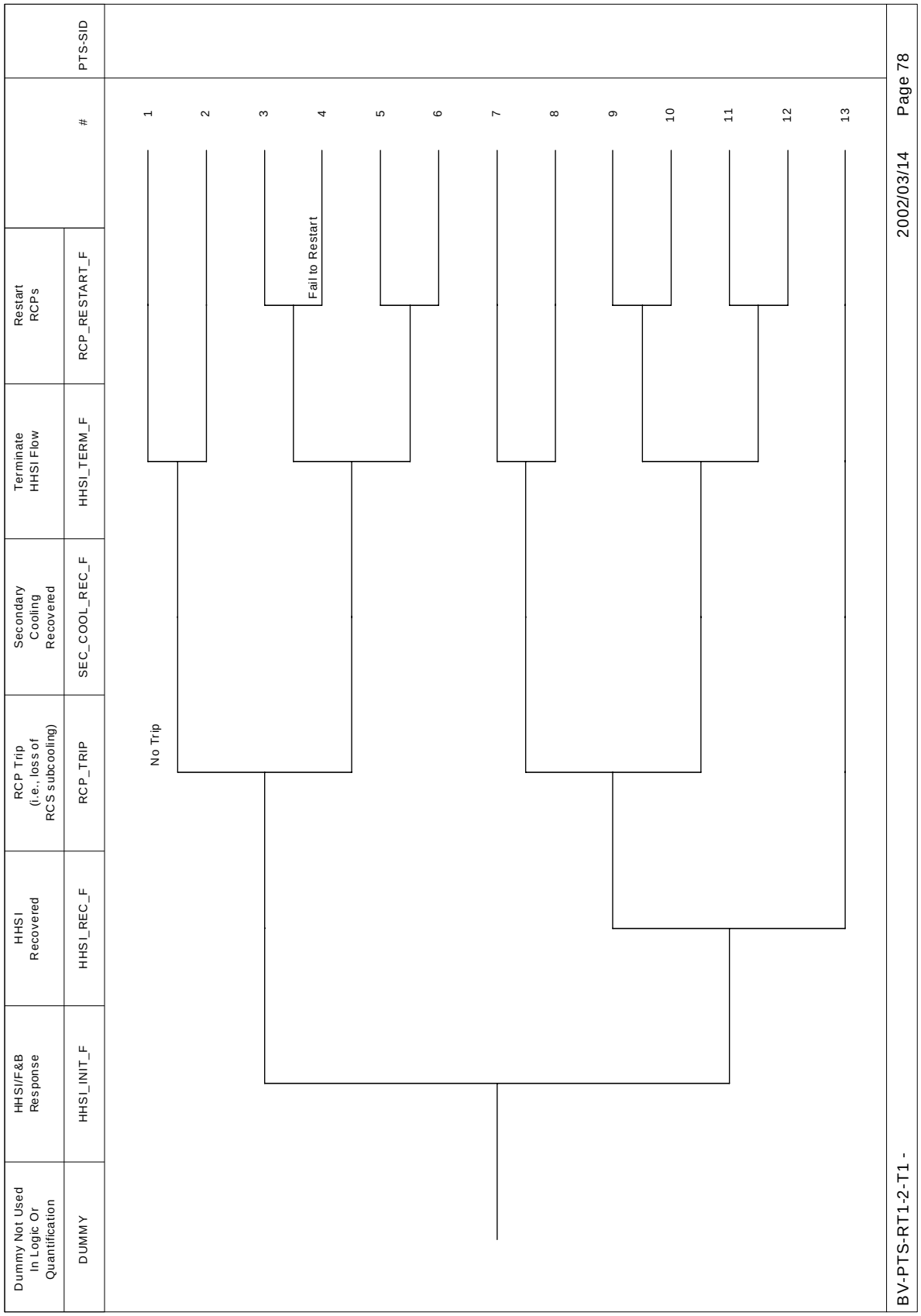

Figure 4.79. Beaver Valley RT1-2-T1: Reactor trip with turbine trip–primary system intact (HHSI not F&B).

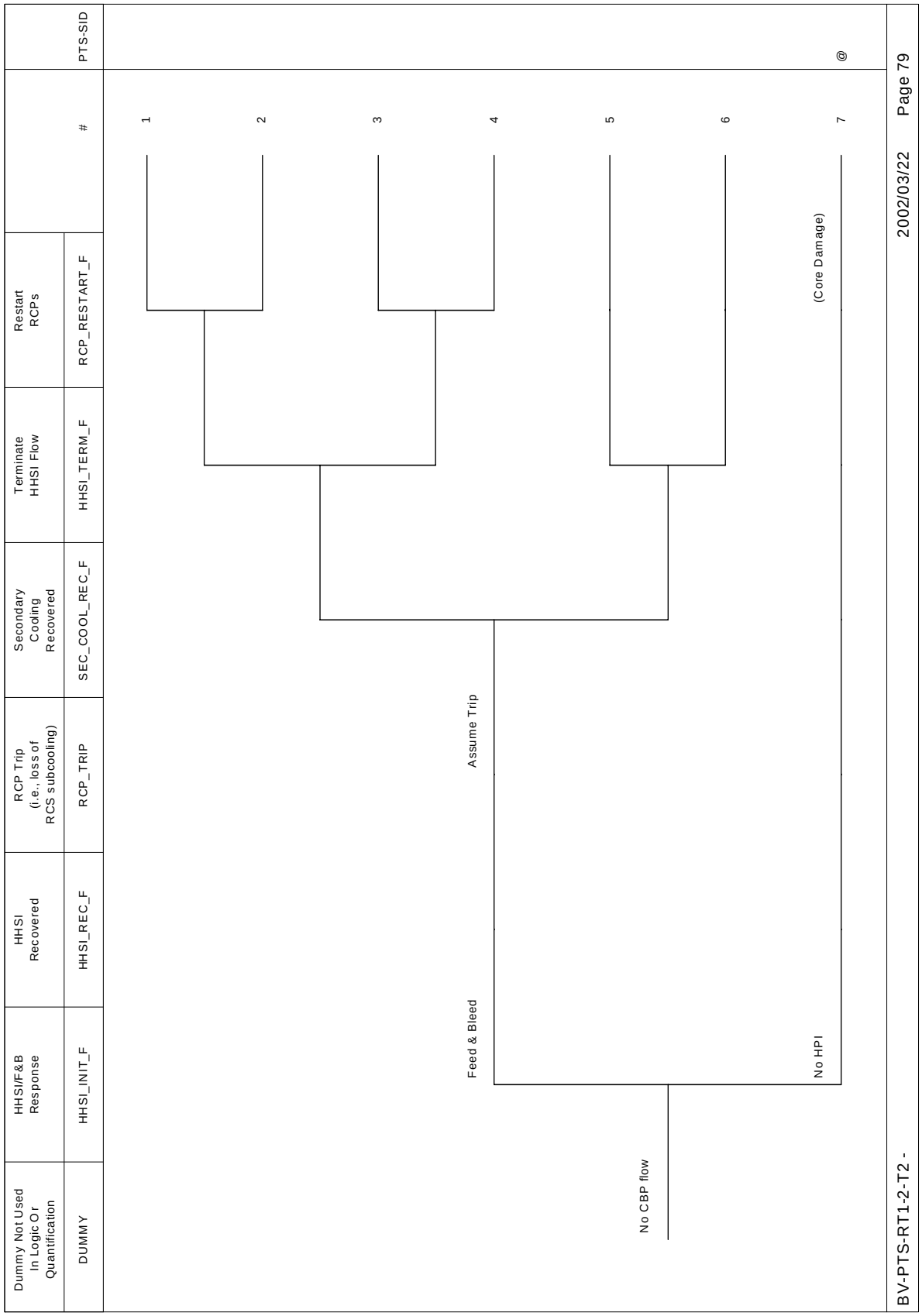

Figure 4.80. Beaver Valley RT1-2-T2: Reactor trip with turbine trip–primary system intact (HHSI F&B).

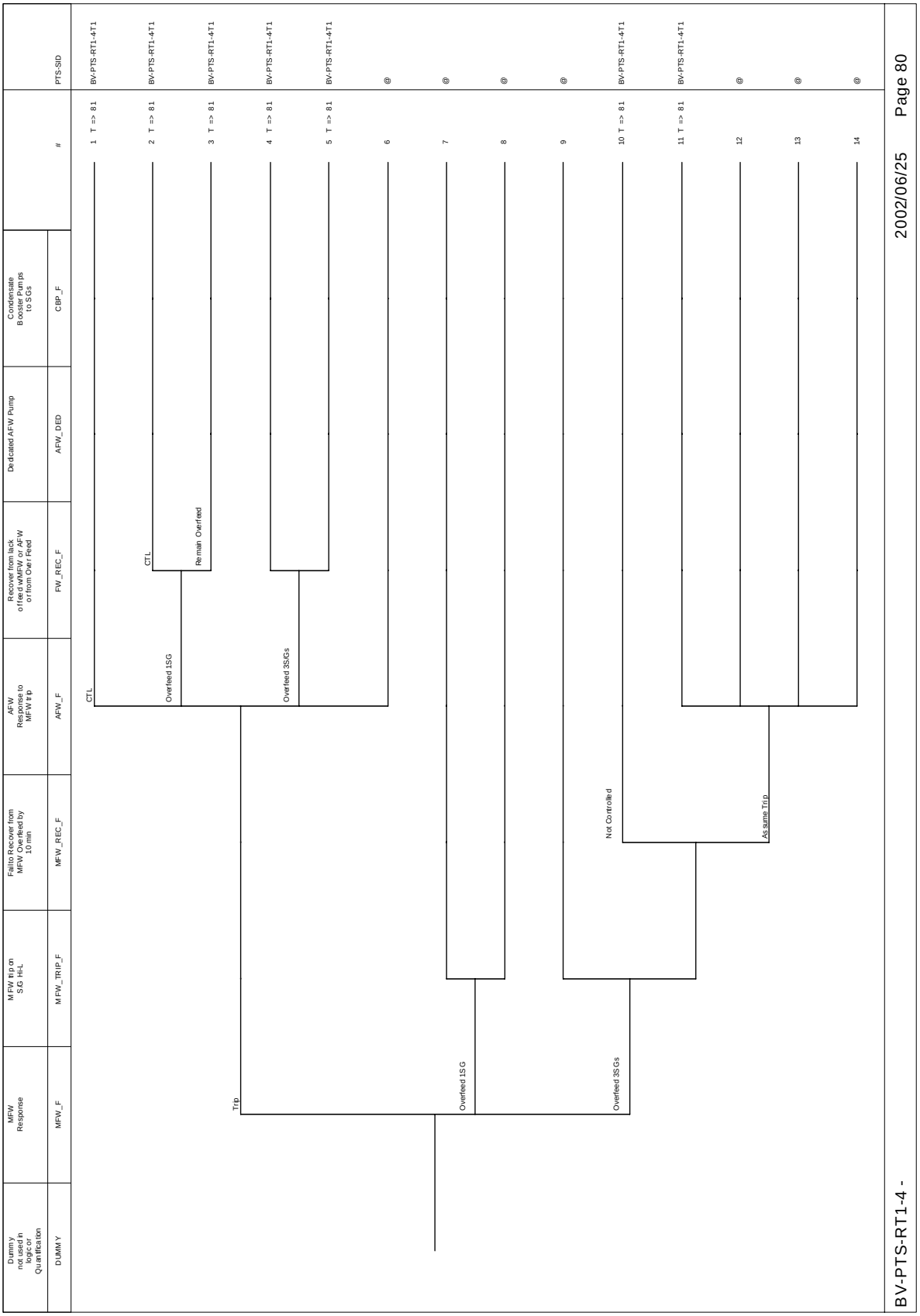

Figure 4.81. Beaver Valley RT1-4: Reactor trip with turbine trip (at least one SRV initially open.

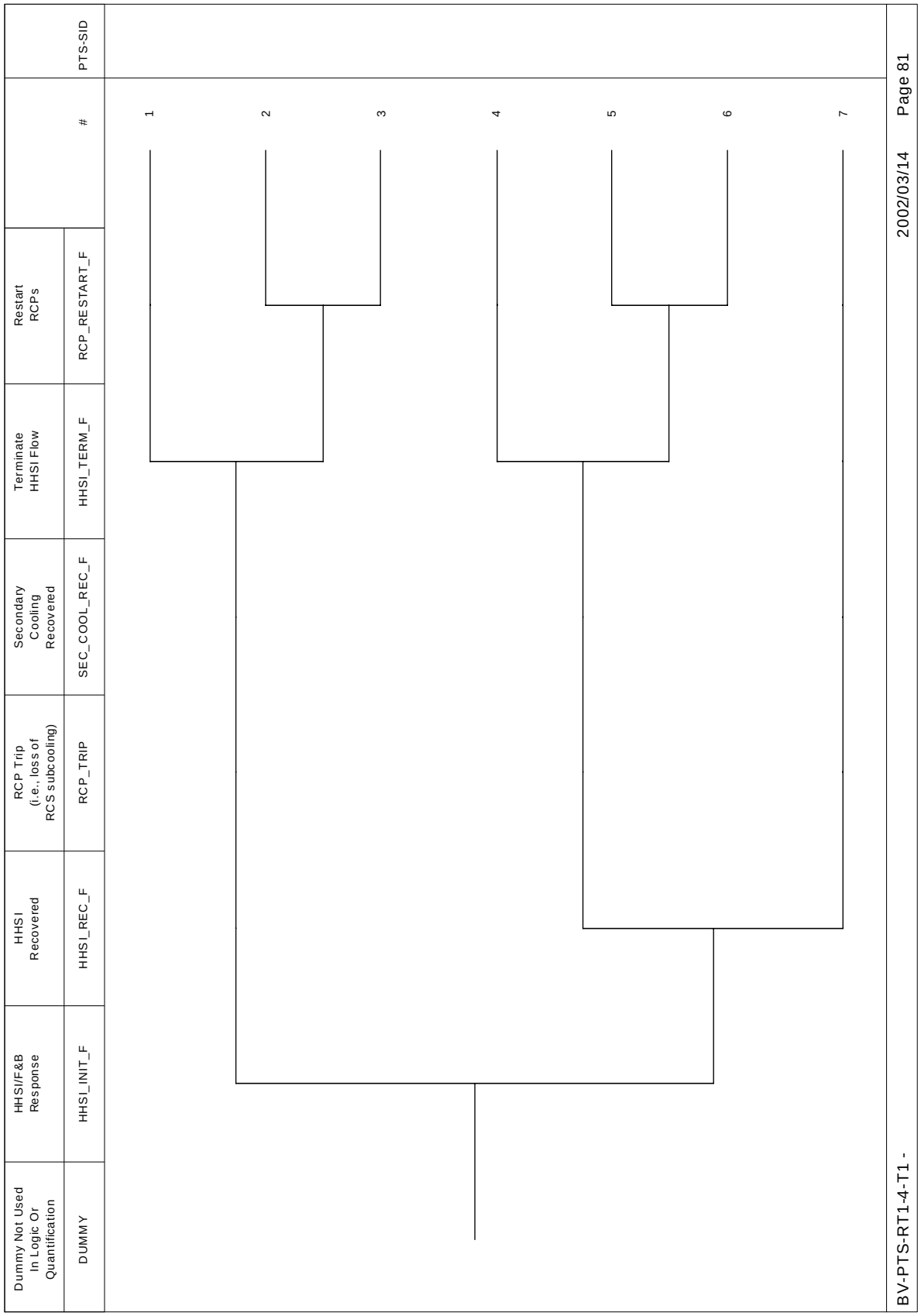

Figure 4.82. Beaver Valley RT1-4-T1: Reactor trip with turbine trip–at least one SRV initially open (HHSI not F&B).

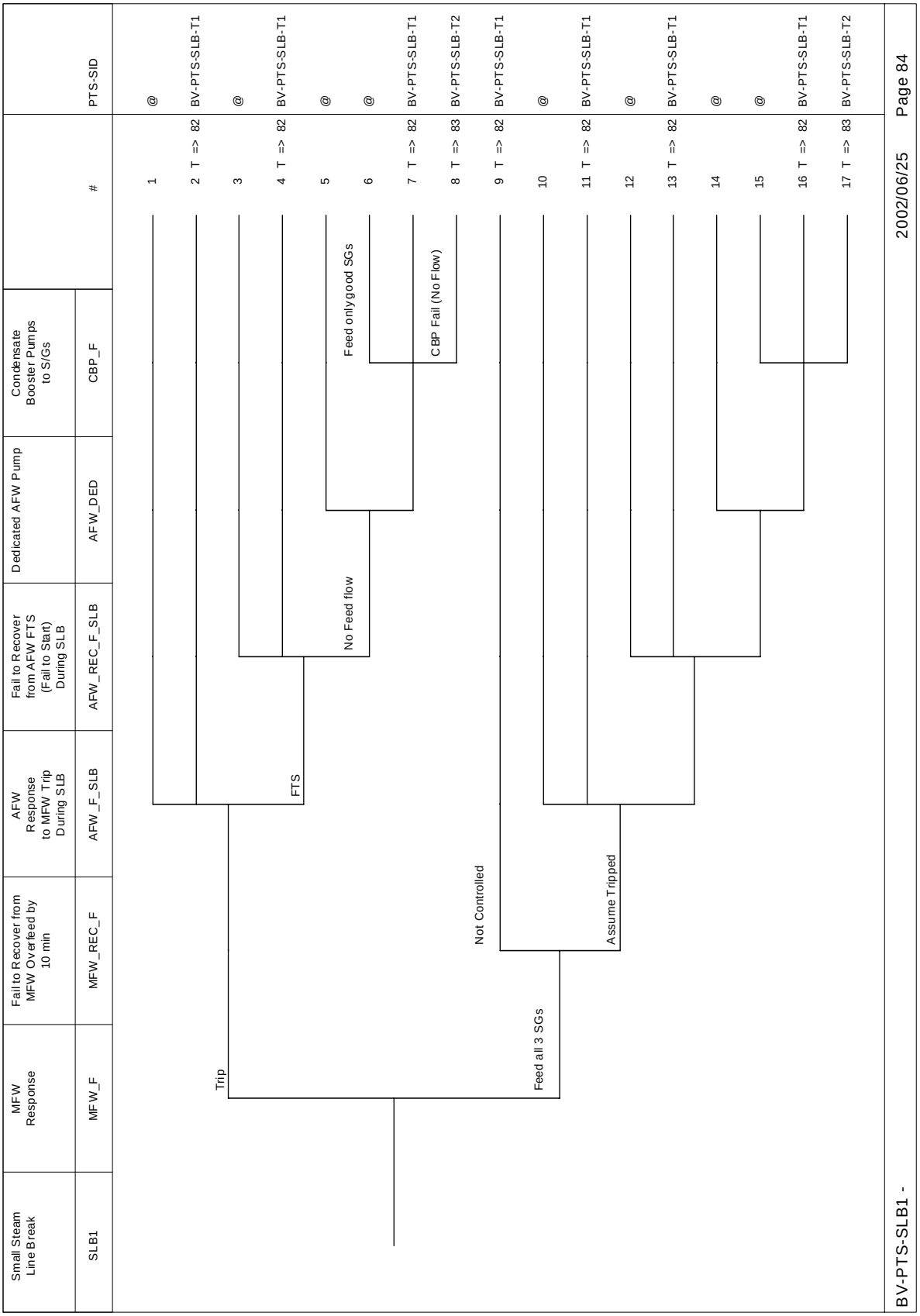

Figure 4.83. Beaver Valley SLB1: Small steam line break.

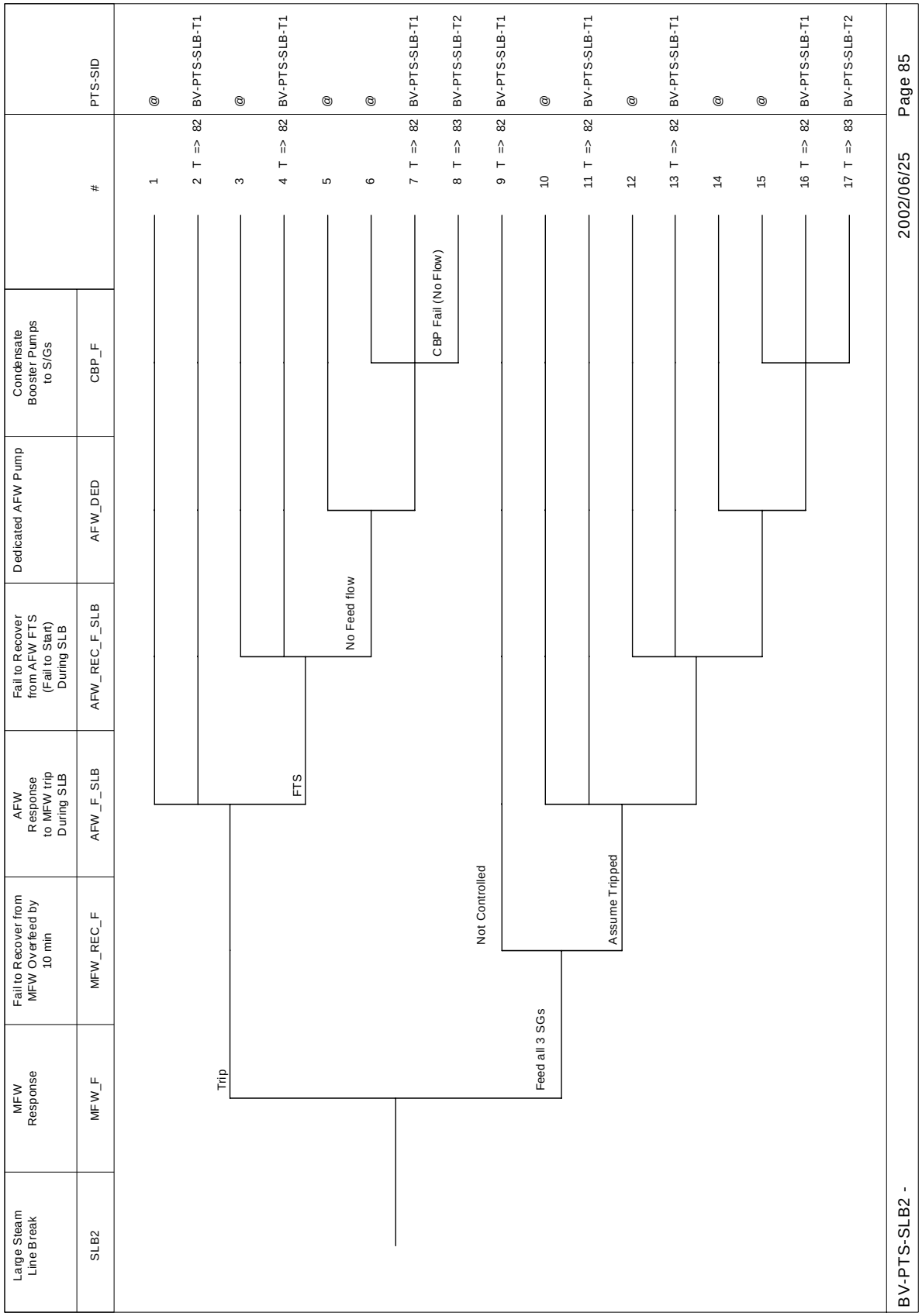

Figure 4.84. Beaver Valley SLB2: Large steam line break.

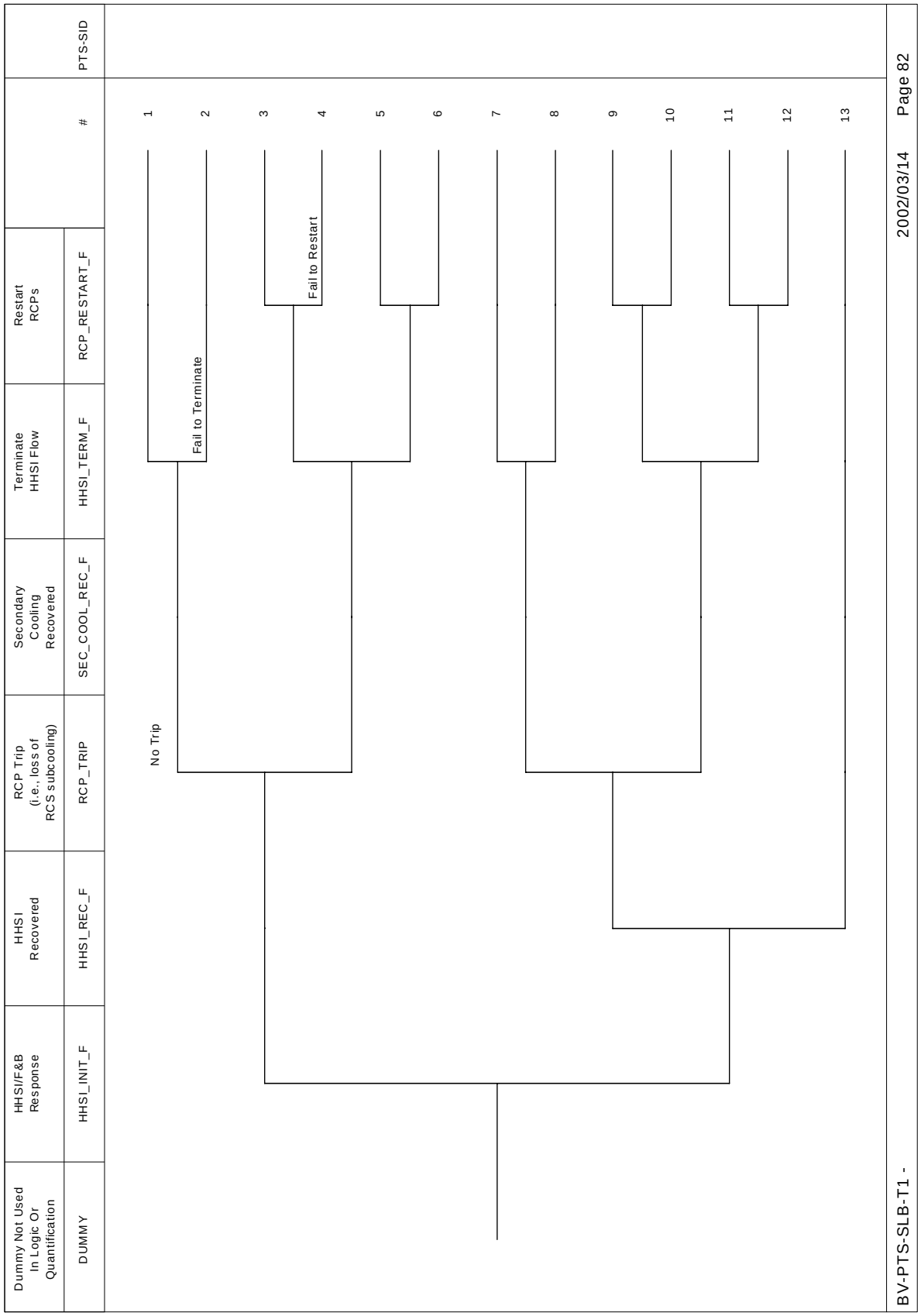

Figure 4.85. Beaver Valley SLB-T1: Steam line break (HHSI not F&B).

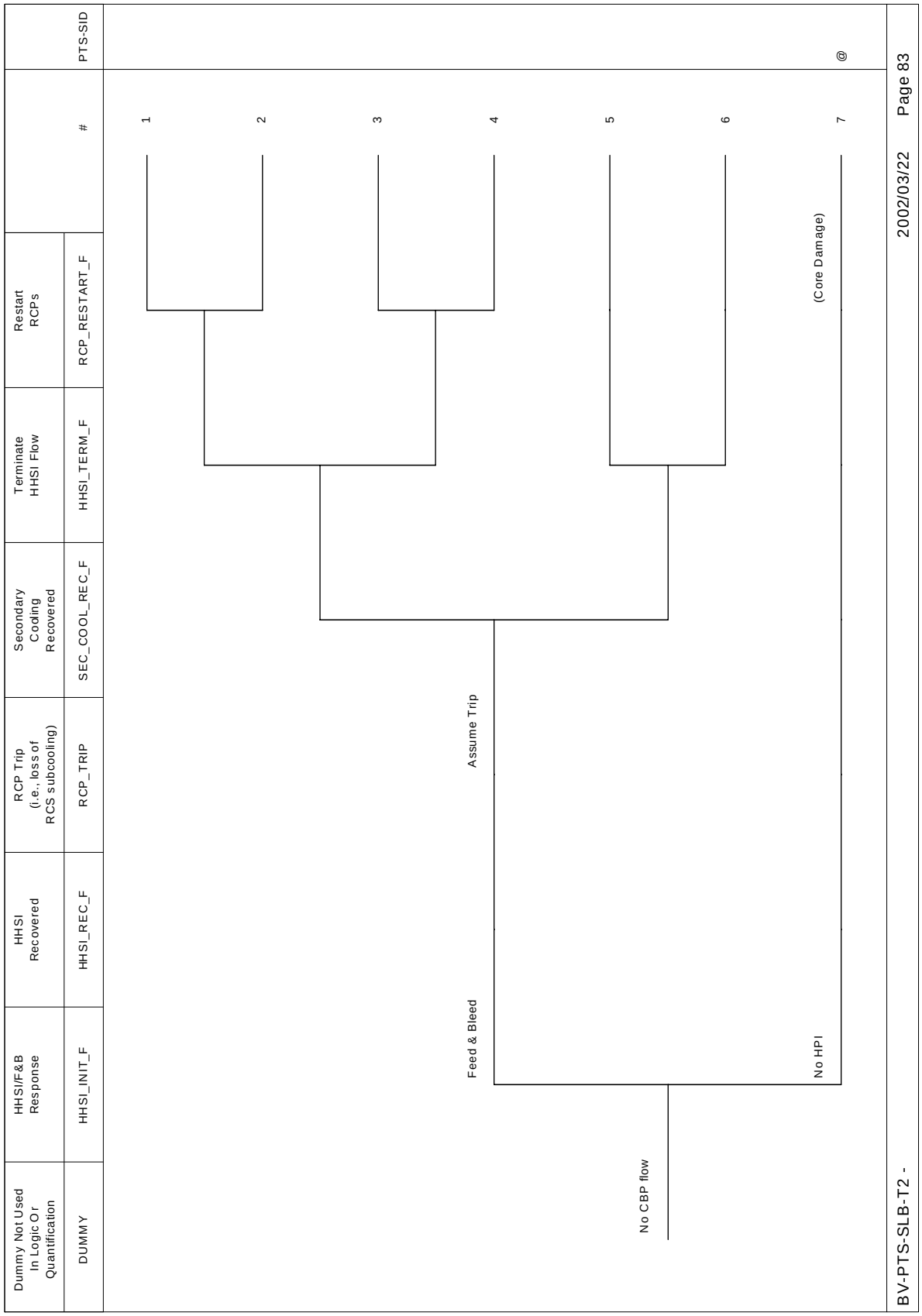

Figure 4.86. Beaver Valley SLB-T2: Steam line break (HHSI F&B).

Small LOCA	PORV or SRV Stuck Open	Stuck Open PORVs Isolated	Stuck Open SRV(s) Closes	ADV Stuck Open (unlikely to demand MSSRVs)	Stuck Open ADV Isolated		
SLOCA	PORV_SRV_SO	PORV_ISO_F	SRV_ISO_F	ADV_SO	ADV_ISO_F	#	PTS-SID
						1 T => 87	BV-PTS-SLOCA-4

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Figure 4.87. Beaver Valley SLOCA: Small LOCA.

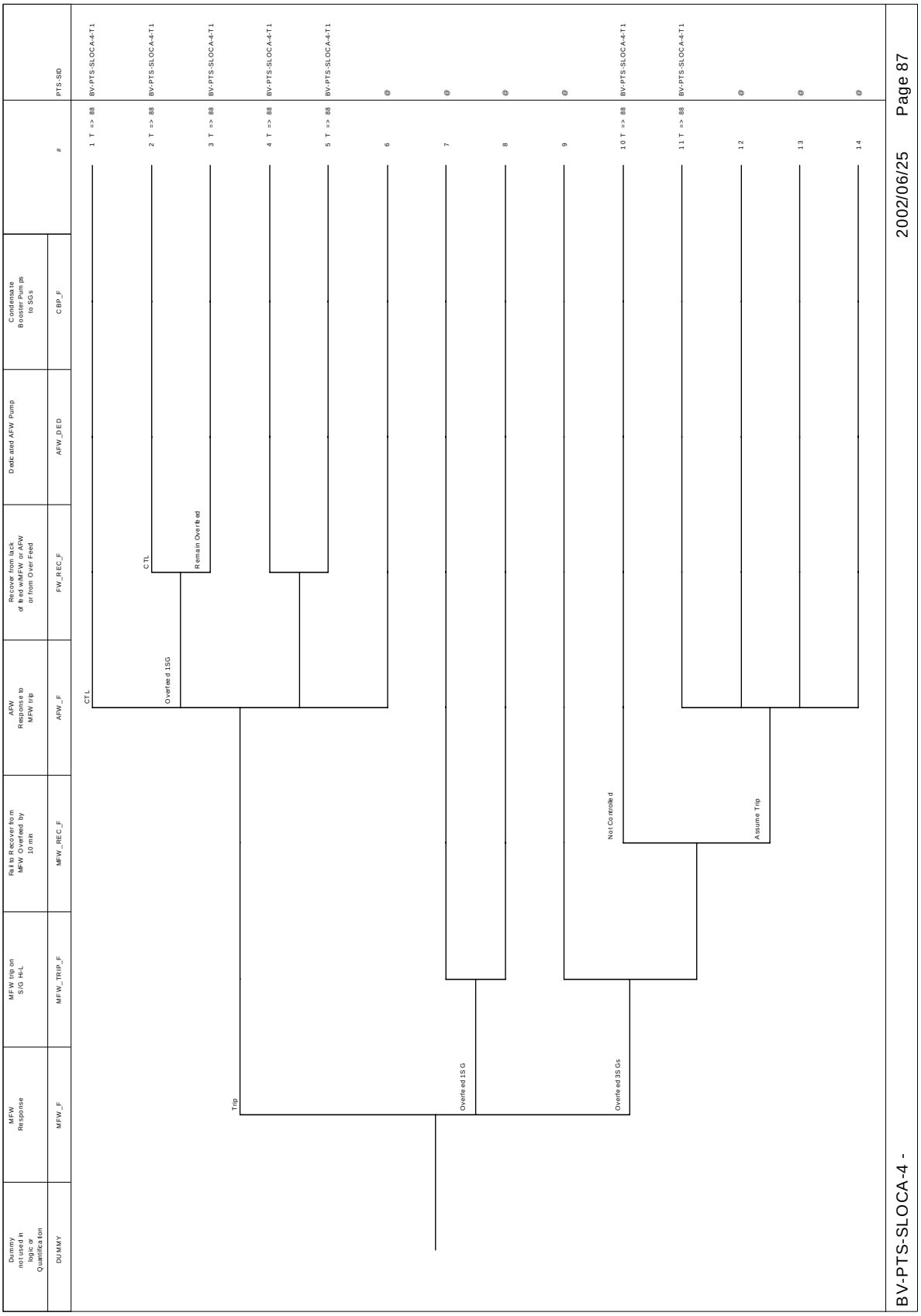

Figure 4.88. Beaver Valley SLOCA-4: Small LOCA (primary system open).

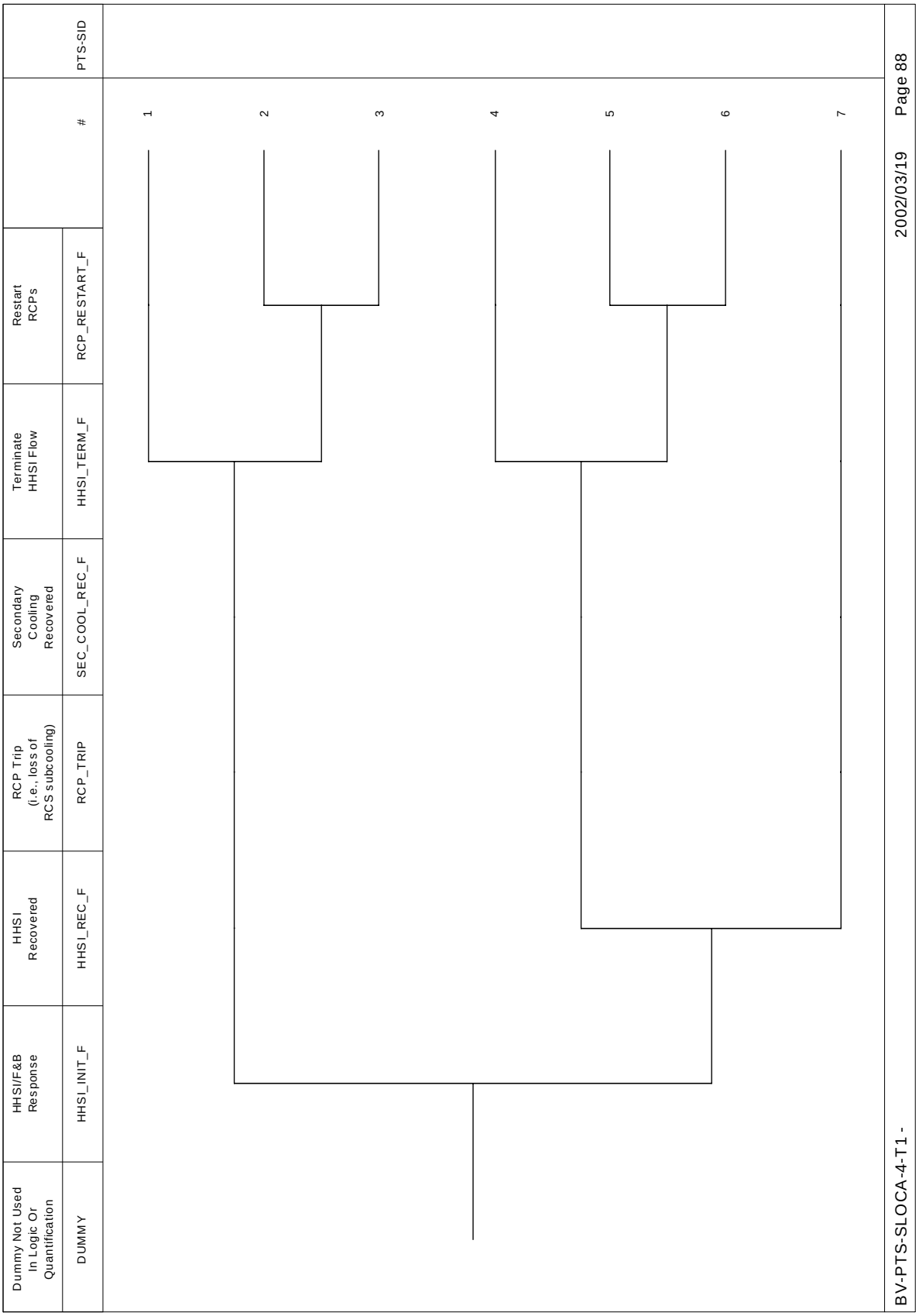

Figure 4.89. Beaver Valley SLOCA-4-T1: Small LOCA–primary system open (HHSI not F&B).

4.2.1.1 LLOCA Top Events

The top event and the logic structure for the LLOCA initiator event tree are shown in Figure 4.2. The LLOCA event tree includes:

LLOCA: A large LOCA.

DUMMY: A “dummy” top event.

This DUMMY top event allows SAPHIRE [SAPHIRE] to generate the sequence logic for the one potential PTS relevant sequence included in the LLOCA initiating event model (i.e., a “sequence” consisting solely of the initiating event.).

4.2.1.2 LOAC Top Events

The top events and the logic structure for the LOAC initiator event tree are shown in Figures 4.3 (initiator tree) and 4.4 through 4.16 (transfer trees).

Top events for Figure 4.3 include:

LOAC: A loss of 120 V ac instrument bus initiating event occurs.

AC_BUS: The determination of which bus is lost. The top branch represents loss of the “Red” bus, the second branch represents loss of the “White” bus, the third branch represents loss of the “Blue” bus, and the bottom branch represents loss of the “Yellow” bus.

PORV_SRV_SO: The determination of whether a pressurizer PORV or SRV is stuck open. The top branch implies that neither are stuck open, second branch represents the case where two PORVs are initially stuck open, the third branch represents the case where one SRV is initially stuck open, and the bottom branch represents the case where two SRVs are initially stuck open.

PORV_ISO_F: The success or failure of isolating the stuck open PORVs. Success implies that the PORVs were isolated by closing their block valves. Failure implies that the operators failed to close the block valves.

SRV_ISO_F: The determination of whether the stuck open SRV or SRVs close. Two situations exist. For the situation where one SRV is stuck open the top branch is not used, the middle branch represents the case where the one valve closes, and the bottom branch represents the case where the one valve does not close. For the situation where two SRVs are stuck open the top branch is not used, the second branch represents the case where both SRVs close, the third branch represents the case where one of two SRVs closes, and the bottom branch represents the case where both SRVs do not close.

MSSRV_SO: The determination of whether MSSRVs are stuck open. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

The top events for Figure 4.4 include:

PORV_SRV_SO: The determination of whether a pressurizer PORV or SRV is stuck open. The top branch implies that neither are stuck open, second branch represents the case where two PORVs are initially stuck open, the third branch represents the case where one SRV is initially stuck open, and the bottom branch represents the case where two SRVs are initially stuck open.

PORV_ISO_F: The success or failure of isolating the stuck open PORVs. Success implies that the PORVs were isolated by closing their block valves. Failure implies that the operators failed to close the block valves.

SRV_ISO_F: The determination of whether the stuck open SRV or SRVs close. Two situations exist. For the situation where one SRV is stuck open the top branch is not used, the middle branch represents the case where the one valve closes, and the bottom branch represents the case where the one valve does not close. For the situation where two SRVs are stuck open the top branch is not used, the second branch represents the case where both SRVs close, the third branch represents the case where one of two SRVs closes, and the bottom branch represents the case where both SRVs do not close.

ADV_SO: The determination of whether ADVs are stuck open. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

ADV_ISO_F: The determination of whether stuck open ADVs are isolated. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

The top events for Figure 4.5 include:

PORV_SRV_SO_ORGE: The determination of whether a pressurizer PORV or SRV is stuck open. Loss of the “Blue” bus implies that two PORVs cannot open; thus, the top branch implies that no SRVs are stuck open, the middle branch represents the case where one SRV is initially stuck open, and the bottom branch represents the case where two SRVs are initially stuck open.

PORV_ISO_F: The success or failure of isolating the stuck open PORVs. Not used since loss of “Blue” bus implies that two PORVs cannot open.

SRV_ISO_F: The determination of whether the stuck open SRV or SRVs close. Two situations exist. For the situation where one SRV is stuck open the top branch is not used, the middle branch represents the case where the one valve closes, and the bottom branch represents the case where the one valve does not close. For the situation where two SRVs are stuck open the top branch is not used, the second branch represents the case where both SRVs close, the third branch represents the case where one of two SRVs closes, and the bottom branch represents the case where both SRVs do not close.

ADV_SO: The determination of whether ADVs are stuck open. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

ADV_ISO_F: The determination of whether stuck open ADVs are isolated. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

The top events for Figure 4.6 include:

MFW_F: The determination of MFW response to the initiating event. The top branch represents the case where MFW trips as designed in response to the initiator. The middle branch represents the case where MFW overfeeds one steam generator. The bottom branch represents the case of overfeeding three steam generators.

MFW_TRIP_F: The success or failure of the high steam generator level trip for MFW. Success implies that MFW tripped. Failure implies that MFW did not trip.

MFW_REC_F: The success or failure of controlling (i.e., recovering from) a MFW overfeed event by 10 minutes. The top branch implies that the operators fail to control (i.e., fail to trip) MFW, resulting in overfeed by MFW. The bottom branch implies that the operators control (i.e., trip) MFW, terminating the overfeed by MFW.

AFW_F: The determination of AFW response given a demand for AFW. The top branch represents the case where AFW successfully operates to remove decay heat, maintaining appropriate temperature and pressure. The second branch represents the case where AFW overfeeds one steam generator. The third branch represents the case where AFW overfeeds three steam generators. The fourth branch represents the case where AFW fails to provide flow.

FW_REC_F: The success or failure of recovering from overfeed or the success or failure of recover from a lack of feed with MFW or AFW. Two situations exist. For the situation where AFW is overfeeding three steam generators, the success branch represents the case where operators control overfeeding and the failure branch represents the case where operators fail to control overfeeding. For the situation

where AFW fails to provide flow, the top branch represents the case where recovery and control of feed flow occurs, the middle branch represents the case where operators fail to control feed flow, and the bottom branch represents the case feed flow is not recovered.

AFW_DED: The success or failure of the dedicated AFW pump. Success implies the dedicated AFW pump worked. Failure implies the dedicated AFW pump did not work.

CBP_F: The determination of condensate booster pump (CBP) response given a demand for CBP. The top branch represents the case where the operators successfully depressurize the steam generator(s) so that the CBPs can inject, the CBPs successfully operated to remove decay heat, and the operators successfully control injection by the CBPs to prevent overfeeding of a steam generator (i.e., they feed only the good steam generator if one steam generator is faulted). The middle branch represents the case where the operators successfully depressurize the steam generator(s) so that the CBPs can inject, the CBPs work, but operators fail to control flow from the pump(s) (i.e., they feed both steam generators). The bottom branch represents the case where the CBPs fail to function (i.e., no flow).

Top events for Figure 4.7 include:

HHSI_INIT_F: The success or failure of high head safety injection. Success implies that injection with high pressure water occurs. Failure implies no injection of high pressure water.

HHSI_REC_F: Recovery of high head safety injection given initial failure. Success implies that high pressure injection is recovered. Failure implies that it was not recovered.

RCP_TRIP: The determination of whether the RCPs trip. Success implies the pumps did not trip. Failure implies tripping of the pumps. Question not asked.

SEC_COOL_REC_F: Recovery of secondary cooling. Success implies that secondary cooling is recovered. Failure implies that it is not recovered. Question not asked.

HHSI_TERM_F: The determination of whether high pressure injection is throttled to control pressure. Success implies the operators successfully throttled injection to control pressure. Failure implies the operators did not throttle injection; thus, pressure was not controlled.

RCP_RESTART_F: The determination of whether the RCPs are restarted. Success implies the restart of a RCP. Failure implies no RCP restarted. Question not asked.

Top events for Figure 4.8 are the same as Figure 4.7.

Top events for Figure 4.9 are the same as Figure 4.6 except that MFW is assumed to overfeed three steam generators for MFW_F.

Top events for Figure 4.10 are the same as Figure 4.7.

Top events for Figure 4.11 are the same as Figure 4.7.

Top events for Figure 4.12 are the same as Figure 4.4.

Top events for Figure 4.13 are the same as Figure 4.6 except for the following:

FW_REC_F: The success or failure of recovering from overfeed. The success branch represents the case where operators control overfeeding and the failure branch represents the case where operators fail to control overfeeding.

AFW_DED: The success or failure of the dedicated AFW pump. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

CBP_F: The determination of condensate booster pump (CBP) response given a demand for CBP. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

Top events for Figure 4.14 are the same as Figure 4.7.

Top events for Figure 4.15 are the same as Figure 4.6 except for the following:

MFW_F: The determination of MFW response to the initiating event. MFW is assumed to overfeed three steam generators.

FW_REC_F: The success or failure of recovering from overfeed. The success branch represents the case where operators control overfeeding and the failure branch represents the case where operators fail to control overfeeding.

AFW_DED: The success or failure of the dedicated AFW pump. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

CBP_F: The determination of condensate booster pump (CBP) response given a demand for CBP. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

Top events for Figure 4.16 are the same as Figure 4.7.

4.2.1.3 LOCAIR Top Events

The top events and the logic structure for the LOCAIR initiator event tree are shown in Figure 4.17 (initiator tree) and Figures 4.18 through 4.22 (transfer trees).

The top events for Figure 4.17 include:

LOCAIR: A loss of containment air initiator occurs.

PORV_SRV_SO: The determination of whether a pressurizer PORV or SRV is stuck open. The top branch implies that neither are stuck open, second branch represents the case where two PORVs are initially stuck open, the third branch represents the case where one SRV is initially stuck open, and the bottom branch represents the case where two SRVs are initially stuck open.

PORV_ISO_F: The success or failure of isolating the stuck open PORVs. Success implies that the PORVs were isolated by closing their block valves. Failure implies that the operators failed to close the block valves.

SRV_ISO_F: The determination of whether the stuck open SRV or SRVs close. Two situations exist. For the situation where one SRV is stuck open the top branch is not used, the middle branch represents the case where the one valve closes, and the bottom branch represents the case where the one valve does not close. For the situation where two SRVs are stuck open the top branch is not used, the second branch represents the case where both SRVs close, the third branch represents the case where one of two SRVs closes, and the bottom branch represents the case where both SRVs do not close.

ADV_SO: The determination of whether ADVs are stuck open. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

ADV_ISO_F: The determination of whether stuck open ADVs are isolated. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

The top events for Figure 4.18 include:

MFW_F: The determination of MFW response to the initiating event. The top branch represents the case where MFW trips as designed in response to the initiator. The middle branch represents the case where MFW overfeeds one steam generator. The bottom branch represents the case of overfeeding three steam generators.

MFW_TRIP_F: The success or failure of the high steam generator level trip for MFW. Success implies that MFW tripped. Failure implies that MFW did not trip.

MFW_REC_F: The success or failure of controlling (i.e., recovering from) a MFW overfeed event by 10 minutes. The top branch implies that the operators fail to control (i.e., fail to trip) MFW, resulting in overfeed by MFW. The bottom branch implies that the operators control (i.e., trip) MFW, terminating the overfeed by MFW.

AFW_F: The determination of AFW response given a demand for AFW. The top branch represents the case where AFW successfully operates to remove decay heat, maintaining appropriate temperature and pressure. The second branch represents the case where AFW overfeeds one steam generator. The third branch represents the case where AFW overfeeds three steam generators. The fourth branch represents the case where AFW fails to provide flow.

FW_REC_F: The success or failure of recovering from overfeed or the success or failure of recover from a lack of feed with MFW or AFW. Two situations exist. For the situation where AFW is overfeeding three steam generators, the success branch represents the case where operators control overfeeding and the failure branch represents the case where operators fail to control overfeeding. For the situation where AFW fails to provide flow, the top branch represents the case where recovery and control of feed flow occurs, the middle branch represents the case where operators fail to control feed flow, and the bottom branch represents the case feed flow is not recovered.

AFW_DED: The success or failure of the dedicated AFW pump. Success implies the dedicated AFW pump worked. Failure implies the dedicated AFW pump did not work.

CBP_F: The determination of condensate booster pump (CBP) response given a demand for CBP. The top branch represents the case where the operators successfully depressurize the steam generator(s) so that the CBPs can inject, the CBPs successfully operated to remove decay heat, and the operators successfully control injection by the CBPs to prevent overfeeding of a steam generator (i.e., they feed only the good steam generator if one steam generator is faulted). The middle branch represents the case where the operators successfully depressurize the steam generator(s) so that the CBPs can inject, the CBPs work, but operators fail to control flow from the pump(s) (i.e., they feed both steam generators). The bottom branch represents the case where the CBPs fail to function (i.e., no flow).

Top events for Figure 4.19 are the same as Figure 4.7.

Top events for Figure 4.20 are the same as Figure 4.7.

Top events for Figure 4.21 are the same as Figure 4.18 except for the following:

FW_REC_F: The success or failure of recovering from overfeed. The success branch represents the case where operators control overfeeding and the failure branch represents the case where operators fail to control overfeeding.

AFW_DED: The success or failure of the dedicated AFW pump. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

CBP_F: The determination of condensate booster pump (CBP) response given a demand for CBP. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

Top events for Figure 4.22 are the same as Figure 4.7.

4.2.1.4 LODC Top Events

The top events and the logic structure for the LODC initiator event tree are shown in Figure 4.23 (initiator tree) and Figures 4.23 through 4.29 (transfer trees).

Top events for Figure 4.23 include:

LODC: A loss of 125V dc bus initiator occurs.

DC_BUS: The determination of which bus is lost. The top branch represents the loss of the "Orange" bus. The bottom branch represents the loss of the "Purple" bus.

PORV_SRV_SO_ORGE: The determination of whether a pressurizer PORV or SRV is stuck open. Loss of the "Orange" bus implies that two PORVs cannot open; thus, the top branch implies that no SRVs are stuck open, the middle branch represents the case where one SRV is initially stuck open, and the bottom branch represents the case where two SRVs are initially stuck open.

PORV_ISO_F: The success or failure of isolating the stuck open PORVs. Not used since loss of "Orange" bus implies that two PORVs cannot open.

SRV_ISO_F: The determination of whether the stuck open SRV or SRVs close. Two situations exist. For the situation where one SRV is stuck open the top branch is not used, the middle branch represents the case where the one valve closes, and the bottom branch represents the case where the one valve does not close. For the situation where two SRVs are stuck open the top branch is not used, the second branch represents the case where both SRVs close, the third branch represents the case where one of two SRVs closes, and the bottom branch represents the case where both SRVs do not close.

MSSRV_SO: The determination of whether MSSRVs are stuck open. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

Top events for Figure 4.24 include:

PORV_SRV_SO: The determination of whether a pressurizer PORV or SRV is stuck open. The top branch implies that neither are stuck open, second branch represents the case where two PORVs are initially stuck open, the third branch represents the case where one SRV is initially stuck open, and the bottom branch represents the case where two SRVs are initially stuck open.

PORV_ISO_F: The success or failure of isolating the stuck open PORVs. Success implies that the PORVs were isolated by closing their block valves. Failure implies that the operators failed to close the block valves.

SRV_ISO_F: The determination of whether the stuck open SRV or SRVs close. Two situations exist. For the situation where one SRV is stuck open the top branch is not used, the middle branch represents the case where the one valve closes, and the bottom branch represents the case where the one valve does not close. For the situation where two SRVs are stuck open the top branch is not used, the second branch represents the case where both SRVs close, the third branch represents the case where one of two SRVs closes, and the bottom branch represents the case where both SRVs do not close.

MSSRV_SO: The determination of whether MSSRVs are stuck open. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

Top events for Figure 4.25 include:

MFW_F: The determination of MFW response to the initiating event. Question not asked.

MFW_TRIP_F: The success or failure of the high steam generator level trip for MFW. Question not asked.

MFW_REC_F: The success or failure of controlling (i.e., recovering from) a MFW overfeed event by 10 minutes. Question not asked.

AFW_F: The determination of AFW response given a demand for AFW. The top branch represents the case where AFW successfully operates to remove decay heat, maintaining appropriate temperature and pressure; however this branch is not developed based on the model simplifications identified in section 4.1.2. The second branch represents the case where AFW overfeeds one steam generator; however, this branch is not developed based on the model simplifications identified in section 4.1.2. The third branch represents the case where AFW overfeeds three steam generators. The fourth branch represents the case where AFW fails to provide flow.

FW_REC_F: The success or failure of recovering from overfeed or the success or failure of recover from a lack of feed with MFW or AFW. Two situations exist. For the situation where AFW is overfeeding three steam generators, the success branch represents the case where operators control overfeeding and the failure branch represents the case where operators fail to control overfeeding. For the situation where AFW fails to provide flow, the top branch represents the case where recovery and control of feed flow occurs, the middle branch represents the case where operators fail to control feed flow, and the bottom branch represents the case feed flow is not recovered.

AFW_DED: The success or failure of the dedicated AFW pump. Success implies the dedicated AFW pump worked. Failure implies the dedicated AFW pump did not work.

CBP_F: The determination of condensate booster pump (CBP) response given a demand for CBP. The top branch represents the case where the operators successfully depressurize the steam generator(s) so that the CBPs can inject, the CBPs successfully operated to remove decay heat, and the operators successfully control injection by the CBPs to prevent overfeeding of a steam generator (i.e., they feed only the good steam generator if one steam generator is faulted). The middle branch represents the case where the operators successfully depressurize the steam generator(s) so that the CBPs can inject, the CBPs work, but operators fail to control flow from the pump(s) (i.e., they feed both steam generators). The bottom branch represents the case where the CBPs fail to function (i.e., no flow).

Top events for Figure 4.26 include:

HHSI_INIT_F: The success or failure of high head safety injection. Success implies that injection with high pressure water occurs. Failure implies no injection of high pressure water.

HHSI_REC_F: Recovery of high head safety injection given initial failure. Success implies that high pressure injection is recovered. Failure implies that it was not recovered.

RCP_TRIP: The determination of whether the RCPs trip. Success implies the pumps did not trip. Failure implies tripping of the pumps.

A_SEC_COOL_REC_F: Recovery of secondary cooling (AFW only). Success implies that secondary cooling is recovered. Failure implies that it is not recovered.

HHSI_TERM_F: The determination of whether high pressure injection is throttled to control pressure. Success implies the operators successfully throttled injection to control pressure. Failure implies the operators did not throttle injection; thus, pressure was not controlled.

RCP_RESTART_F: The determination of whether the RCPs are restarted. Success implies the restart of a RCP. Failure implies no RCP restarted.

Top events for Figure 4.27 are the same as Figure 4.26.

Top events for Figure 4.28 include:

MFW_F: The determination of MFW response to the initiating event. Question not asked.

MFW_TRIP_F: The success or failure of the high steam generator level trip for MFW. Question not asked.

MFW_REC_F: The success or failure of controlling (i.e., recovering from) a MFW overfeed event by 10 minutes. Question not asked.

AFW_F: The determination of AFW response given a demand for AFW. The top branch represents the case where AFW successfully operates to remove decay heat, maintaining appropriate temperature and pressure. The second branch represents the case where AFW overfeeds one steam generator. The third branch represents the case where AFW overfeeds three steam generators. The fourth branch represents the case where AFW fails to provide flow; however, this branch is not developed based on the model simplifications identified in section 4.1.2.

FW_REC_F: The success or failure of recovering from overfeed or the success or failure of recover from a lack of feed with MFW or AFW. The success branch represents the case where operators control overfeeding and the failure branch represents the case where operators fail to control overfeeding.

AFW_DED: The success or failure of the dedicated AFW pump. Success implies the dedicated AFW pump worked. Question not asked.

CBP_F: The determination of condensate booster pump (CBP) response given a demand for CBP. Question not asked.

Top events for Figure 4.29 are the same as Figure 4.26.

4.2.1.5 LOIA Top Events

The top events and the logic structure for the LOIA initiator event tree are shown in Figure 4.30 (initiator tree) and Figures 4.31 through 4.35 (transfer trees).

Top events for Figure 4.30 include:

LOIA: A loss of instrument (station) air initiating event occurs.

PORV_SRV_SO: The determination of whether a pressurizer PORV or SRV is stuck open. The top branch implies that neither are stuck open, second branch represents the case

where two PORVs are initially stuck open, the third branch represents the case where one SRV is initially stuck open, and the bottom branch represents the case where two SRVs are initially stuck open.

PORV_ISO_F: The success or failure of isolating the stuck open PORVs. Success implies that the PORVs were isolated by closing their block valves. Failure implies that the operators failed to close the block valves.

SRV_ISO_F: The determination of whether the stuck open SRV or SRVs close. Two situations exist. For the situation where one SRV is stuck open the top branch is not used, the middle branch represents the case where the one valve closes, and the bottom branch represents the case where the one valve does not close. For the situation where two SRVs are stuck open the top branch is not used, the second branch represents the case where both SRVs close, the third branch represents the case where one of two SRVs closes, and the bottom branch represents the case where both SRVs do not close.

MSSRV_SO: The determination of whether MSSRVs are stuck open. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2. (Note: ADVs close on LOIA.)

Top events for Figure 4.31 are the same as Figure 4.25.

Top events for Figure 4.32 are the same as Figure 4.26, plus one additional event:

PCCW_VALVE_F: The determination of the status of the primary component cooling water (PCCW) containment valve. Success implies the PCCW valve remains open. Failure implies it closes.

Top events for Figure 4.33 are the same as Figure 4.32.

Top events for Figure 4.34 are the same as Figure 4.28.

Top events for Figure 4.35 are the same as Figure 4.32.

4.2.1.6 LOMC Top Events

The top events and the logic structure for the LOMC initiator event tree are shown in Figure 4.36 (initiator tree) and Figures 4.37 through 4.41 (transfer trees).

The top events for Figure 4.36 are the same as Figure 4.17 except the first event (i.e., the initiator) becomes

LOMC: A loss of main condenser initiating event occurs.

Top events for Figure 4.37 are the same as Figure 4.25

Top events for Figure 4.38 are the same as Figure 4.26.

Top events for Figure 4.39 are the same as Figure 4.26.

Top events for Figure 4.40 are the same as Figure 4.28.

Top events for Figure 4.41 are the same as Figure 4.26.

4.2.1.7 LOMF Top Events

The top events and the logic structure for the LOMF initiator event tree are shown in Figure 4.42 (initiator tree) and Figures 4.43 through 4.47 (transfer trees).

The top events for Figure 4.42 are the same as Figure 4.17 except the first event (i.e., the initiator) becomes

LOMF: A loss of main feedwater initiating event occurs.

Top events for Figure 4.43 are the same as Figure 4.25

Top events for Figure 4.44 are the same as Figure 4.26.

Top events for Figure 4.45 are the same as Figure 4.26.

Top events for Figure 4.46 are the same as Figure 4.28.

Top events for Figure 4.47 are the same as Figure 4.26.

4.2.1.8 LOR-RW Top Events

The top events and the logic structure for the LOR-RW initiator event tree are shown in Figure 4.48 (initiator tree) and Figures 4.49 through 4.53 (transfer trees).

The top events for Figure 4.48 are the same as Figure 4.30 except the first event (i.e., the initiator) becomes

LOR-RW: A loss of river/raw water initiating event occurs.

Top events for Figure 4.49 are the same as Figure 4.25

Top events for Figure 4.50 are the same as Figure 4.26.

Top events for Figure 4.51 are the same as Figure 4.26.

Top events for Figure 4.52 are the same as Figure 4.28.

Top events for Figure 4.53 are the same as Figure 4.26.

4.2.1.9 LOSP Top Events

The top events and the logic structure for the LOSP initiator event tree are shown in Figure 4.54 (initiator tree) and Figures 4.55 through 4.63 (transfer trees).

Top events for Figure 4.54 include:

LOSP:	A loss of offsite power initiating event occurs.
DG_A:	The success or failure of diesel generator (DG) A. The top branch implies DG A successful. The bottom branch implies it is not.
DG_B:	The success or failure of DG B. The top branch implies DG B is successful. The bottom branch implies it is not.
DG_B_GIVEN_A:	The success or failure of DG B given DG A fails. The top branch implies DG B is successful given DG A fails. The bottom branch implies DG B fails.
PORV_SRV_SO:	The determination of whether a pressurizer PORV or SRV is stuck open. The top branch implies that neither are stuck open, second branch represents the case where two PORVs are initially stuck open, the third branch represents the case where one SRV is initially stuck open, and the bottom branch represents the case where two SRVs are initially stuck open.
PORV_CLOSE_2:	The percent of relevant PORV block valve closures (2 PORVs initially open). The top branch represents two PORVs closed via block valves. The bottom branch represents one PORV closed via block valve.
PORV_CLOSE_1:	The percent of relevant PORV block valve closures (1 PORV initially open). The top branch represents one PORV closed via block valve. The bottom branch represents zero PORV closed via block valve.
PORV_ISO_F:	The success or failure of isolating the stuck open PORVs. Success implies that the PORVs were isolated by closing their block valves. Failure implies that the operators failed to close the block valves.
PORV_SELF_CLOSE1:	The determination of whether one stuck open PORV closes by itself. The top branch represents the case where the PORV does close. The bottom branch represents the case where it does not.

PORV_SELF_CLOSE2: The determination of whether two stuck open PORVs closes by themselves. The top branch represents the case where the both PORVs reclose. The bottom branch represents the case where they do not.

SRV_ISO_F: The determination of whether the stuck open SRV or SRVs close. Two situations exist. For the situation where one SRV is stuck open the top branch is not used, the middle branch represents the case where the one valve closes, and the bottom branch represents the case where the one valve does not close. For the situation where two SRVs are stuck open the top branch is not used, the second branch represents the case where both SRVs close, the third branch represents the case where one of two SRVs closes, and the bottom branch represents the case where both SRVs do not close.

ADV_SO: The determination of whether ADVs are stuck open. This event not asked.

ADV_ISO_F: The determination of whether stuck open ADVs are isolated. This event not asked.

MSSRV_SO: The determination of whether MSSRVs are stuck open. This event included in the logic structure of the event tree, but is not developed based on the model simplifications identified in section 4.1.2.

Top events for Figure 4.55 are the same as Figure 4.25.

Top events for Figure 4.56 are the same as Figure 4.7.

Top events for Figure 4.57 are the same as Figure 4.7.

Top events for Figure 4.58 include:

MFW_F: The determination of MFW response to the initiating event. Question not asked.

MFW_TRIP_F: The success or failure of the high steam generator level trip for MFW. Question not asked.

MFW_REC_F: The success or failure of controlling (i.e., recovering from) a MFW overfeed event by 10 minutes. Question not asked.

T_AFW_F: The determination of turbine-driven AFW pump response given a demand for the turbine-driven pump. The top branch represents the case where the turbine-driven AFW pump successfully operates to remove decay heat, maintaining appropriate temperature and pressure; however this branch is not developed based on the model simplifications identified in section 4.1.2. The second branch represents the case where the turbine-driven AFW pump overfeeds one

steam generator; however, this branch is not developed based on the model simplifications identified in section 4.1.2. The third branch represents the case where the turbine-driven AFW pump overfeeds three steam generators. The fourth branch represents the case where the turbine-driven AFW pump fails to provide flow.

A_FW_REC_F: The success or failure of recovering from overfeed or the success or failure of recover from a lack of feed with the turbine-driven AFW pump. Two situations exist. For the situation where the turbine-driven AFW pump is overfeeding three steam generators, the success branch represents the case where operators control overfeeding and the failure branch represents the case where operators fail to control overfeeding. For the situation where the turbine-driven AFW pump fails to provide flow, the top branch represents the case where recovery and control of feed flow occurs, the middle branch represents the case where operators fail to control feed flow, and the bottom branch represents the case feed flow is not recovered.

AFW_DED: The success or failure of the dedicated AFW pump. Success implies the dedicated AFW pump worked. Failure implies the dedicated AFW pump did not work.

CBP_F: The determination of condensate booster pump (CBP) response given a demand for CBP. Question not asked (CBP not available because of the initiator).

Top events for Figure 4.59 are the same as Figure 4.28.

Top events for Figure 4.60 are the same as Figure 4.7.

Top events for Figure 4.61 include:

MFW_F: The determination of MFW response to the initiating event. Question not asked.

MFW_TRIP_F: The success or failure of the high steam generator level trip for MFW. Question not asked.

MFW_REC_F: The success or failure of controlling (i.e., recovering from) a MFW overfeed event by 10 minutes. Question not asked.

T_AFW_F: The determination of turbine-driven AFW pump response given a demand for the turbine-driven pump. The top branch represents the case where the turbine-driven AFW pump successfully operates to remove decay heat, maintaining appropriate temperature and pressure; however this branch is not developed based on the model simplifications identified in section 4.1.2. The second branch represents the case where the turbine-driven AFW pump overfeeds one steam generator; however, this branch is not developed based on the model simplifications identified in section 4.1.2. The third branch represents the case

where the turbine-driven AFW pump overfeeds three steam generators. The fourth branch represents the case where the turbine-driven AFW pump fails to provide flow; however this branch is not developed based on the model simplifications identified in section 4.1.2.

A_FW_REC_F: The success or failure of recovering from overfeed or the success or failure of recover from a lack of feed with the turbine-driven AFW pump. The success branch represents the case where operators control overfeeding and the failure branch represents the case where operators fail to control overfeeding.

AFW_DED: The success or failure of the dedicated AFW pump. Question not asked.

CBP_F: The determination of condensate booster pump (CBP) response given a demand for CBP. Question not asked (CBP not available because of the initiator).

Top events for Figure 4.62 are the same as Figure 4.7; however, none are asked because of blackout conditions.

Top events for Figure 4.63 are the same as Figure 4.7; however, none are asked because of blackout conditions.

4.2.1.10 LPCCW Top Events

The top events and the logic structure for the LPCCW initiator event tree are shown in Figure 4.64 (initiator tree) and Figures 4.65 through 4.69 (transfer trees).

The top events for Figure 4.64 are the same as Figure 4.17 except the first event (i.e., the initiator) becomes

LPCCW: A loss of plant/primary component cooling water initiating event occurs.

Top events for Figure 4.65 are the same as Figure 4.18.

Top events for Figure 4.66 are the same as Figure 4.7.

Top events for Figure 4.67 are the same as Figure 4.7.

Top events for Figure 4.68 are the same as Figure 4.21.

Top events for Figure 4.69 are the same as Figure 4.7.

4.2.1.11 LTPCCW Top Events

The top events and the logic structure for the LTPCCW initiator event tree are shown in Figure 4.70 (initiator tree) and Figures 4.71 through 4.75 (transfer trees).

The top events for Figure 4.70 are the same as Figure 4.30 except the first event (i.e., the initiator) becomes

LTPCCW: A loss of turbine plant component cooling water initiating event occurs.

Top events for Figure 4.71 are the same as Figure 4.25.

Top events for Figure 4.72 are the same as Figure 4.32.

Top events for Figure 4.73 are the same as Figure 4.32.

Top events for Figure 4.74 are the same as Figure 4.28.

Top events for Figure 4.75 are the same as Figure 4.32.

4.2.1.12 MLOCA Top Events

The top event and the logic structure for the MLOCA initiator event tree are shown in Figure 4.76. The MLOCA event tree includes:

MLOCA: A medium LOCA.

DUMMY: A “dummy” top event.

This DUMMY top event allows SAPHIRE [SAPHIRE] to generate the sequence logic for the one potential PTS relevant sequence included in the LLOCA initiating event model (i.e., a “sequence” consisting solely of the initiating event.).

4.2.1.13 RT1 Top Events

The top events and the logic structure for the RTTT initiator event tree are shown in Figure 4.77 (initiator tree) and Figures 4.78 through 4.82 (transfer trees).

The top events for Figure 4.77 are the same as Figure 4.17 except the first event (i.e., the initiator) becomes

RTTT: A reactor trip with turbine trip.

Top events for Figure 4.78 are the same as Figure 4.18.

Top events for Figure 4.79 are the same as Figure 4.7.

Top events for Figure 4.80 are the same as Figure 4.7.

Top events for Figure 4.81 are the same as Figure 4.21.

Top events for Figure 4.82 are the same as Figure 4.7.

4.2.1.14 SLB1 Top Events

The top events and the logic structure for the SLB1 initiator event tree are shown in Figure 4.83 (initiator tree) and Figures 4.85 and 4.86 (transfer trees).

The top events for Figure 4.83 are as follows:

SLB1:	A small steam line break initiating event occurs.
MFW_F:	The determination of MFW response to the initiating event. The top branch represents the case where MFW trips as designed in response to the initiator. The bottom branch represents the case of overfeeding three steam generators.
MFW_REC_F:	The success or failure of controlling (i.e., recovering from) a MFW overfeed event by 10 minutes. The top branch implies that the operators fail to control (i.e., fail to trip) MFW, resulting in overfeed by MFW. The bottom branch implies that the operators control (i.e., trip) MFW, terminating the overfeed by MFW.
AFW_F_SLB:	The determination of AFW response given a demand for AFW. The top branch represents the case where AFW successfully operates to remove decay heat, maintaining appropriate temperature and pressure. The middle branch represents the case where AFW overfeeds three steam generators. The bottom branch represents the case where AFW fails to provide flow.
AFW_REC_F_SLB:	The success or failure of using AFW to recover from a lack of feed during a steam line break. The top branch represents the case where recovery and control of feed flow occurs, the middle branch represents the case where operators fail to control feed flow, and the bottom branch represents the case feed flow is not recovered.
AFW_DED:	The success or failure of the dedicated AFW pump. Success implies the dedicated AFW pump worked. Failure implies the dedicated AFW pump did not work.
CBP_F:	The determination of condensate booster pump (CBP) response given a demand for CBP. The top branch represents the case where the operators successfully depressurize the steam generator(s) so that the CBPs can inject, the CBPs successfully operated to remove decay heat, and the operators successfully control injection by the CBPs to prevent overfeeding of a steam generator (i.e., they feed only the good steam generator if one steam generator is faulted). The middle branch represents the case where the operators successfully depressurize the steam generator(s) so that the CBPs can inject, the CBPs work, but operators fail to control flow from the pump(s) (i.e., they feed both steam generators). The bottom branch represents the case where the CBPs fail to function (i.e., no flow).

4.2.1.15 SLB2 Top Events

The top events and the logic structure for the SLB2 initiator event tree are shown in Figure 4.84 (initiator tree) and Figures 4.85 and 4.86 (transfer trees).

The top events for Figure 4.84 are the same as Figure 4.83 except the first event (i.e., the initiating event) becomes

SLB2: A large steam line break initiating event occurs.

Top events for Figure 4.85 are the same as Figure 4.7.

Top events for Figure 4.86 are the same as Figure 4.7

4.2.1.16 SLOCA Top Events

The top events and the logic structure for the SLOCA initiator event tree are shown in Figure 4.87 (initiator tree) and Figures 4.88 and 4.89 (transfer trees).

The top events for Figure 4.87 include:

SLOCA:	A small LOCA initiating event occurs.
PORV_SRV_SO:	The determination of whether a pressurizer PORV or SRV is stuck open. Question not asked.
PORV_ISO_F:	The success or failure of isolating the stuck open PORVs. Question not asked.
SRV_ISO_F:	The determination of whether the stuck open SRV or SRVs close. Question not asked.
ADV_SO:	The determination of whether ADVs are stuck open. Question not asked.
ADV_ISO_F:	The determination of whether stuck open ADVs are isolated. Question not asked.

Top events for Figure 4.88 are the same as Figure 4.21.

Top events for Figure 4.89 are the same as Figure 4.7.

4.2.2 Event Tree Top Events for Beaver Valley HZP Model

With the list of relevant equipment versus function information identified in section 4.1, system-level event trees were developed for each of the initiators identified in Section 3.3. These system-level event

trees, including transfer trees, are shown in Figures 4.90 through 4.177. The top events included in the system-level event trees used to model each HZP initiating event are the same as those used in the corresponding power event trees, with the addition of one other top event to each of the initiator trees. This top event is a multiplier to convert the power frequency to an HZP frequency and is described in section 3.5. Two different events were used. They include:

HZP-FRACTION: Conversion factor to convert power frequency to HZP frequency. Its value is 0.02.

HZP-MULTIPLIER: Conversion factor to convert power frequency to HZP frequency. Its value is 0.2.

4.3 Event Tree Sequence Generation

4.3.1 Power Model Sequence Generation

After developing the power event trees, the logic associated with each path through the trees (i.e., the unique combination of successes and failures) was constructed. SAPHIRE was used to generate this list of sequence logic by employing event tree rules. These rules modified selected top events in the event trees based on the specific path through the trees (i.e., the specific combination of successes and failures) prior to the top event being modified. A single integrated set of event tree rules was developed and used to produce the sequence logic for all event trees. Table 4.1 provides a listing of the rules used to modify event tree top events. The rules employ a sequential “if-then-else” logic structure to test for specific combinations of top events. Application of these rules to the event trees produced the sequence logic for each initiating event. Table 4.2 lists the number of sequences by initiating event produced by this application. As can be seen from Table 4.2, a total of 4,149 sequences was generated. (NOTE: Because so many sequences were generated, the actual logic for each sequence is not reproduced in this report; however, it can be provided in electronic form.) Once the sequence logic was generated, SAPHIRE was used to solve for the minimal cut sets for each sequence. Sequences were solved using no truncation on cut set frequency. Once the sequence cut sets were obtained, SAPHIRE applied a set of “if-then” recovery rules that had been developed to search for specific combinations of events and modify the identified cut sets as appropriate. These recovery rules are provided in Table 4.3. (NOTE: As with the sequence logic, the actual cut sets for each sequence are not reproduced in this report; however, they can be provided in electronic form.)

4.3.2 HZP Model Sequence Generation

Using the same approach as described in section 4.3.1, sequence logic was developed for the HZP event trees. Because the only difference between corresponding HZP and power event trees was the top event to convert the power initiating event frequency to HZP frequency (see section 4.2.2), generation of the HZP sequence logic employed the same set of event tree rules as was used to generate the power sequences (see Table 4.1). Since the same rules were used, the number of sequences generated for each

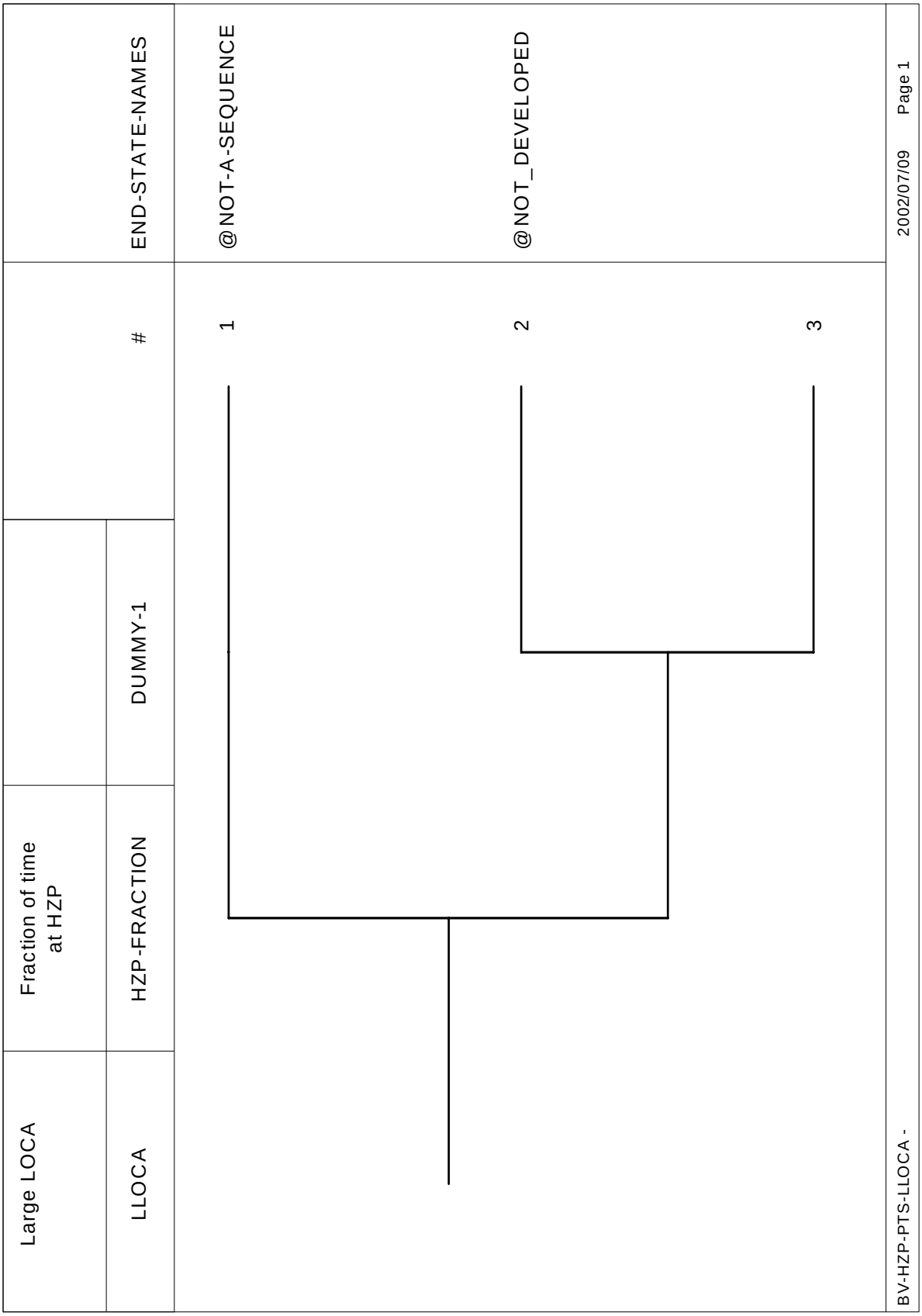

Figure 4.90. Beaver Valley HZP-LLOCA: Large LOCA.

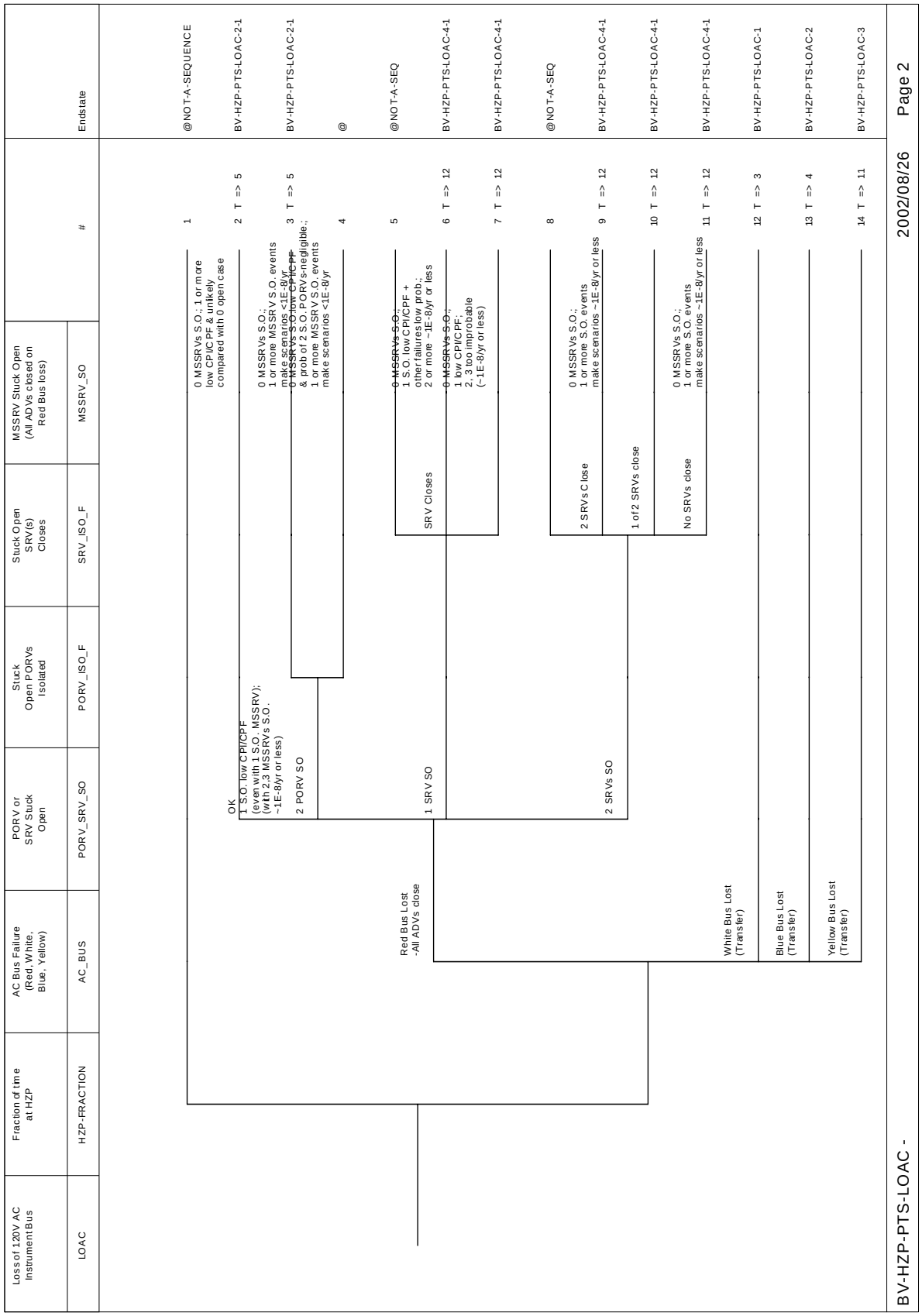

Figure 4.91. Beaver Valley HZP-LOAC: Loss of 120V AC (red bus lost).

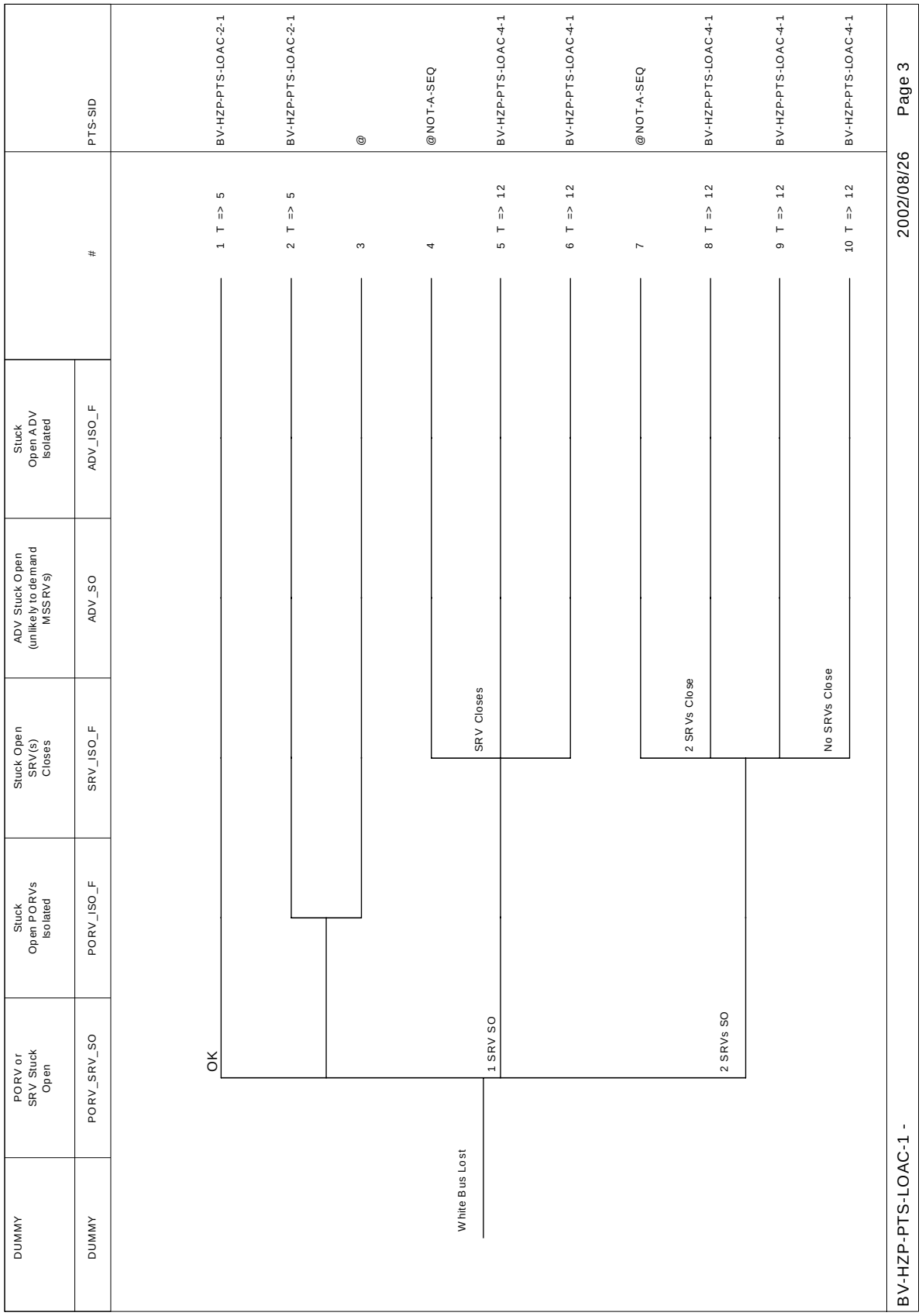

Figure 4.92. Beaver Valley -HZP-LOAC-1: Loss of 120V AC (white bus lost).

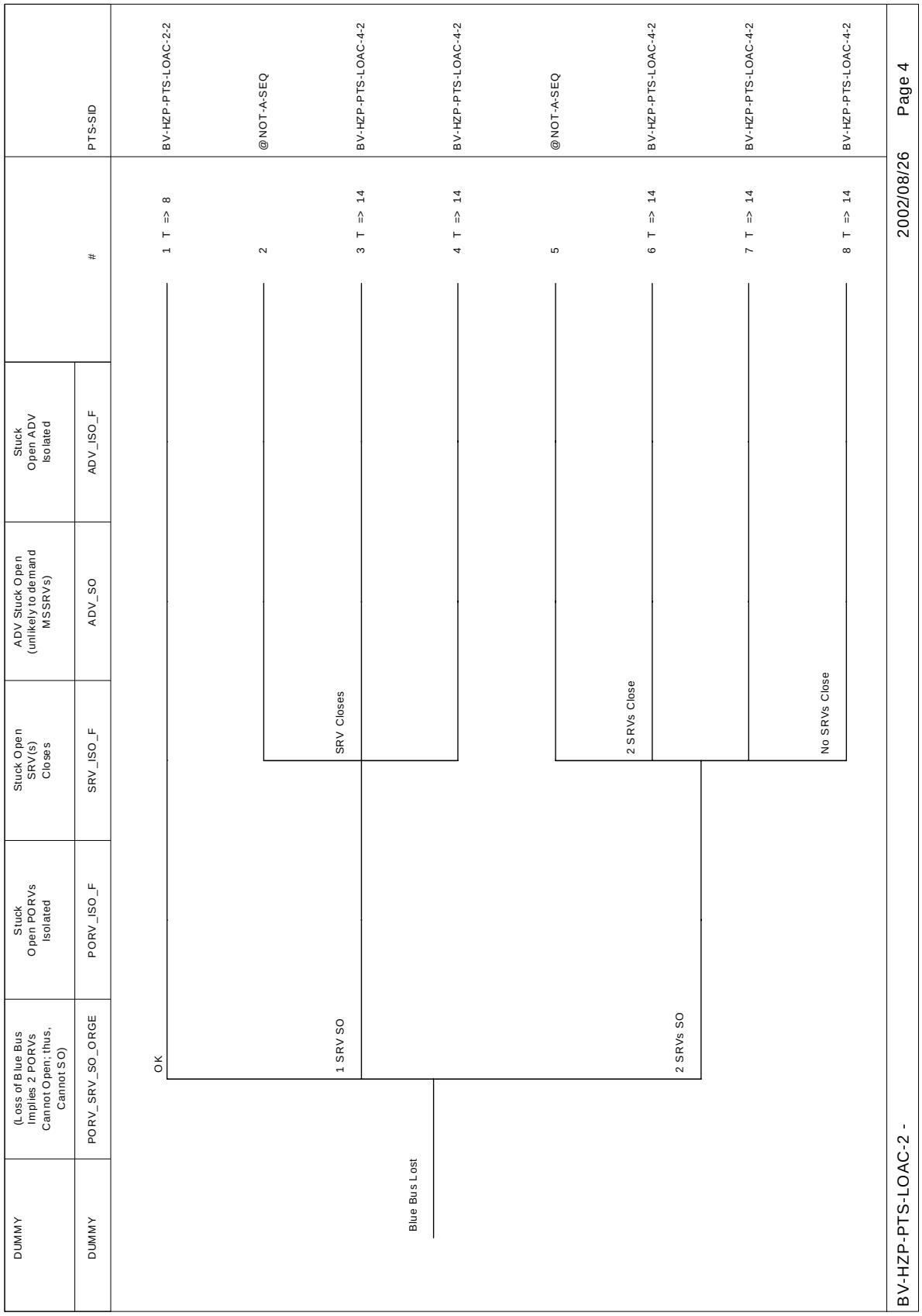

Figure 4.93. Beaver Valley -HZP-LOAC-2: Loss of 120V AC (blue bus lost).

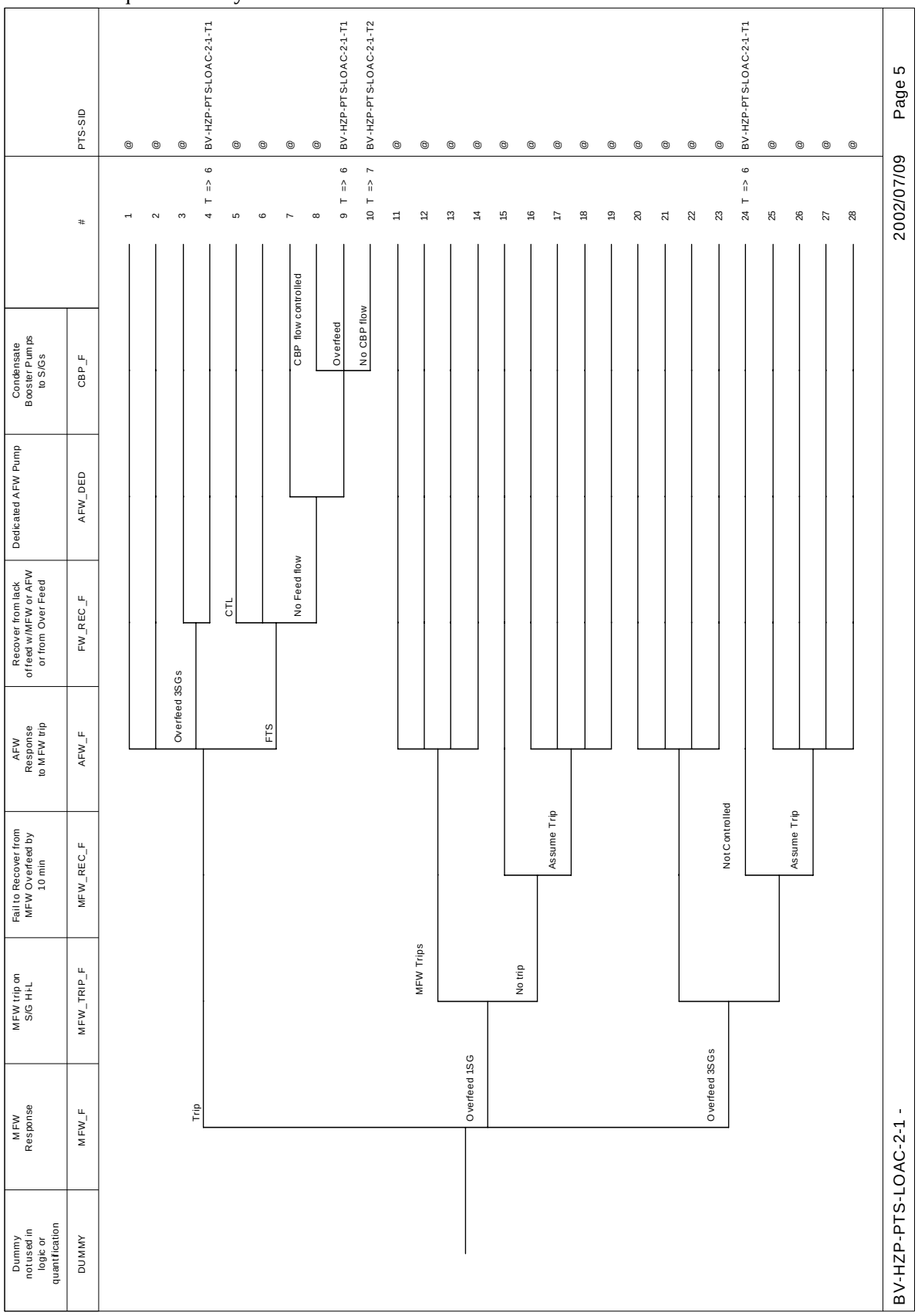

Figure 4.94. Beaver Valley -HZP-LOAC-2-1: Loss of 120V AC red or white bus (primary system intact).

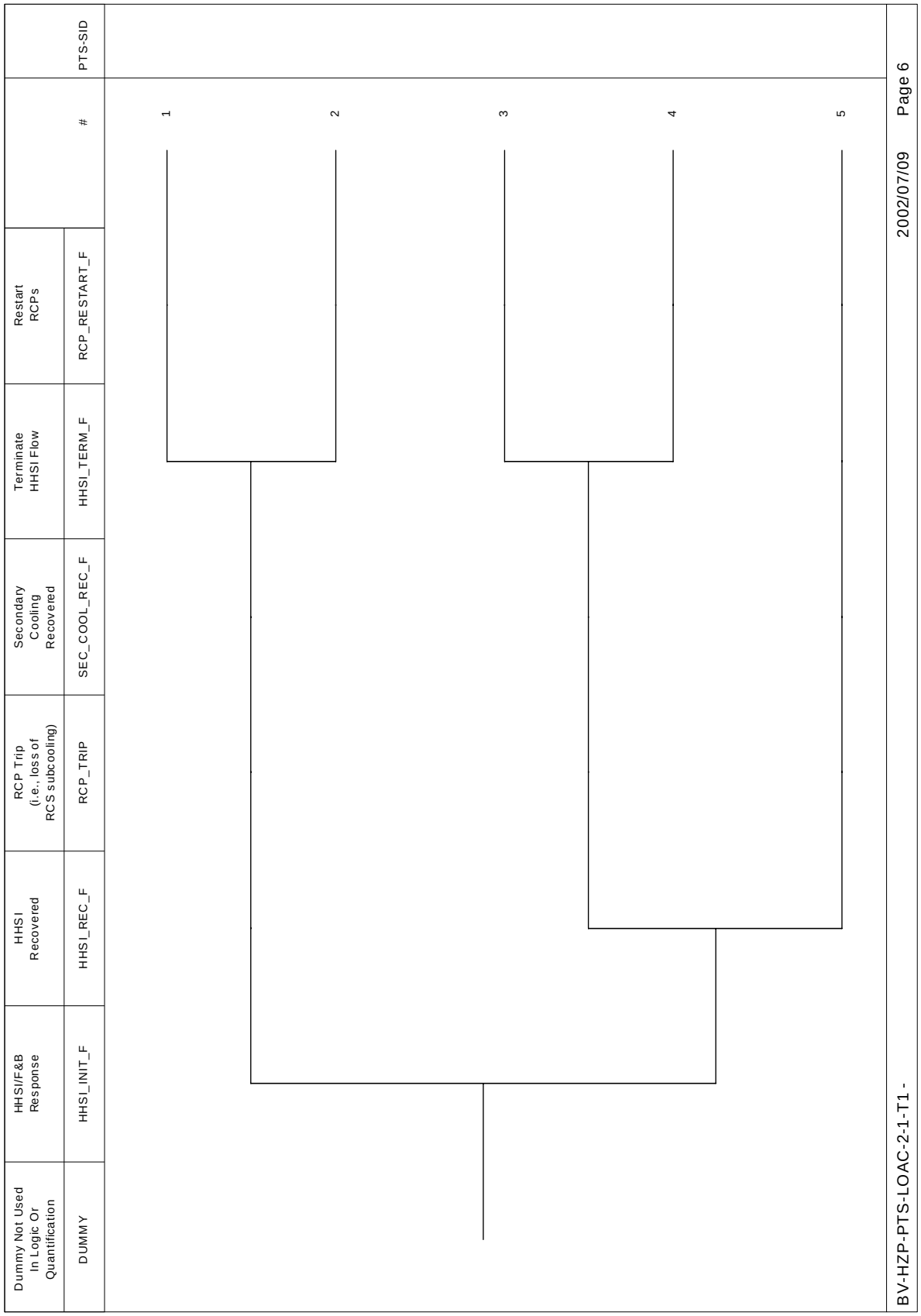

Figure 4.95. Beaver Valley -HZP-LOAC-2-1-T1: Loss of 120V AC red or white bus–primary system intact (HHSI not F&B).

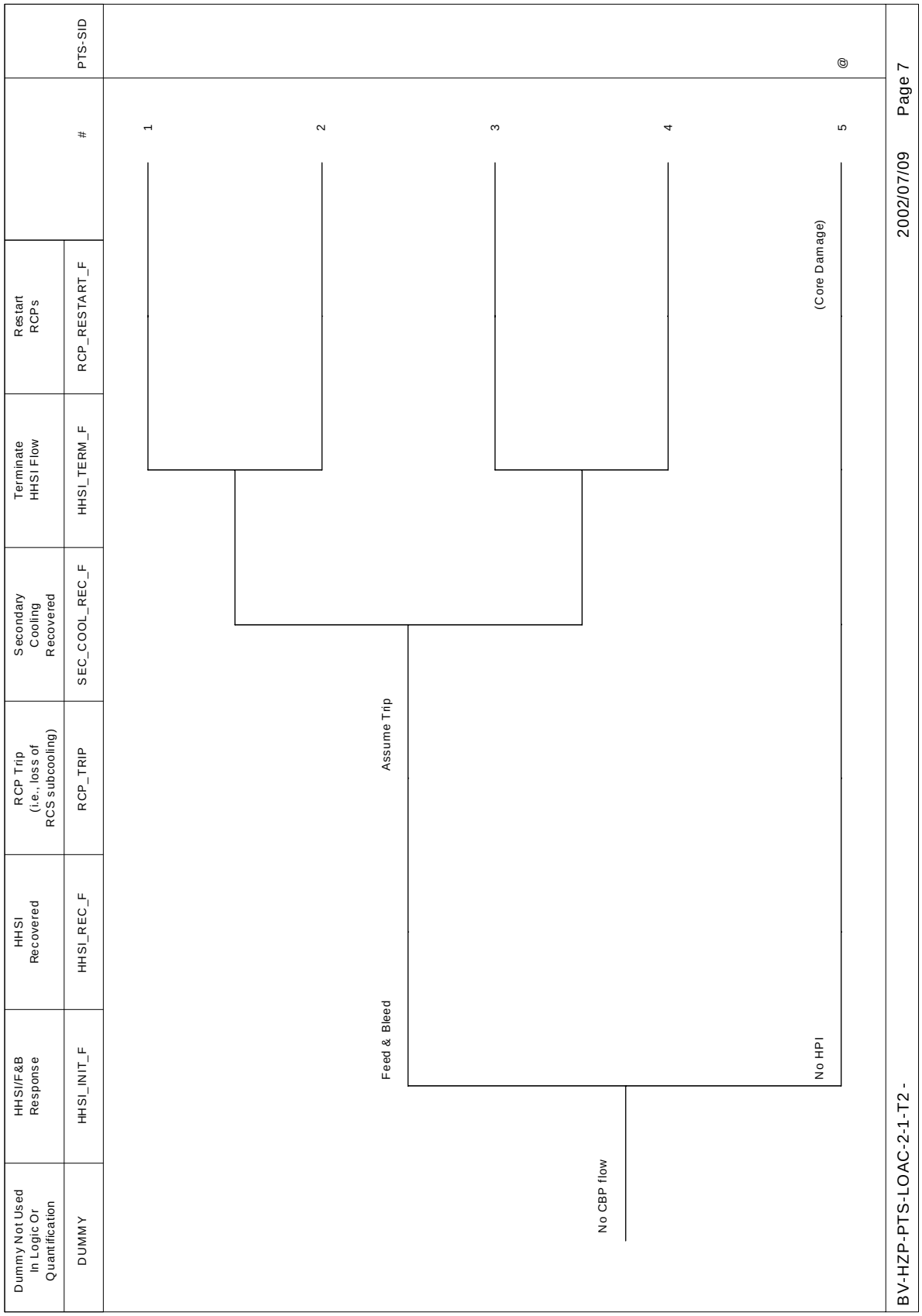

Figure 4.96. Beaver Valley -HZP-LOAC-2-1-T2: Loss of 120V AC red or white bus–primary system intact (HHSI F&B).

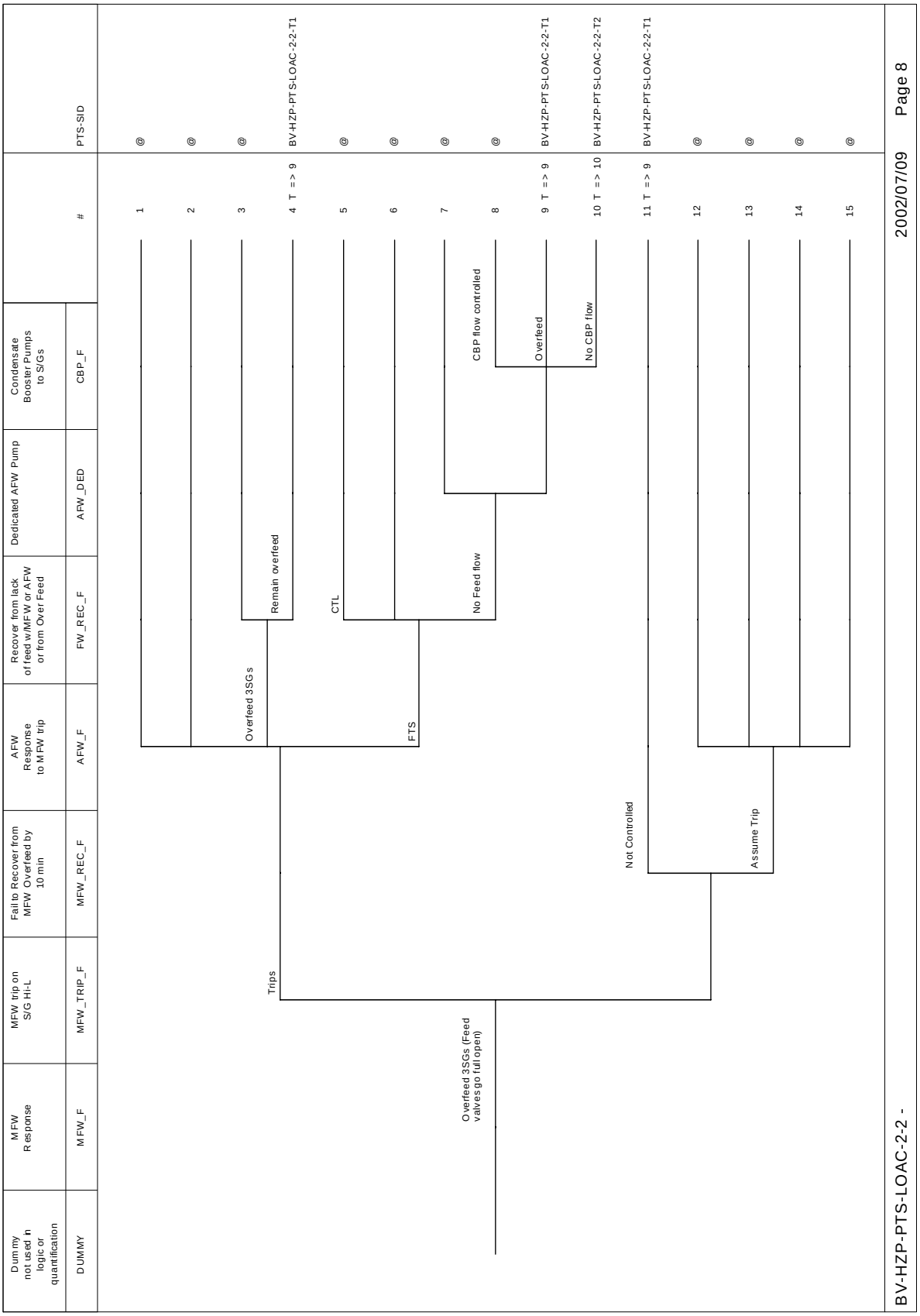

Figure 4.97. Beaver Valley -HZP-LOAC-2-2: Loss of 120V AC blue or yellow bus (primary system intact).

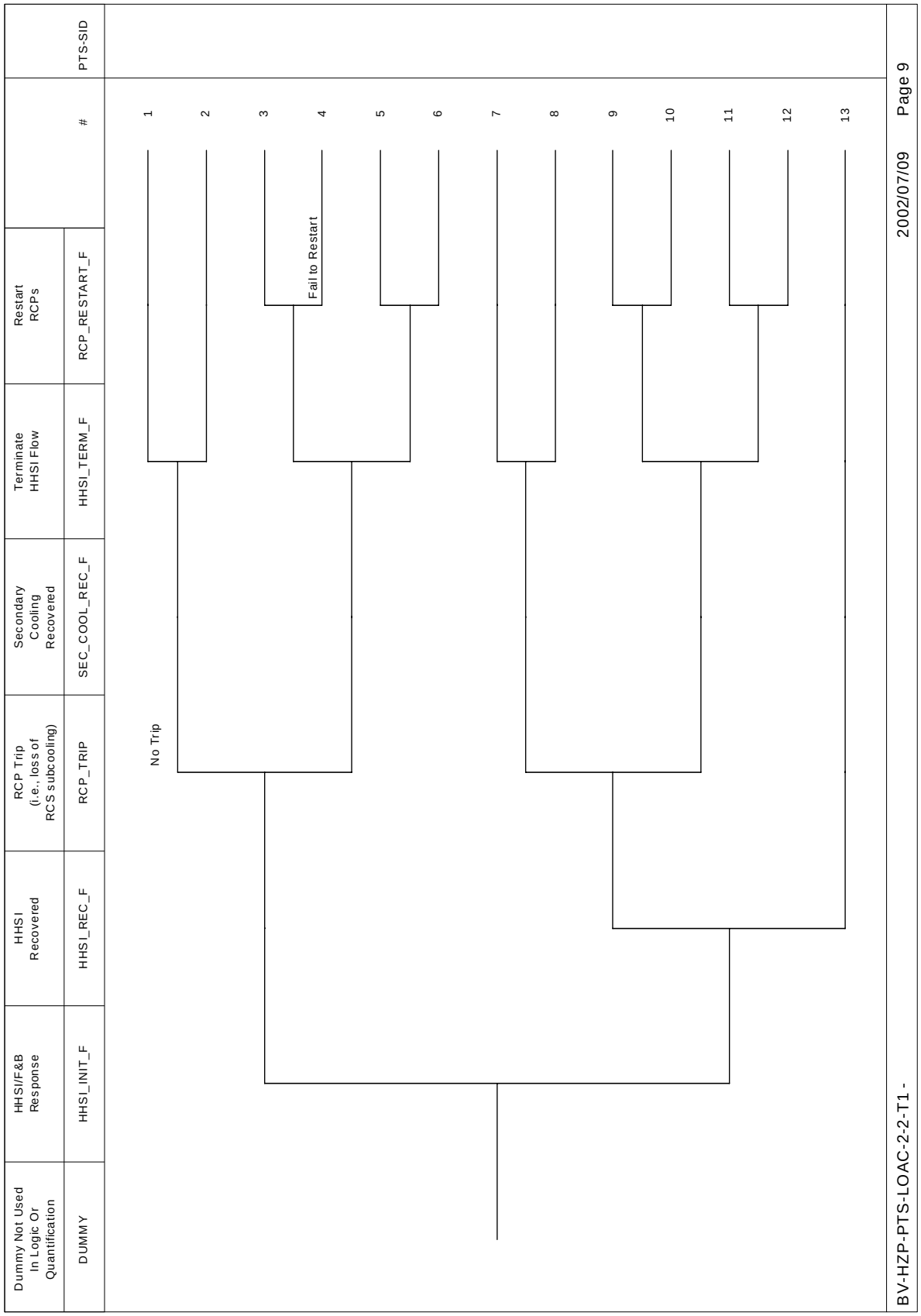

Figure 4.98. Beaver Valley -HZP-LOAC-2-2-T1: Loss of 120V AC blue or yellow bus–primary system intact (HHSI not F&B).

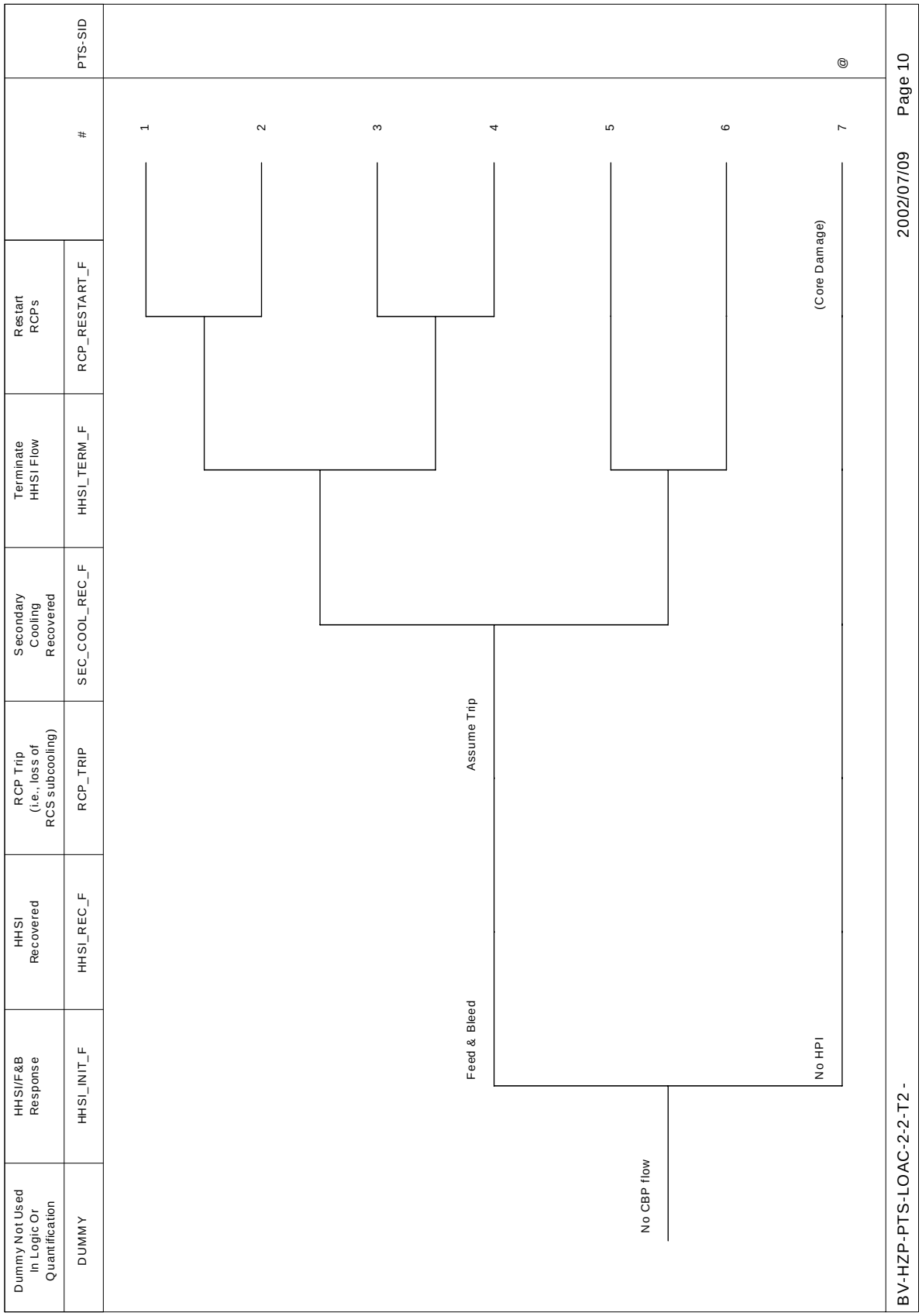

Figure 4.99. Beaver Valley -HZP-LOAC-2-2-T2: Loss of 120V AC blue or yellow bus–primary system intact (HHSI F&B).

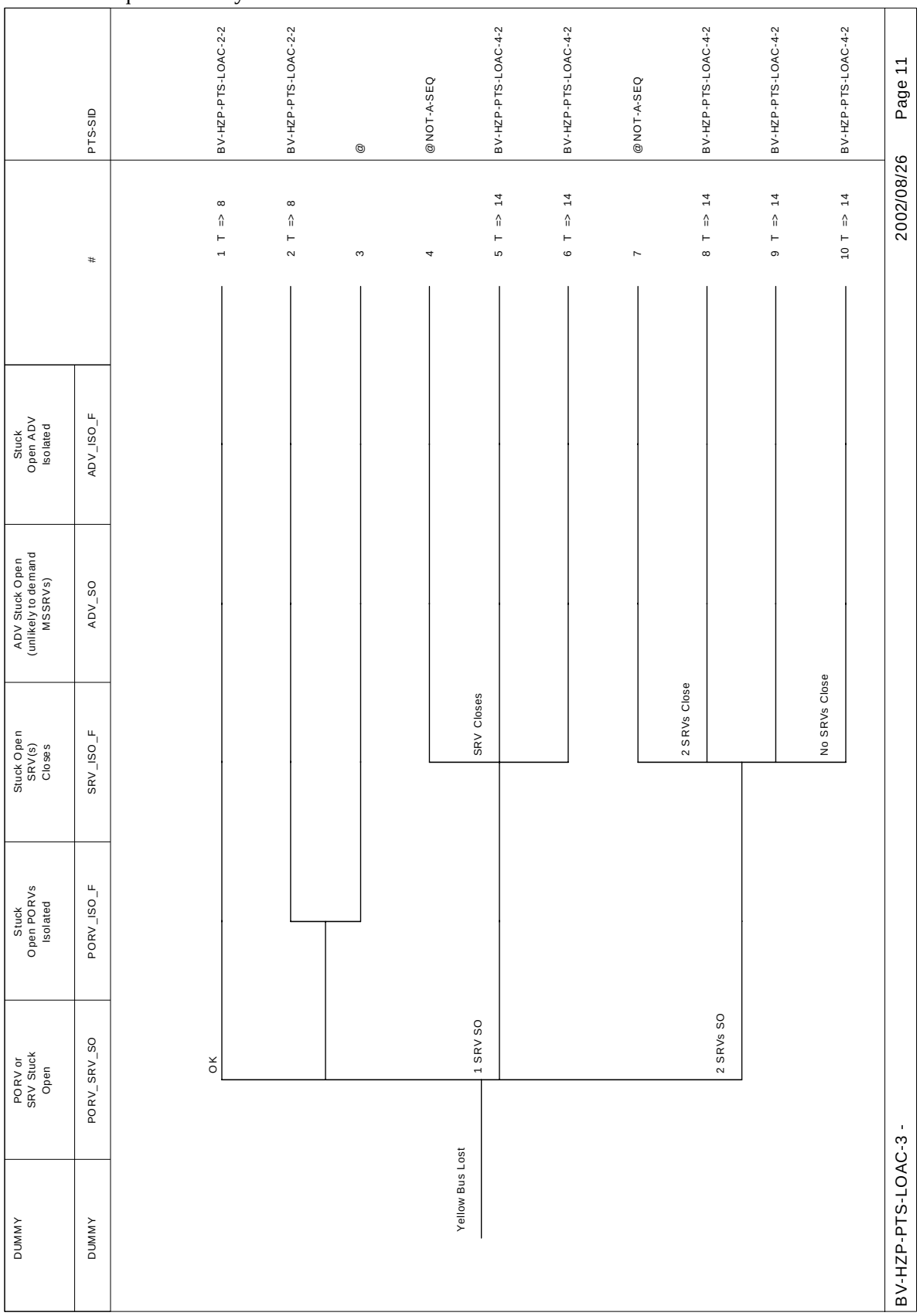

Figure 4.100. Beaver Valley -HZP-LOAC-3: Loss of 120V AC (yellow bus lost).

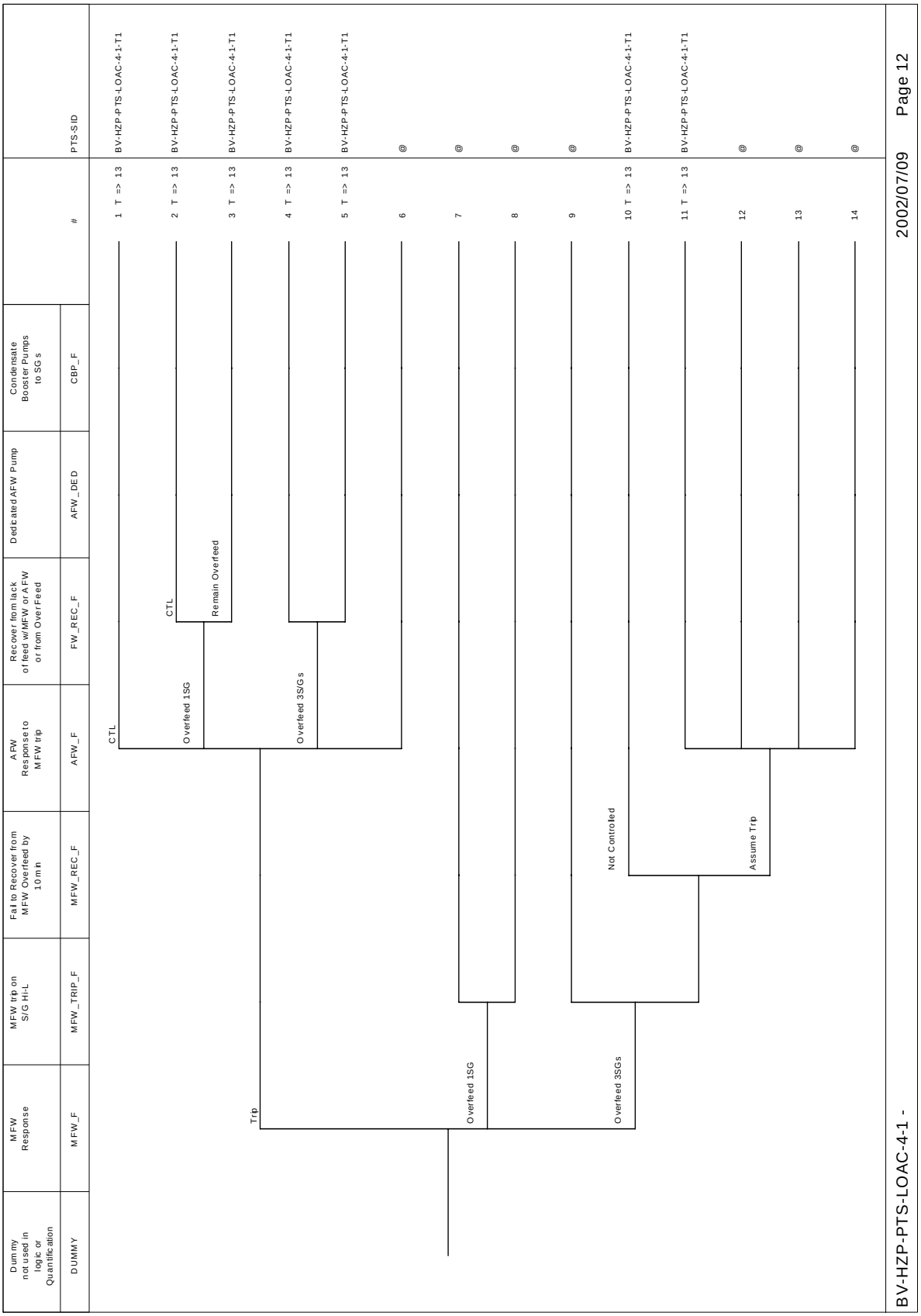

Figure 4.101. Beaver Valley -HZP-LOAC-4-1: Loss of 120V AC red or white bus (at least one SRV initially open).

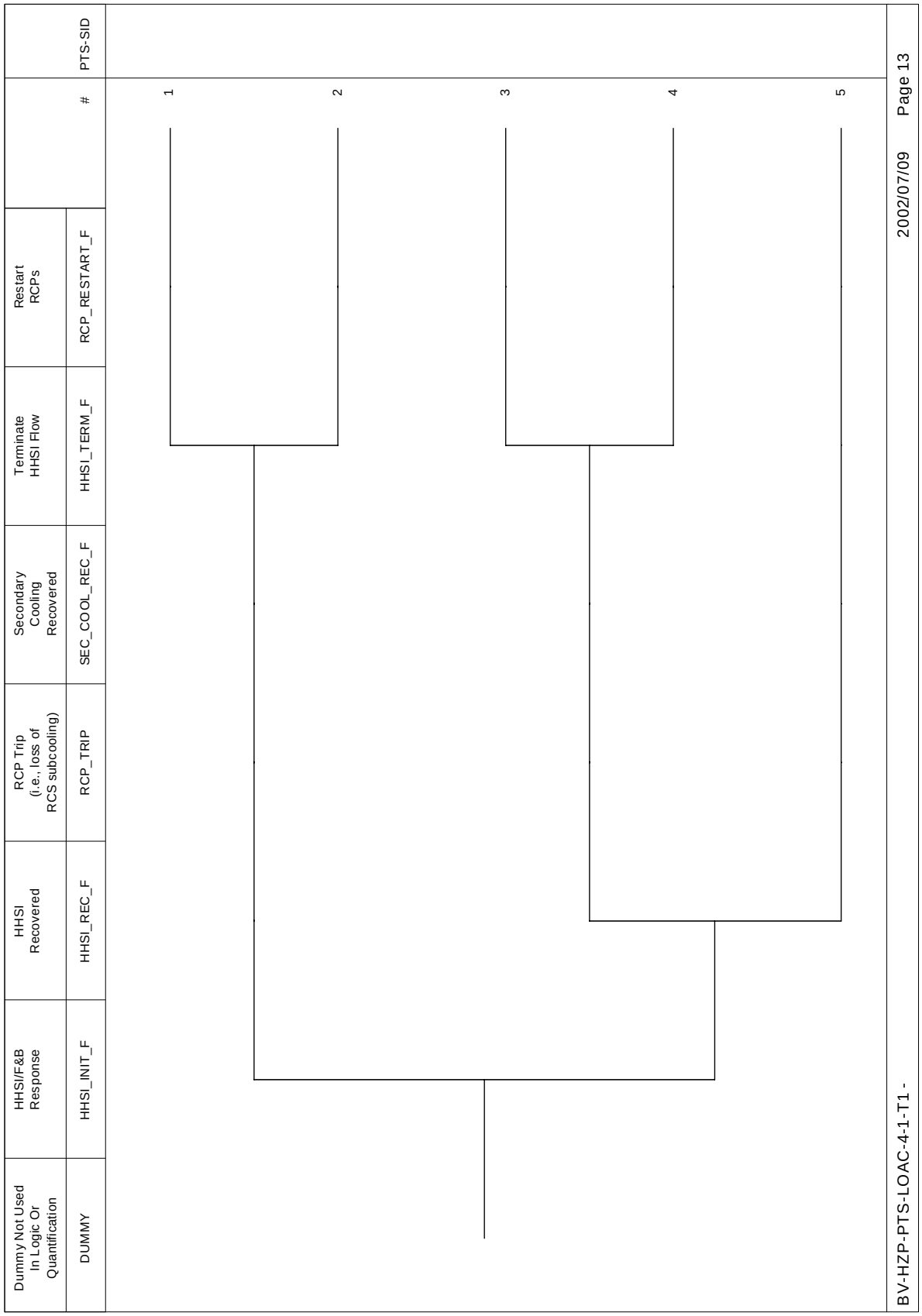

Figure 4.102. Beaver Valley -HZP-LOCA-4-1-T1: Loss of 120V AC red or white bus–at least one SRV initially open (HHSI not F&B).

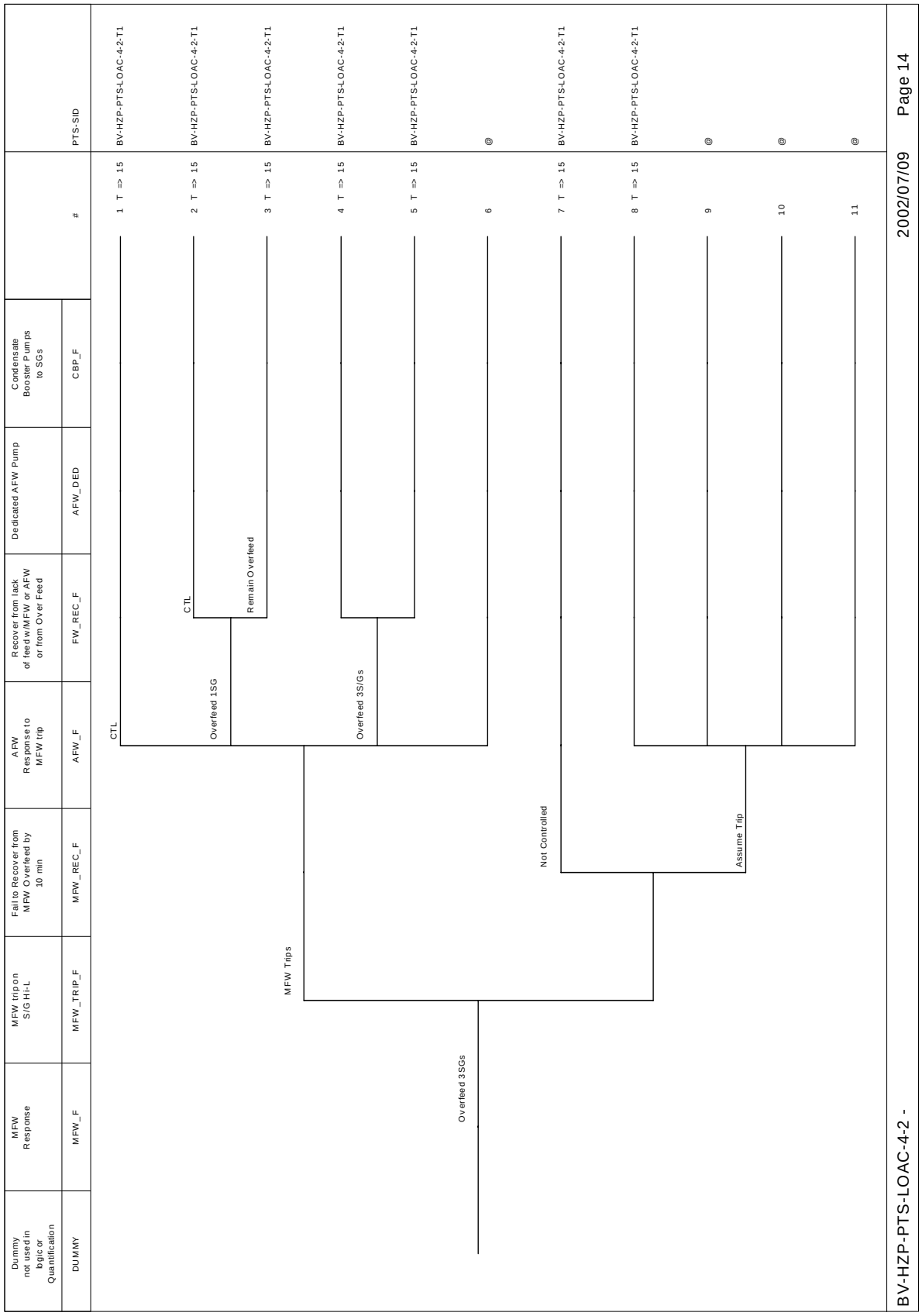

Figure 4.103. Beaver Valley -HZP-LOCA-4-2: Loss of 120V AC blue or yellow bus (at least one SRV initially open).

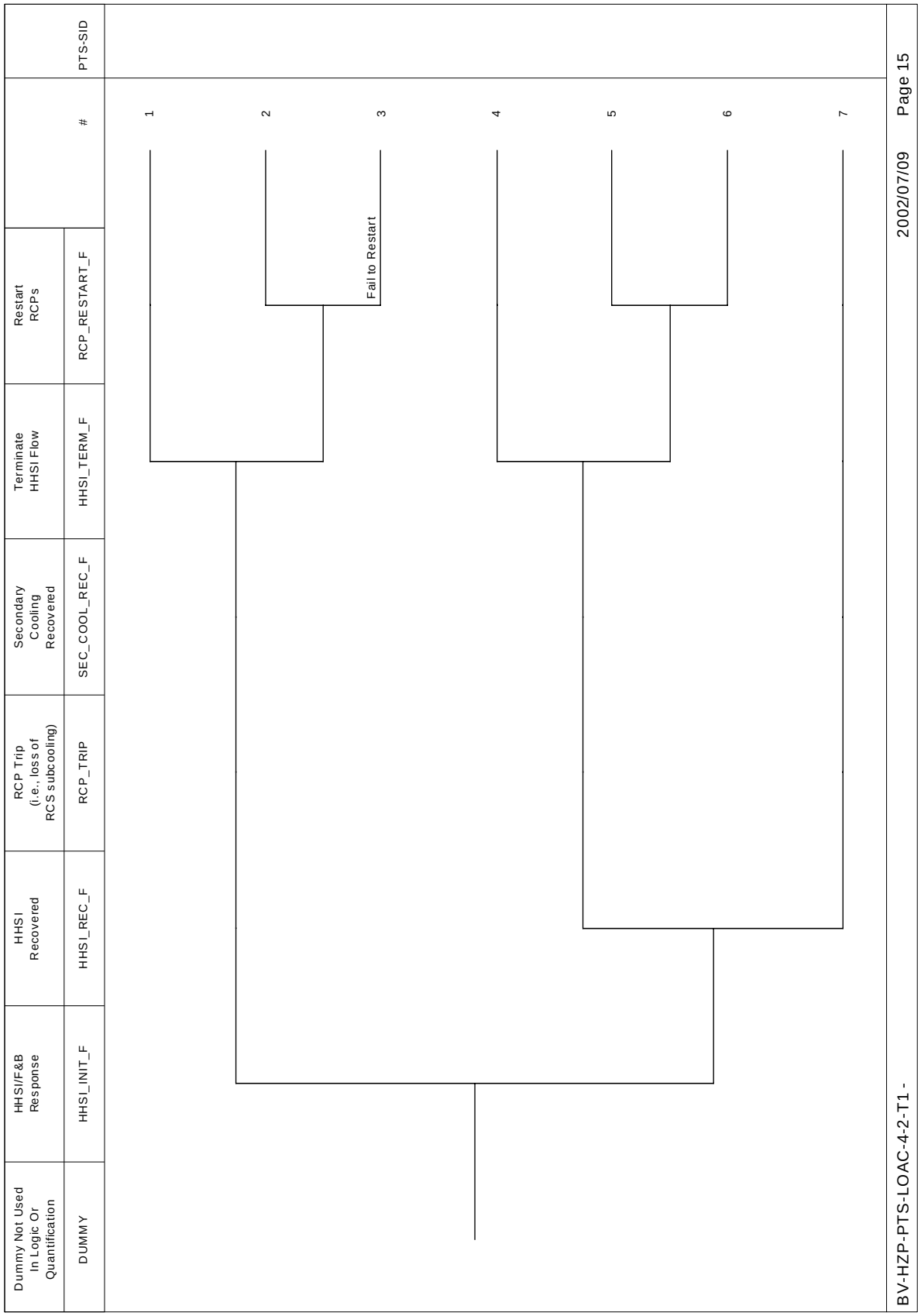

Figure 4.104. Beaver Valley -HZP-LOAC-4-2-T1: Loss of 120V AC blue or yellow bus–at least one SRV initially open (HHSI not F&B).

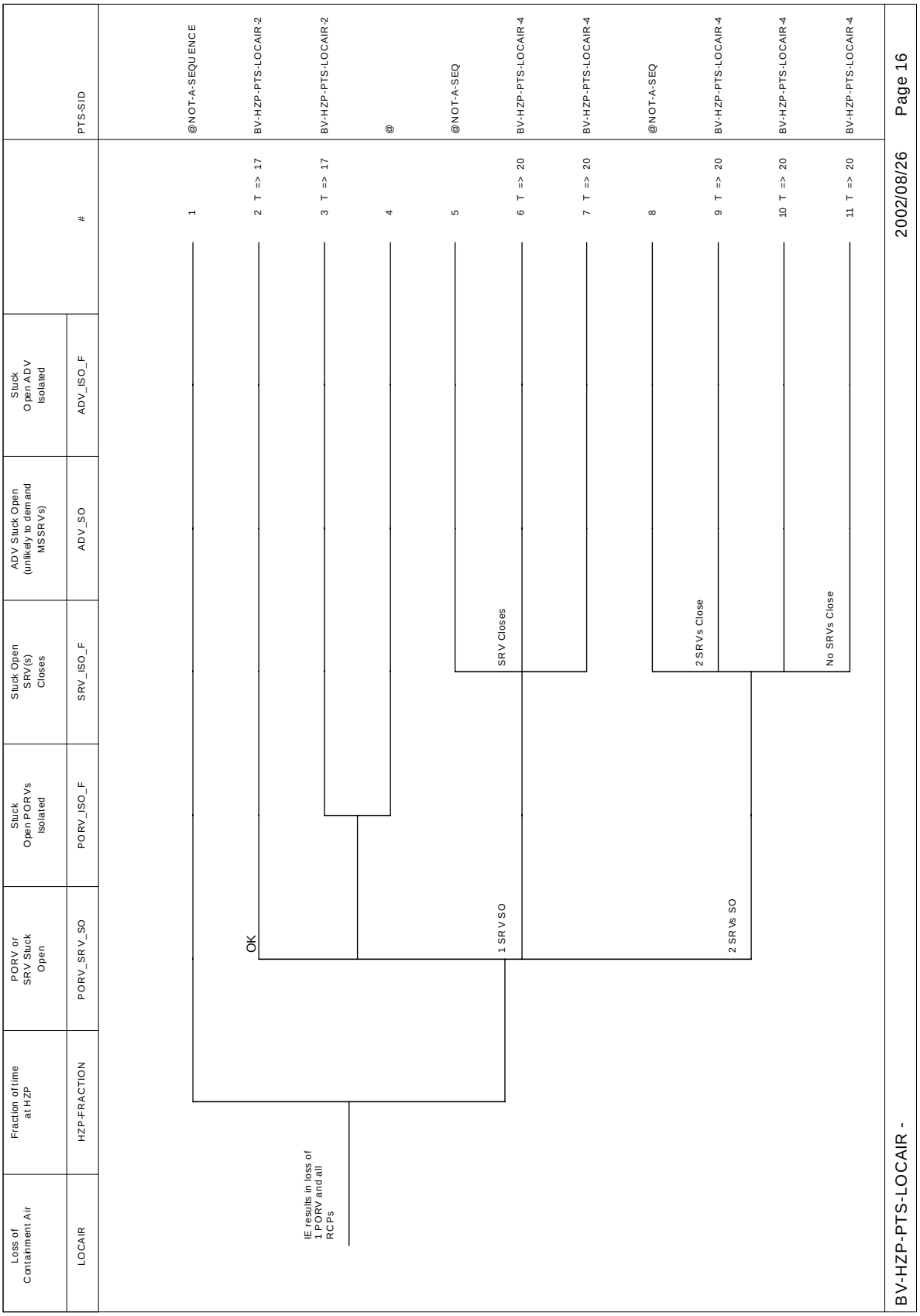

Figure 4.105. Beaver Valley -HZP-LOCAIR: Loss of containment air.

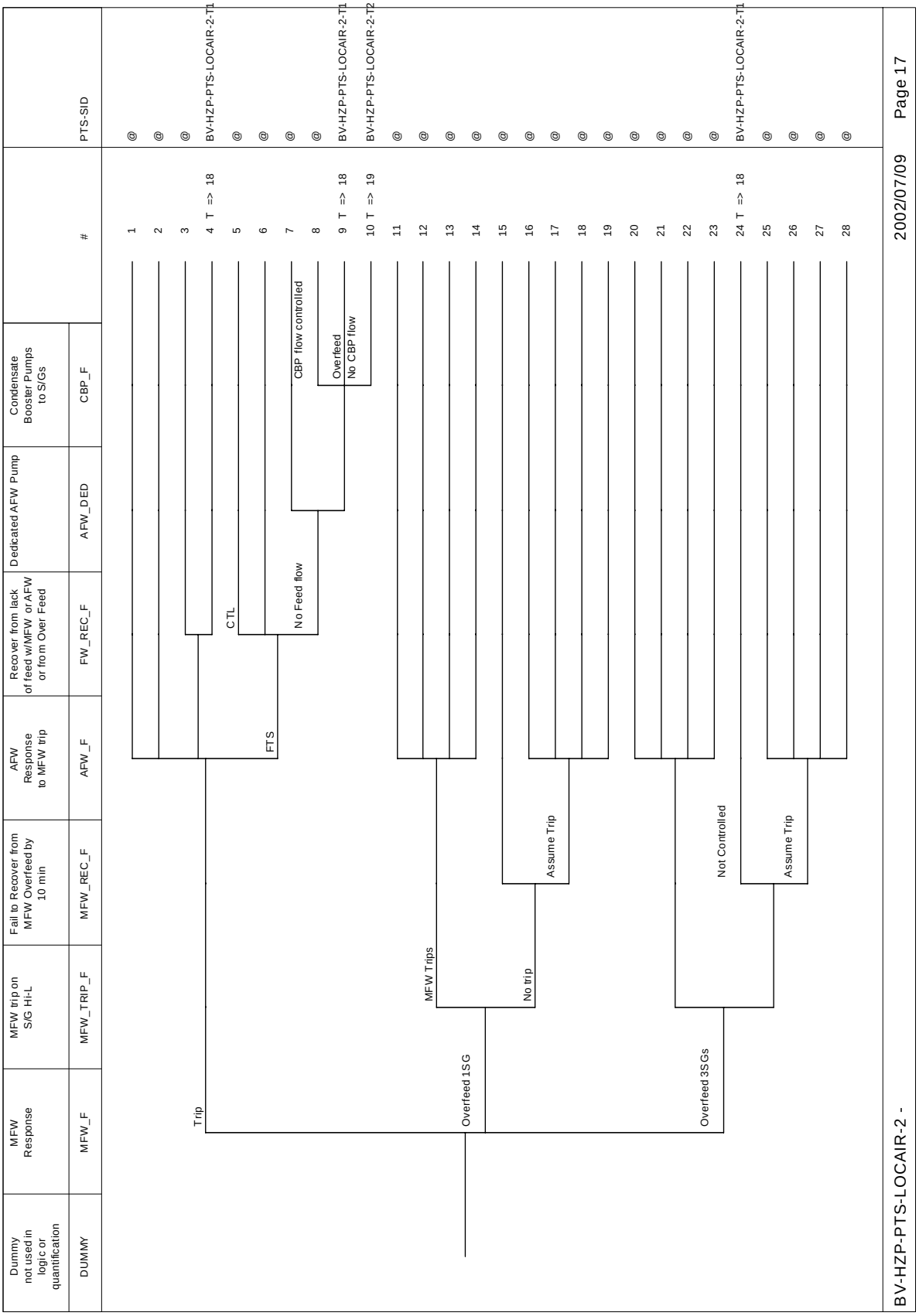

Figure 4.106. Beaver Valley -HZP-LOCAIR-2: Loss of containment air (primary system intact).

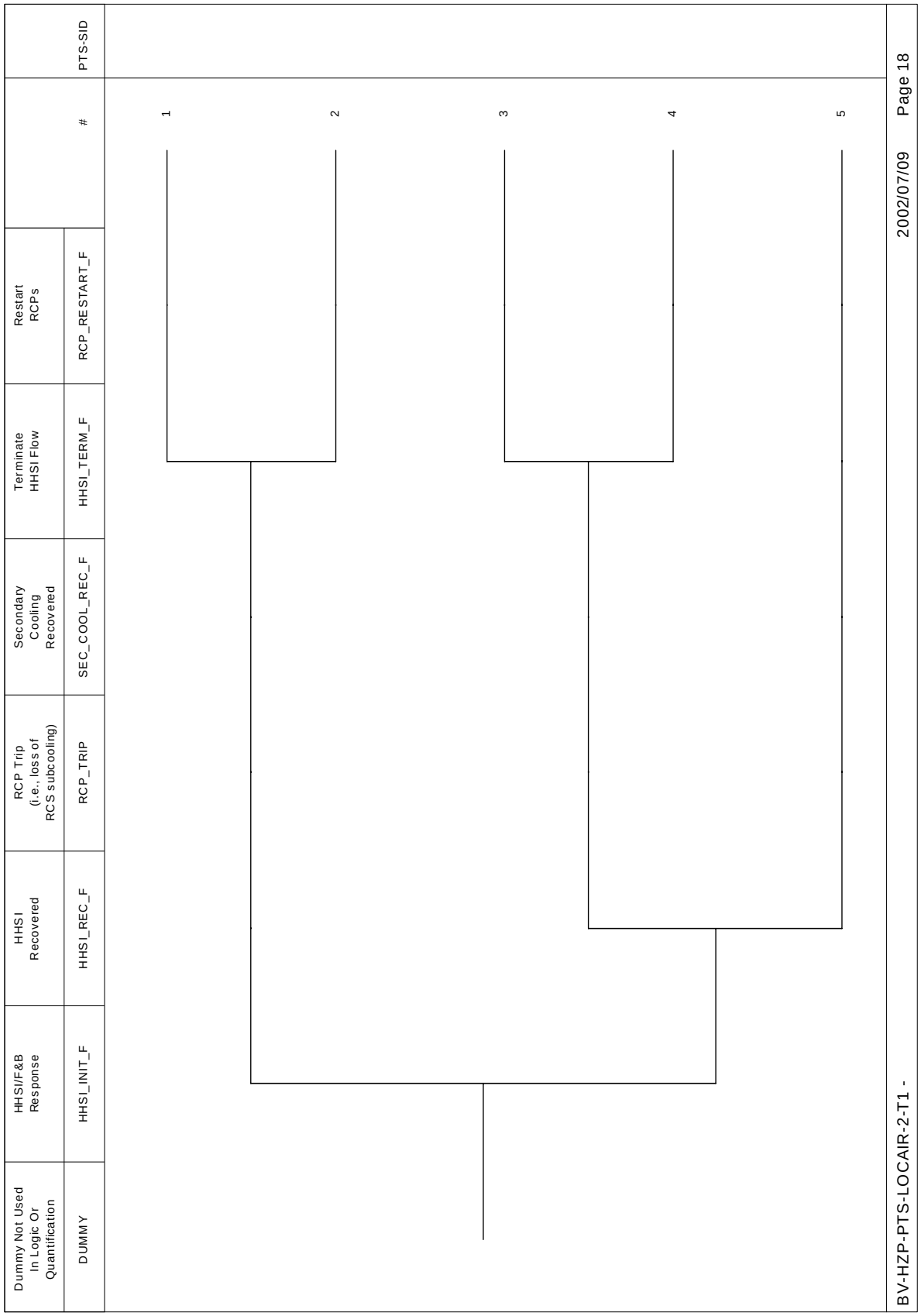

Figure 4.107. Beaver Valley -HZP-LOCAIR-2-T1: Loss of containment air–primary system intact (HHSI not F&B).

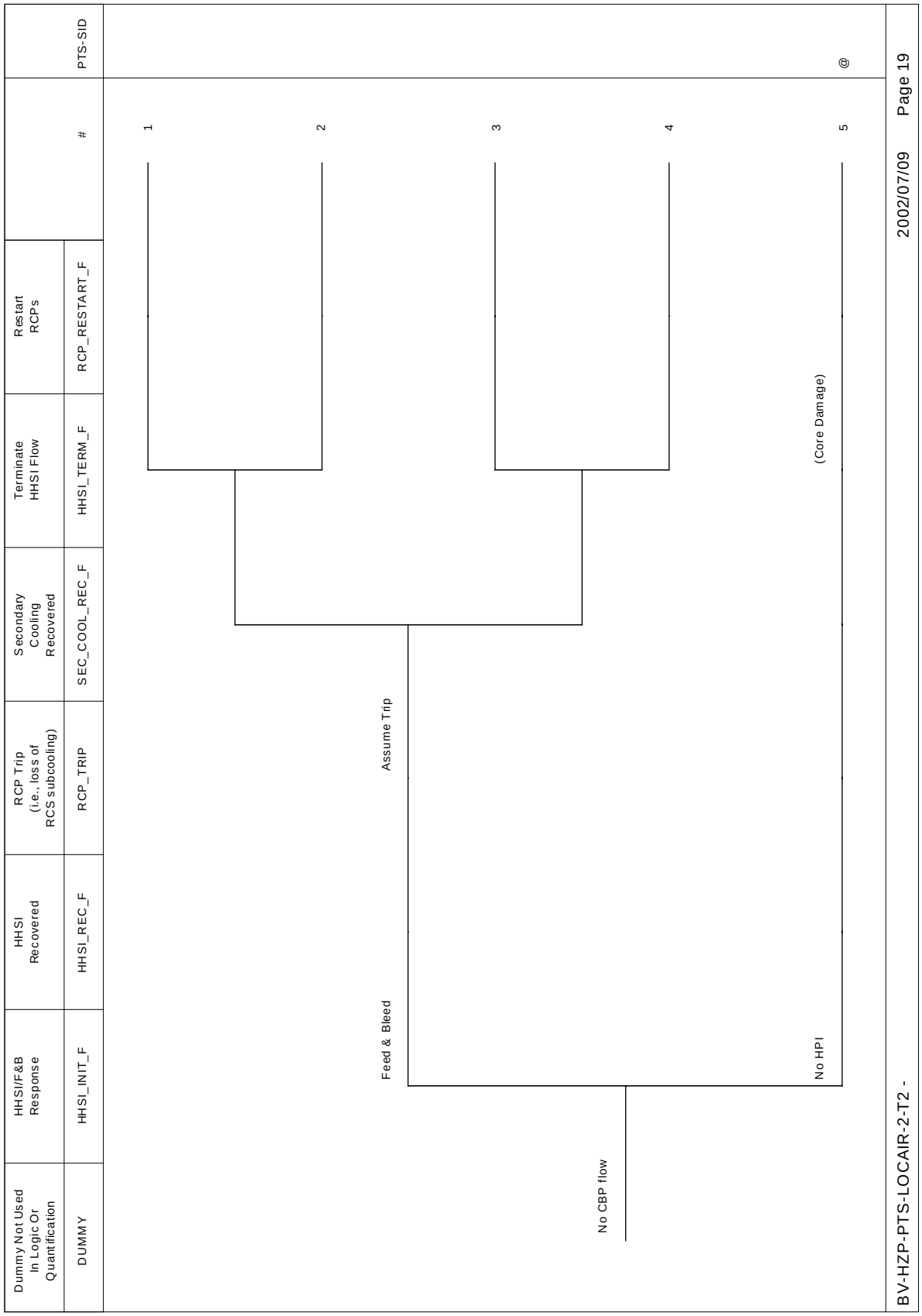

Figure 4.108. Beaver Valley -HZP-LOCAIR-2-T2: Loss of containment air–primary system intact (HHSI F&B).

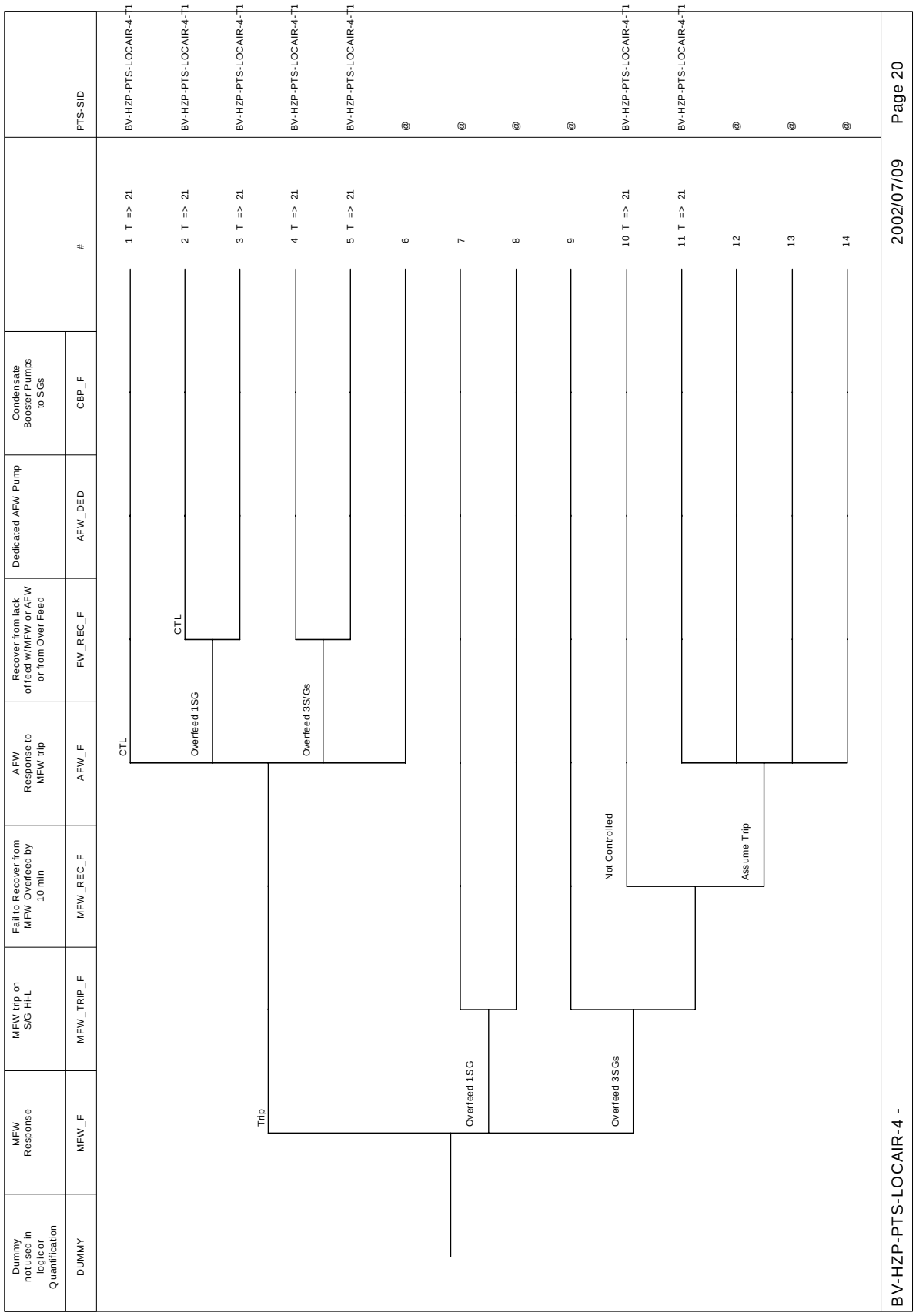

Figure 4.109. Beaver Valley -HZP-LOCAIR-4: Loss of containment air (at least one SRV initially open).

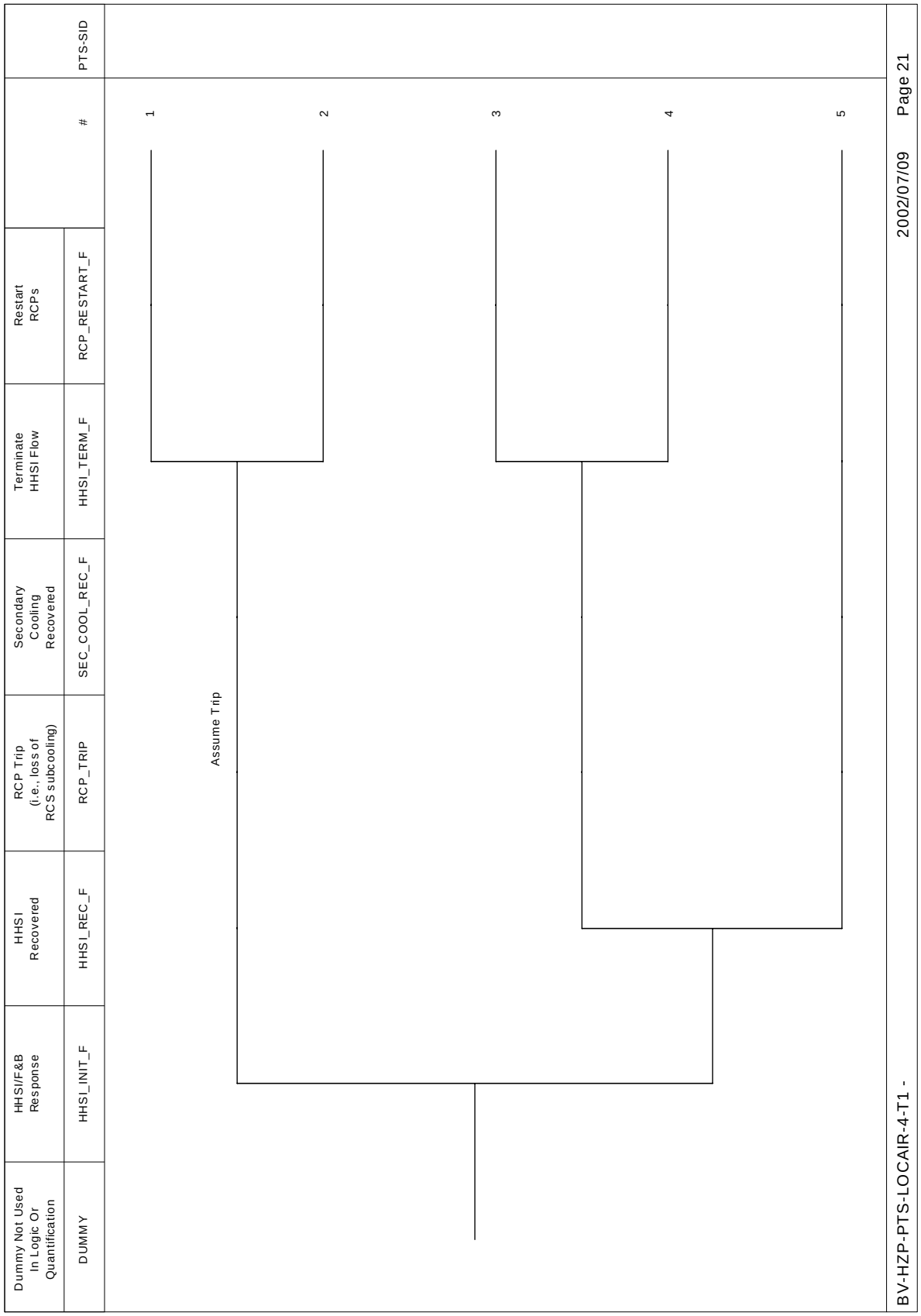

Figure 4.110. Beaver Valley -HZP-LOCAIR-4-T1: Loss of containment air–at least one SRV initially open (HHSI not F&B).

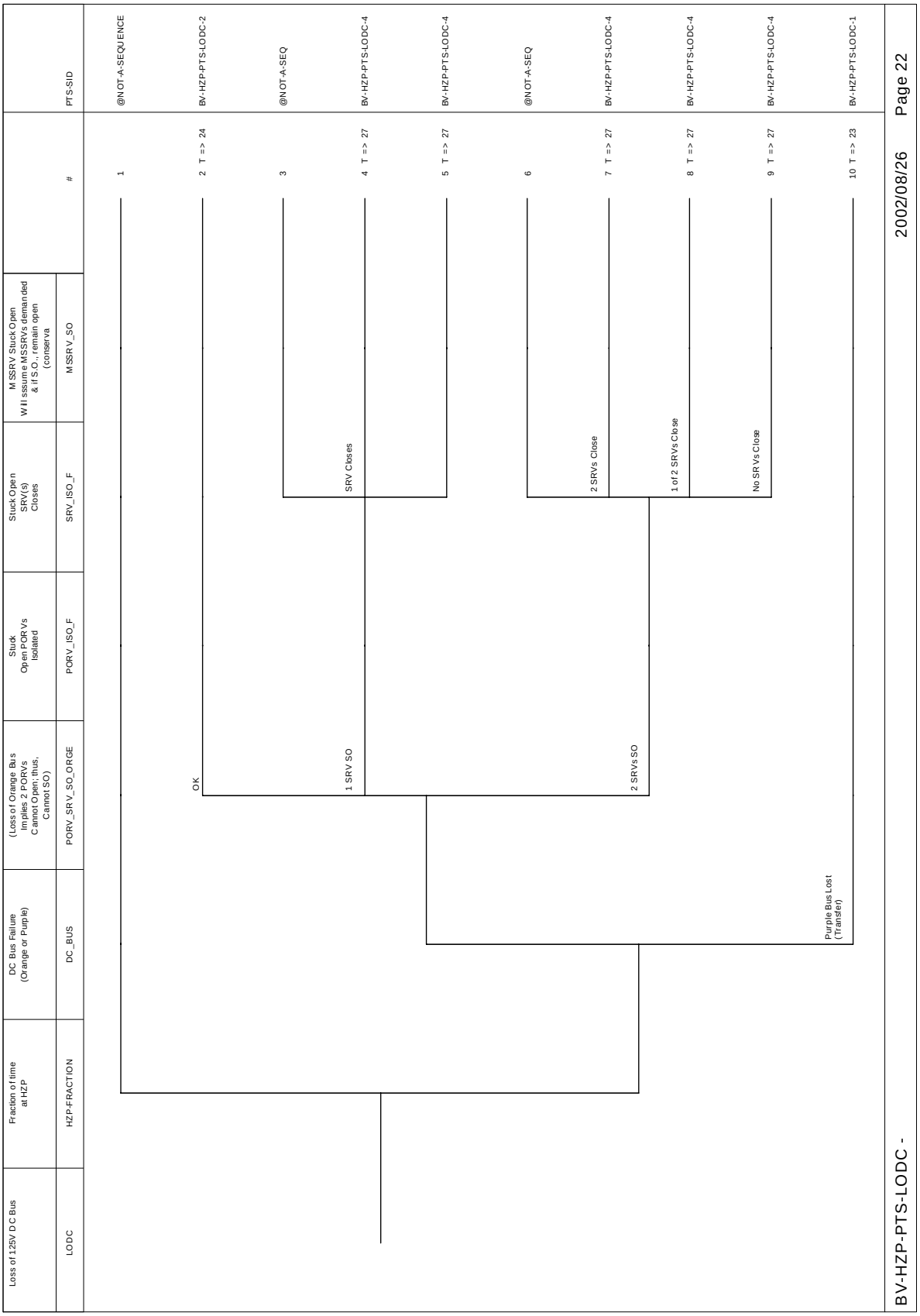

Figure 4.111. Beaver Valley -HZP-LODC: Loss of 125V DC bus (orange bus lost).

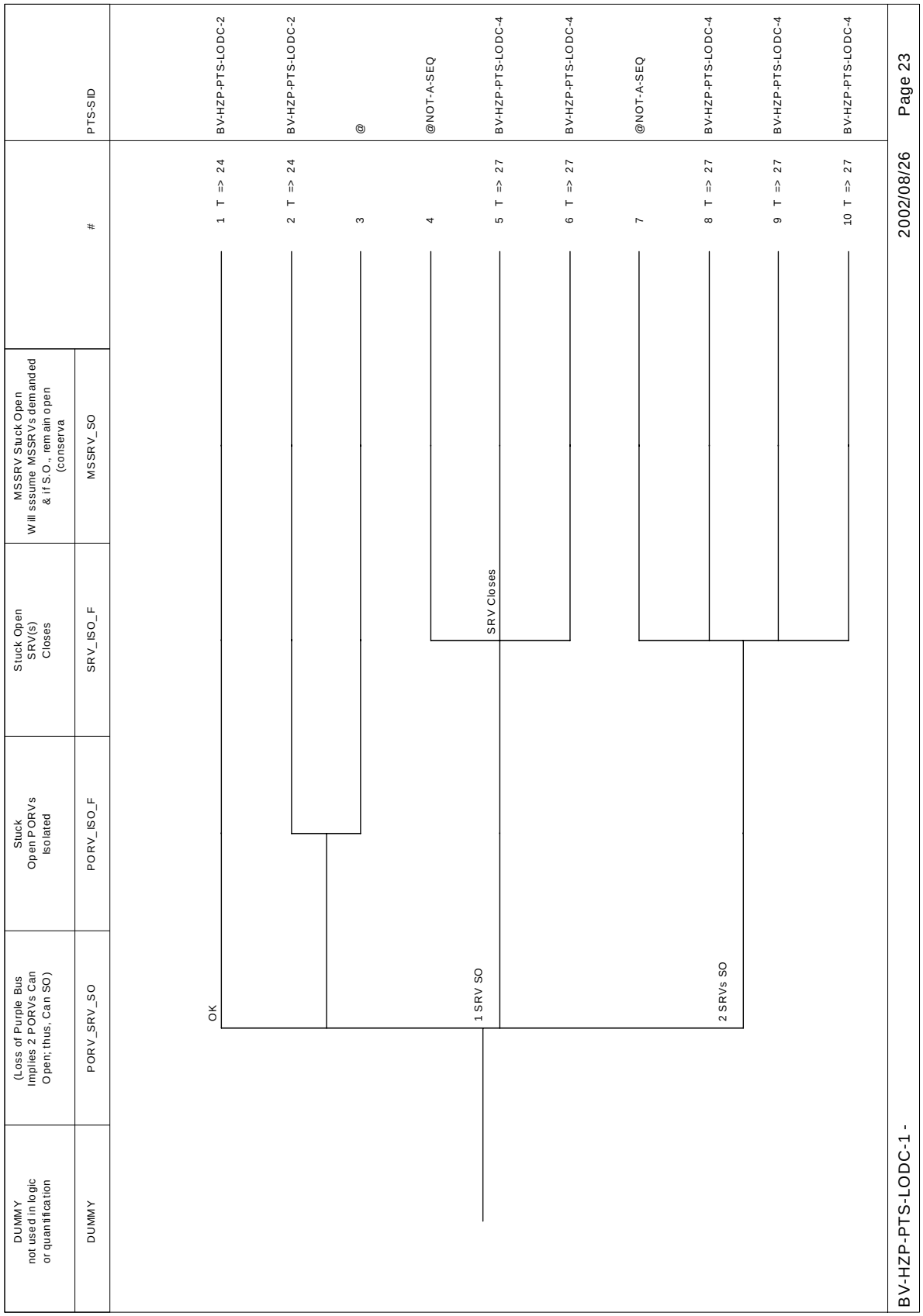

Figure 4.112. Beaver Valley -HZP-LODC-1: Loss of 125V DC bus (purple bus lost).

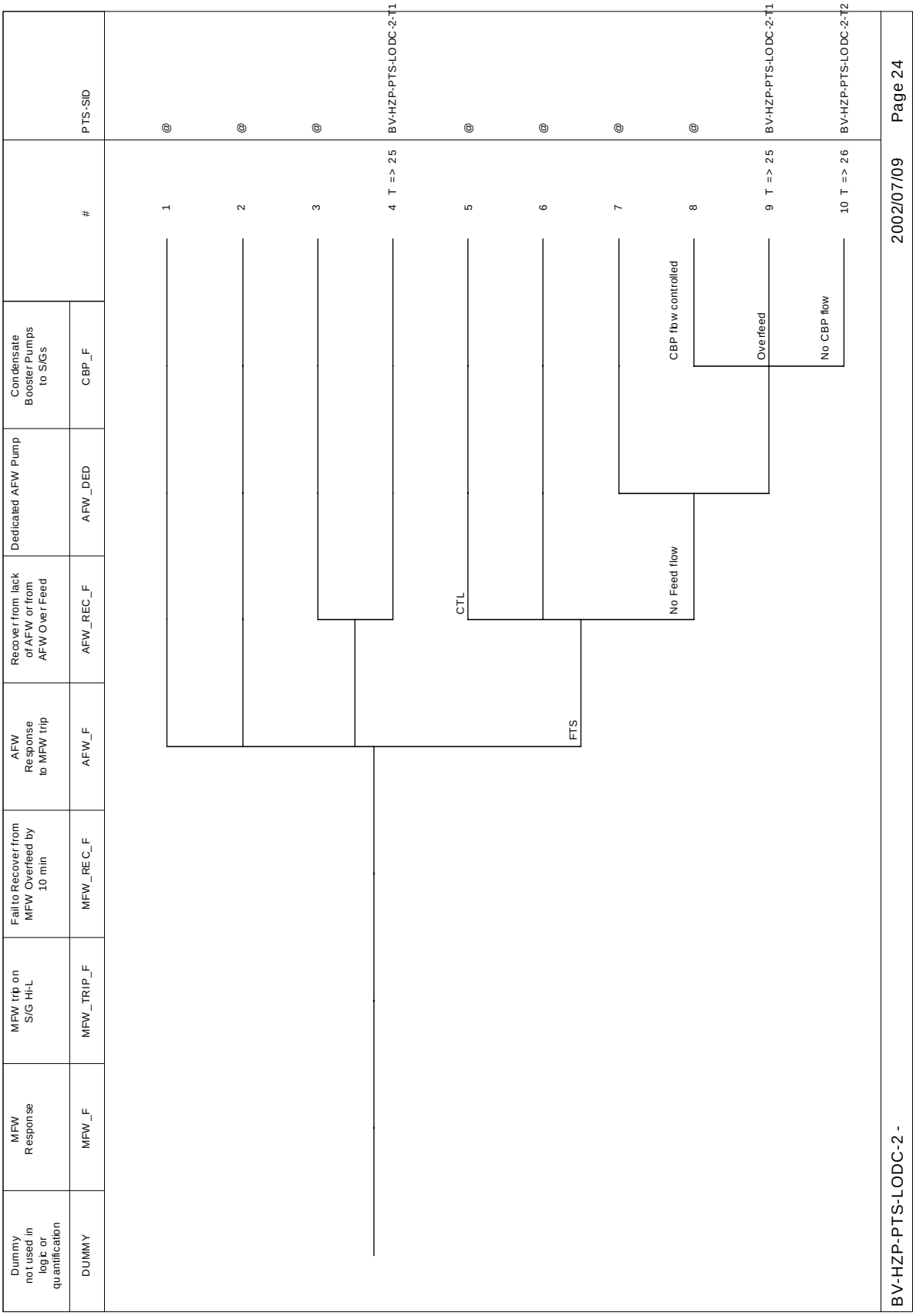

Figure 4.113. Beaver Valley -HZP-LODC-2: Loss of 125V DC orange or purple bus (primary system intact).

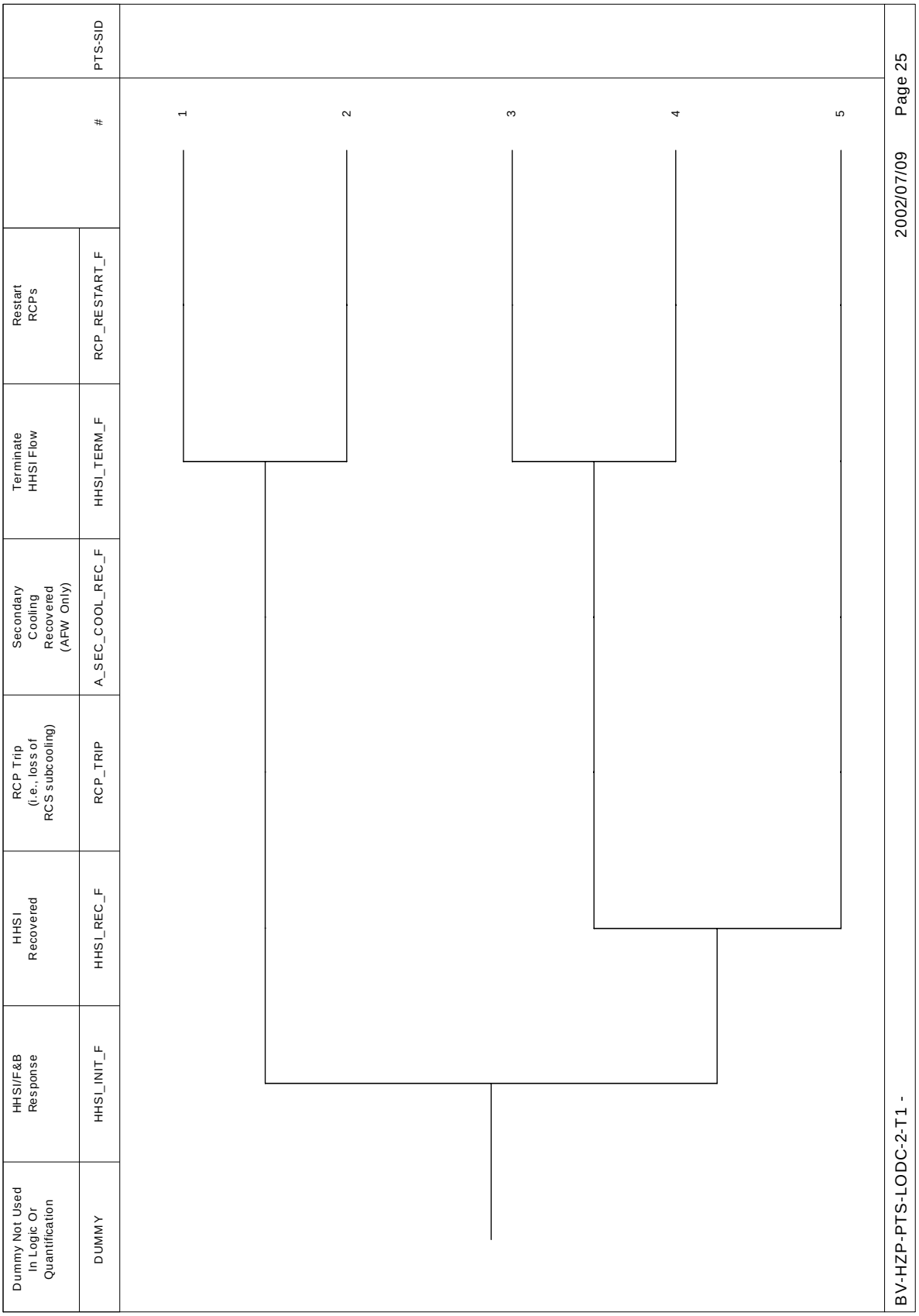

Figure 4.114. Beaver Valley -HZP-LODC-2-T1: Loss of 125V DC orange or purple bus–primary system intact (HHSI not F&B).

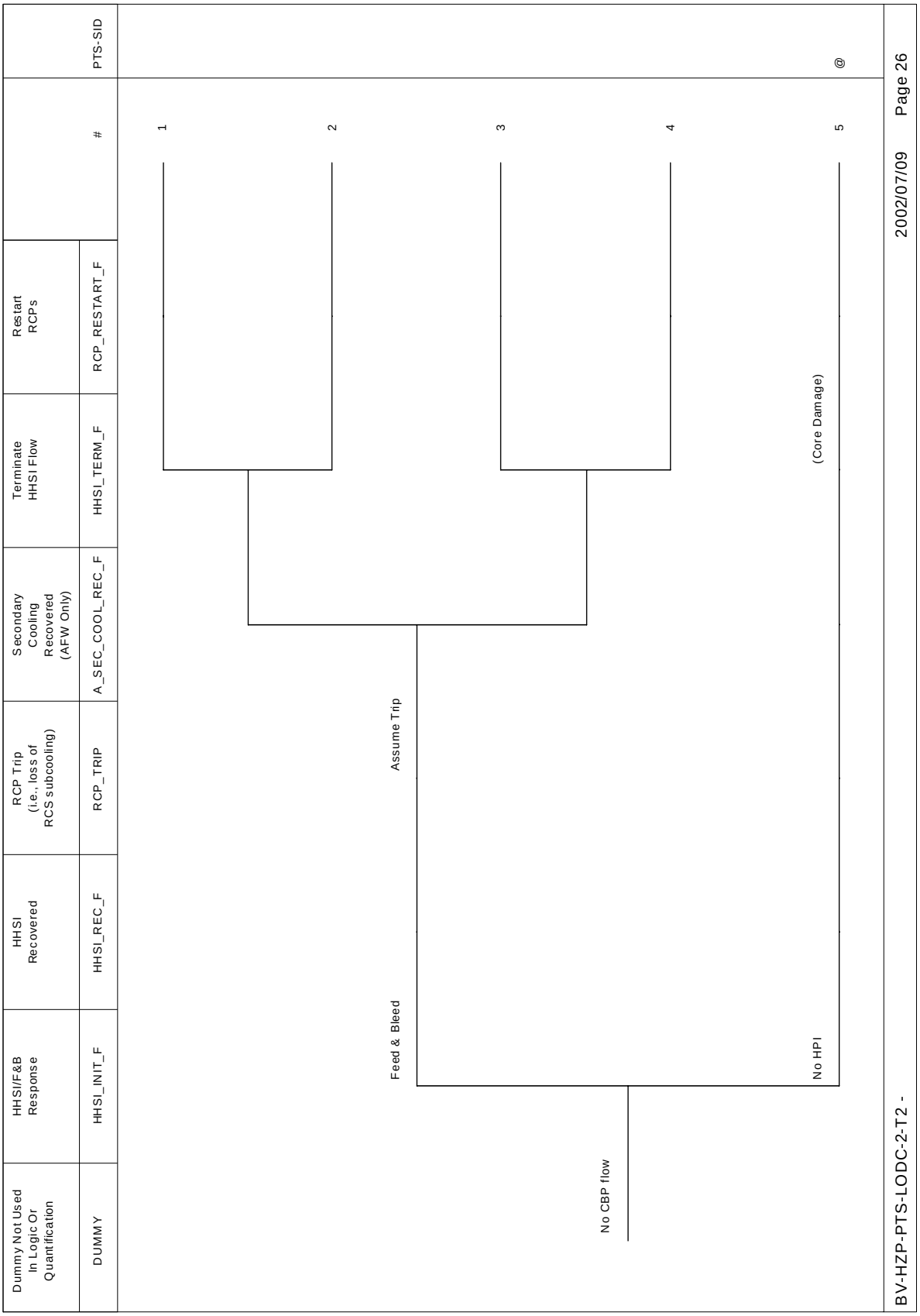

Figure 4.115. Beaver Valley -HZP-LODC-2-T2: Loss of 125V DC orange or purple bus–primary system intact (HHSI F&B).

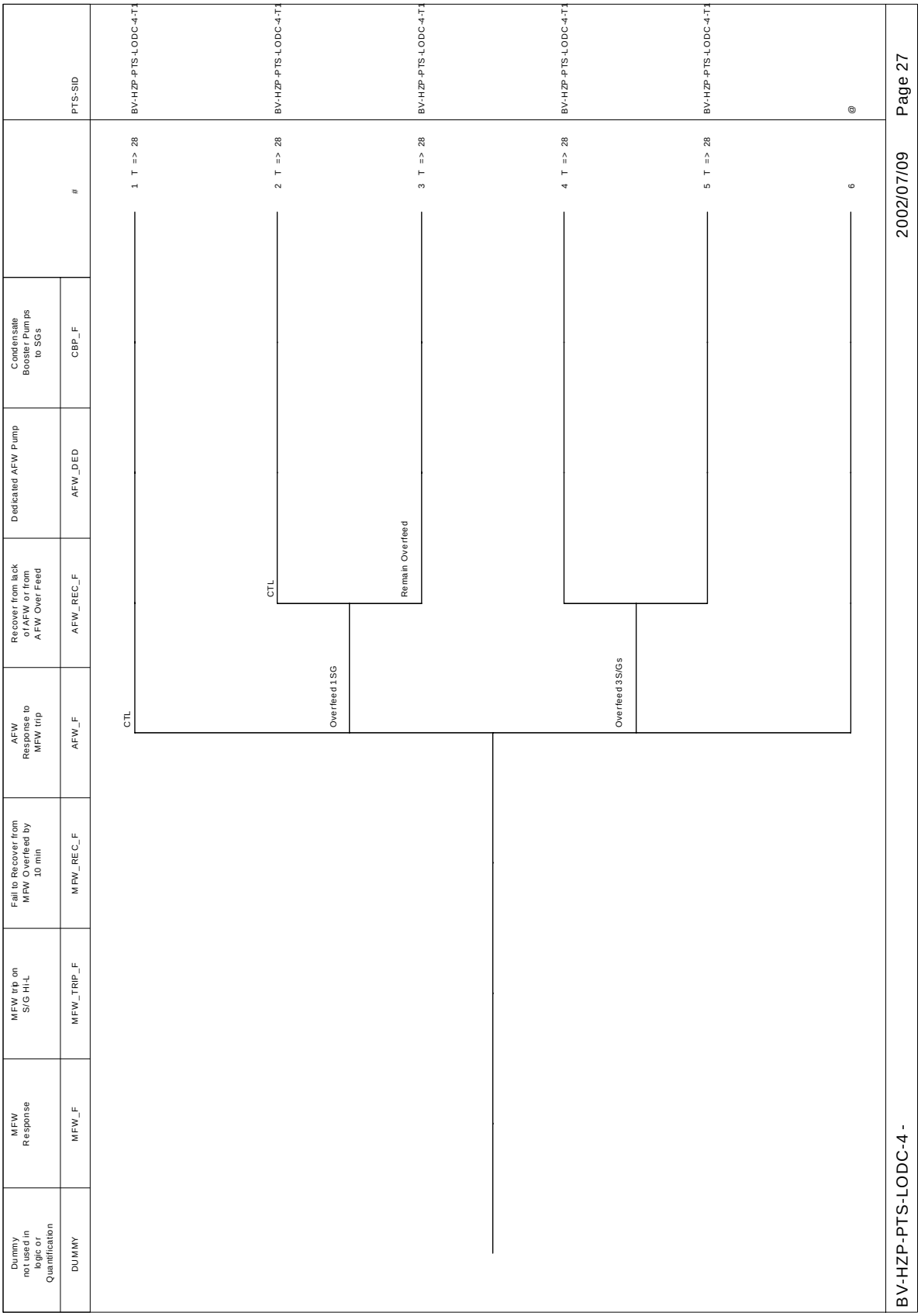

Figure 4.116. Beaver Valley -HZP-LODC-4: Loss of 125V DC orange or purple bus (at least one SRV initially open).

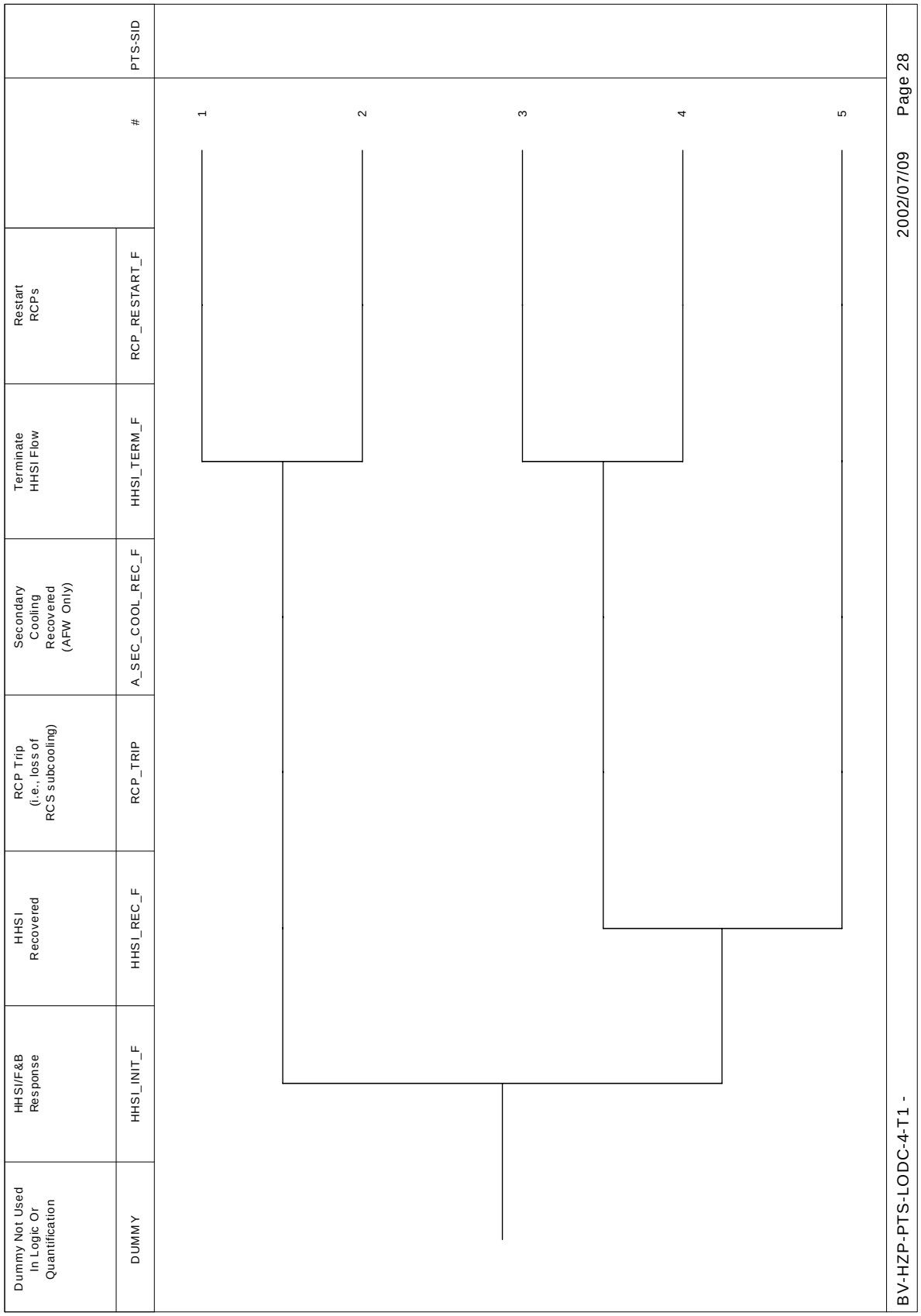

Figure 4.117. Beaver Valley -HZP-LODC-4: Loss of 125V DC orange or purple bus–at least one SRV initially open (HHSI not F&B)).

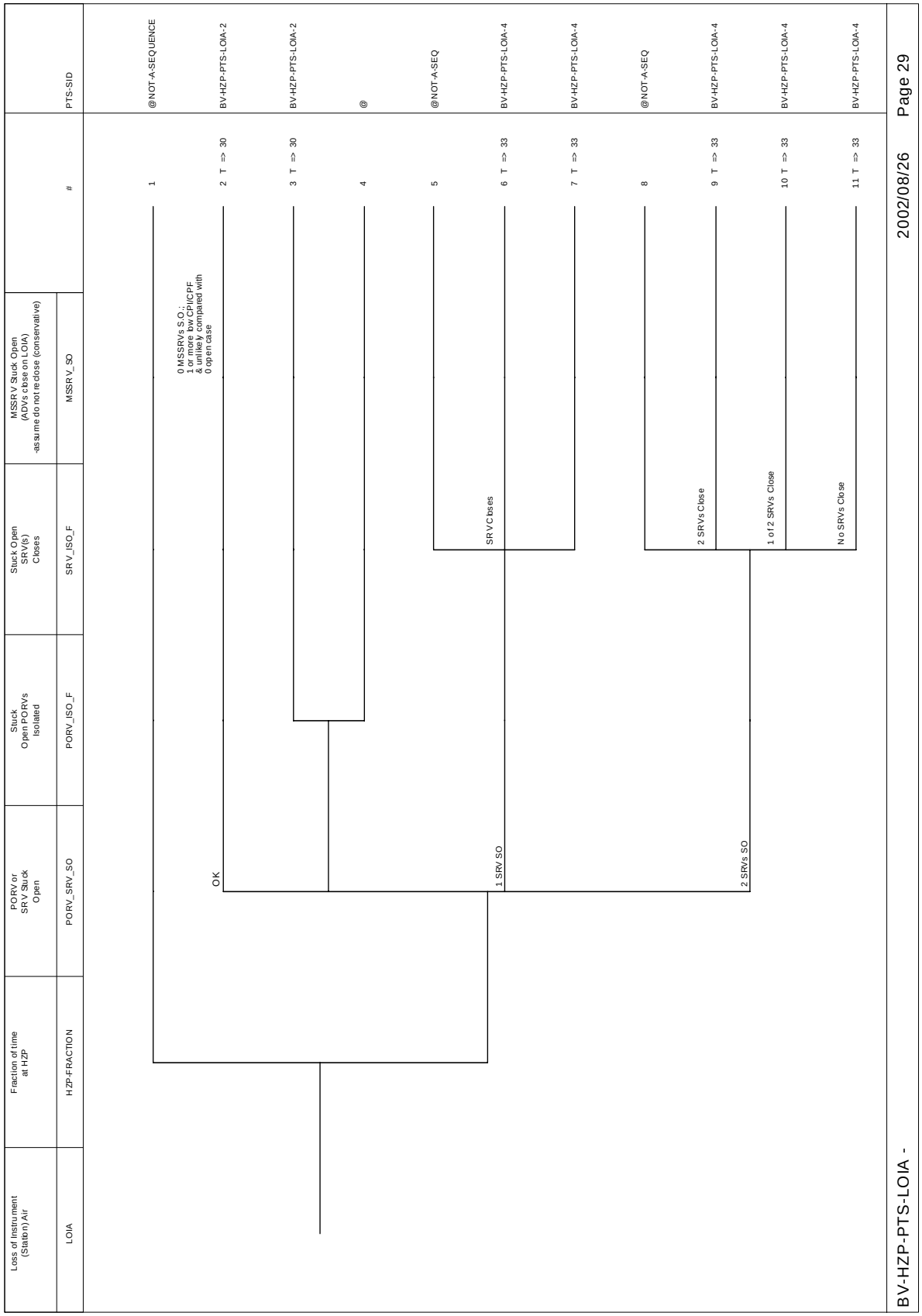

Figure 4.118. Beaver Valley -HZP-LOIA: Loss of instrument (station) air.

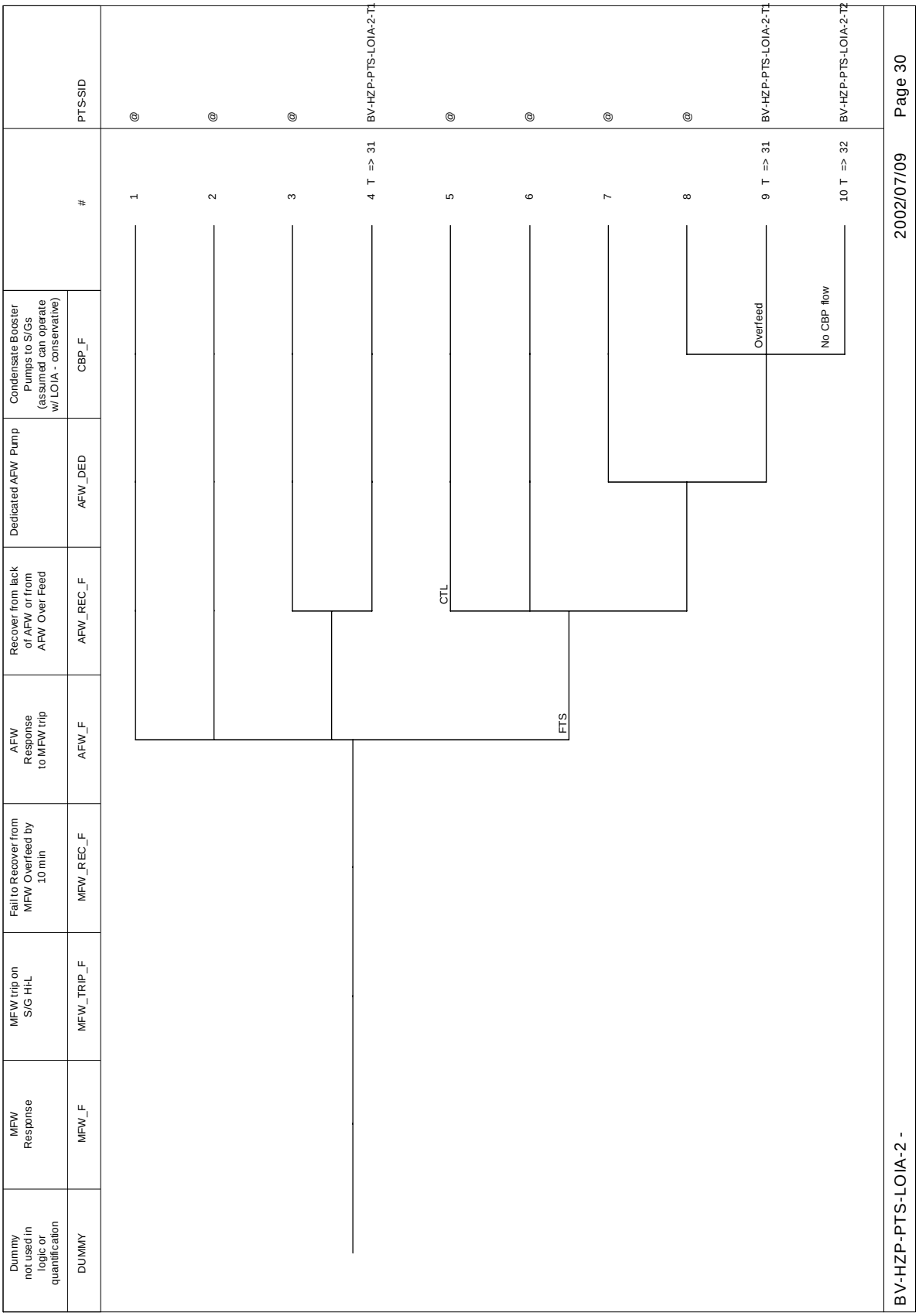

Figure 4.119. Beaver Valley -HZP-LOIA-2: Loss of instrument (station) air (primary system intact).

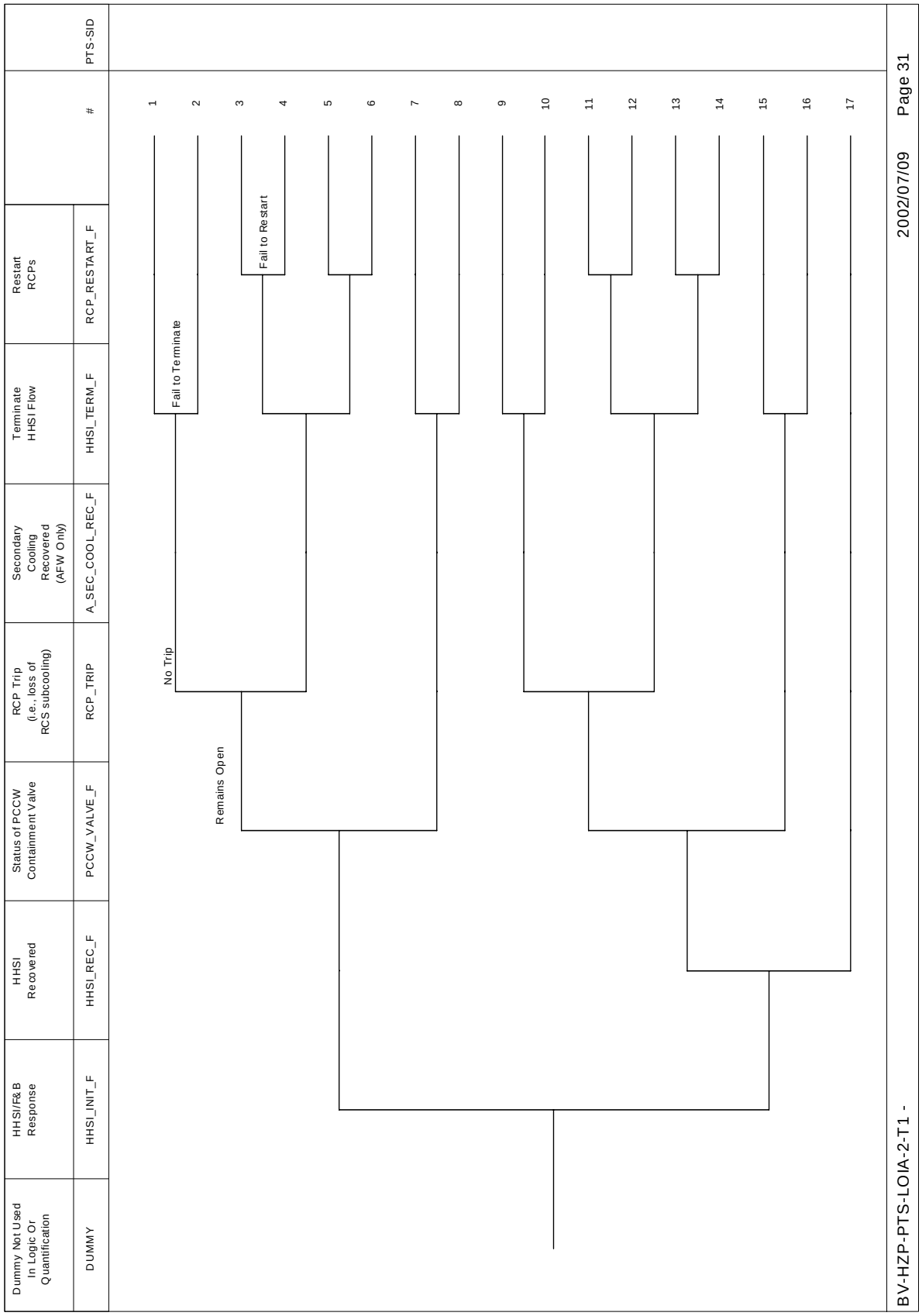

Figure 4.120. Beaver Valley -HZP-LOIA-2-T1: Loss of instrument (station) air–primary system intact (HHSI not F&B).

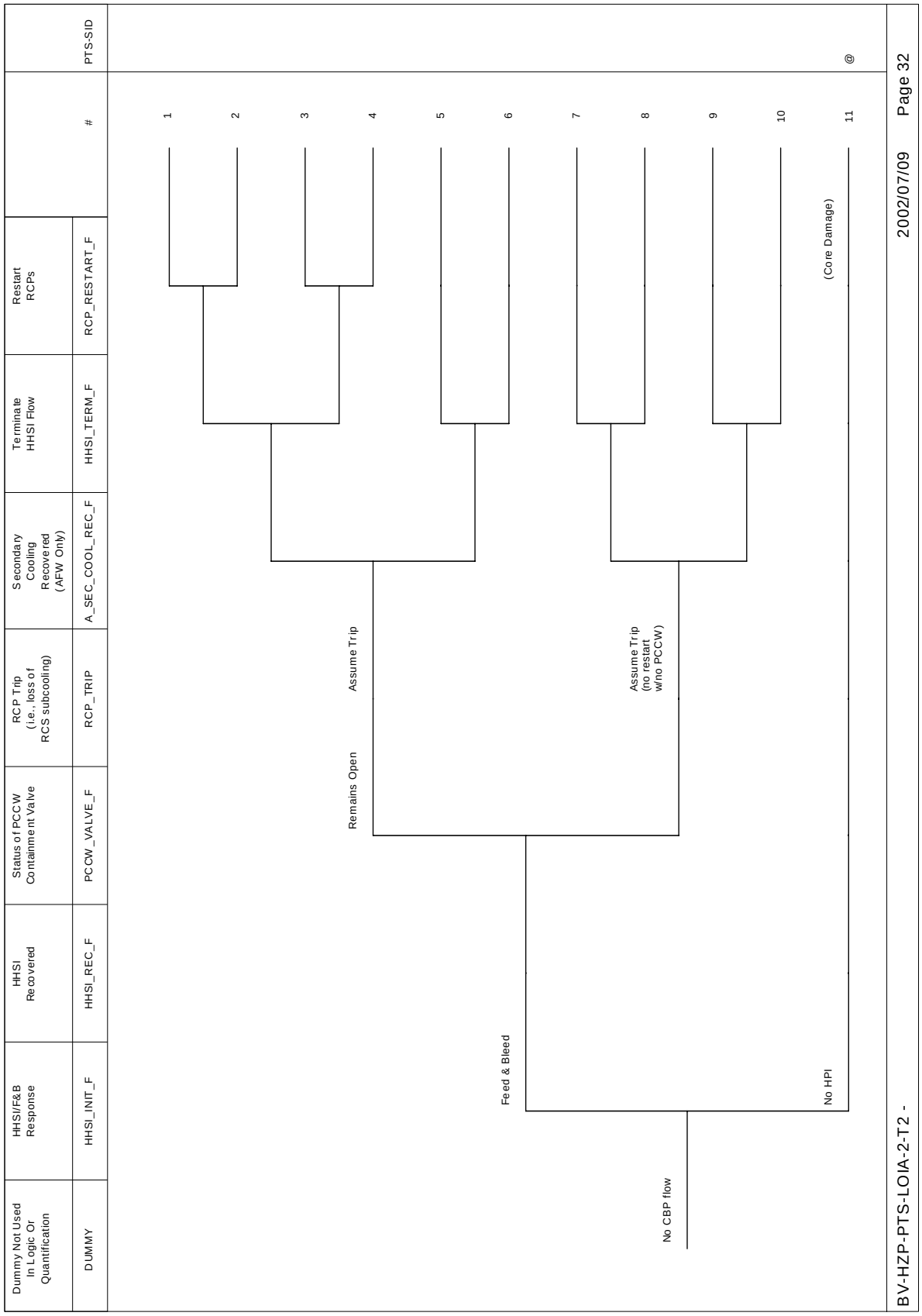

Figure 4.121. Beaver Valley -HZP-LOIA-2-T2: Loss of instrument (station) air–primary system intact (HHSI F&B).

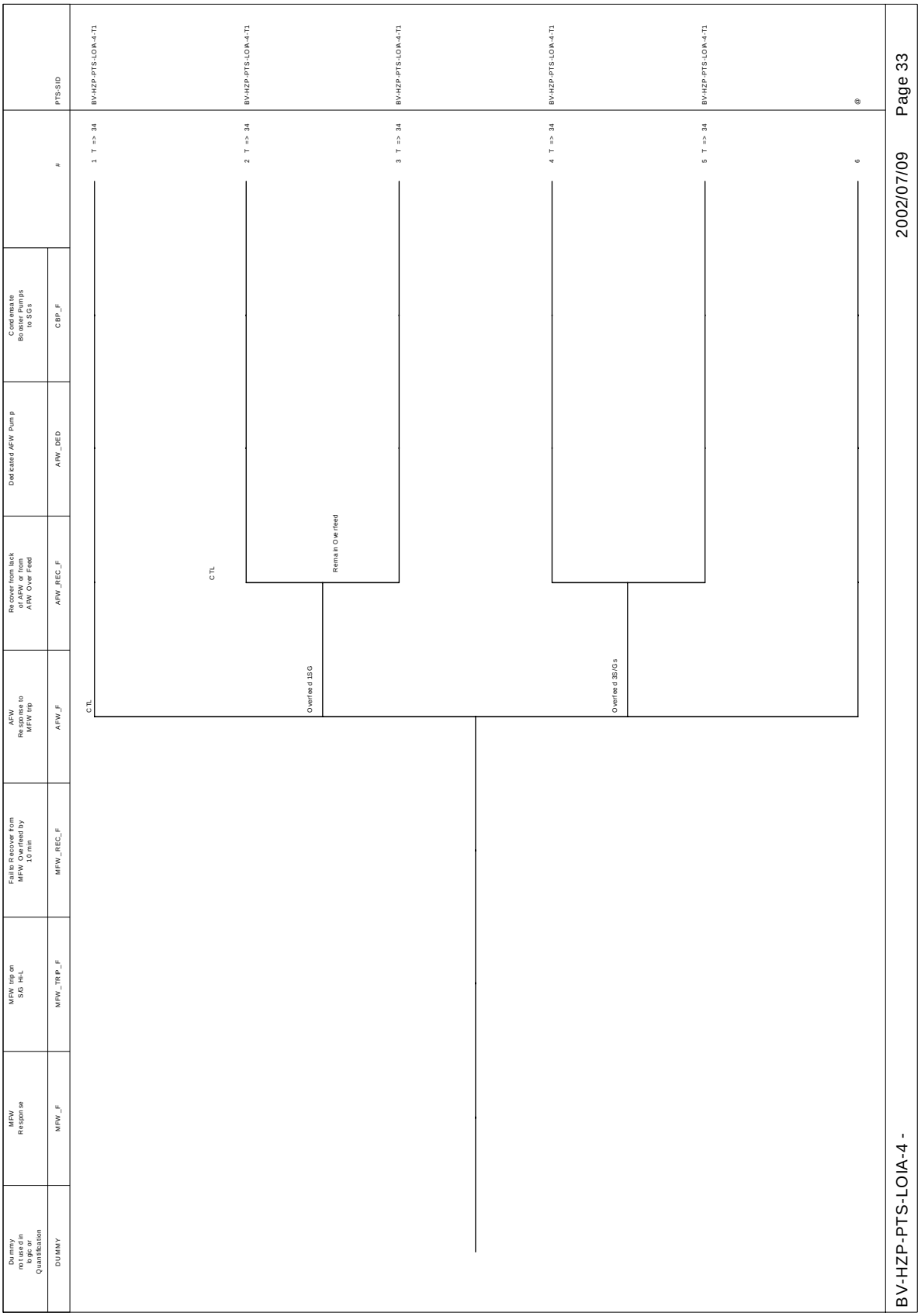

Figure 4.122. Beaver Valley -HZP-LOIA-4: Loss of instrument (station) air (at least one SRV initially open).

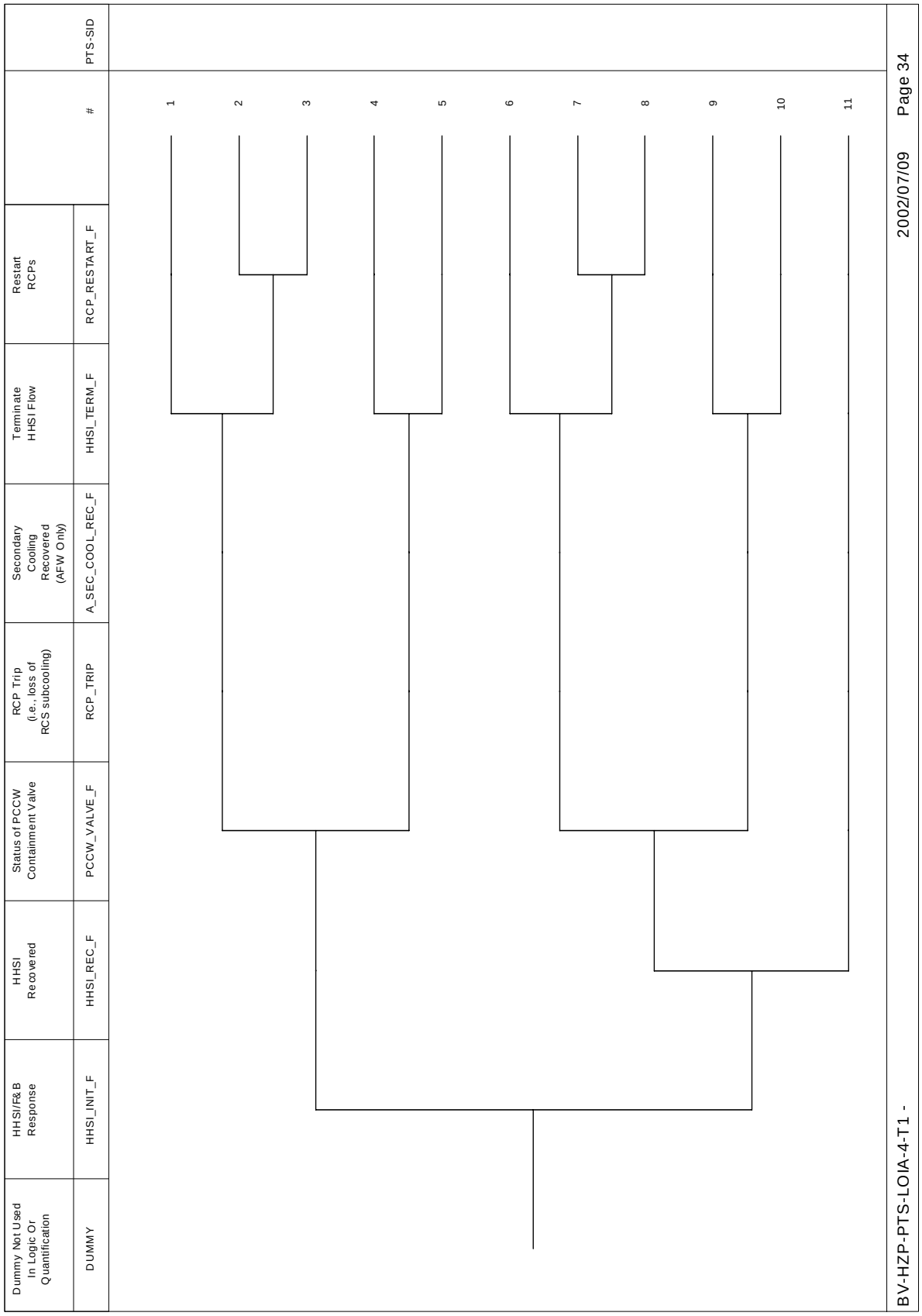

Figure 4.123. Beaver Valley -HZP-LOIA-4-T1: Loss of instrument (station) air–at least one SRV initially open (HHSI not F&B).

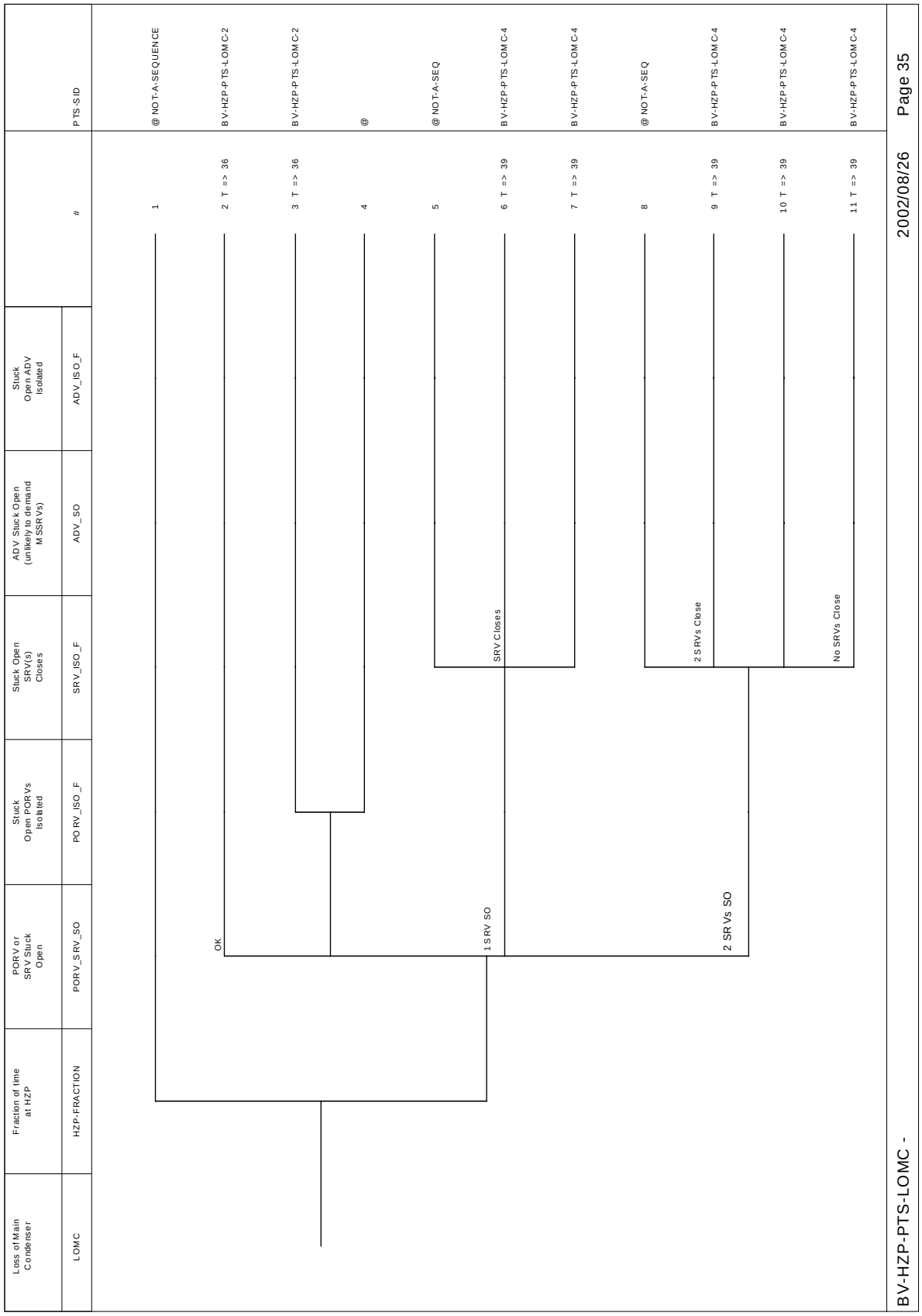

Figure 4.124. Beaver Valley -HZP-LOMC: Loss of main condenser.

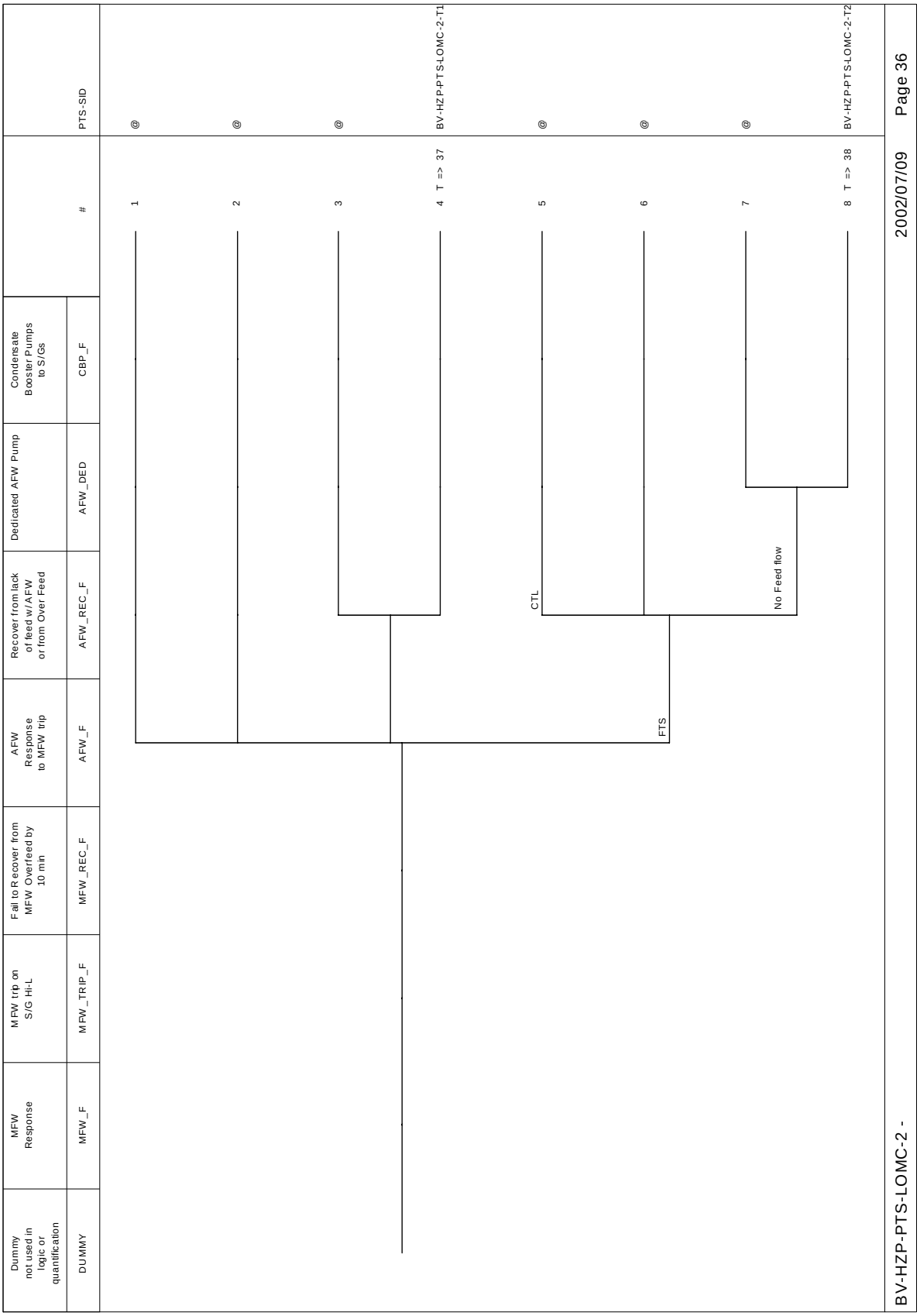

Figure 4.125. Beaver Valley -HZP-LOMC-2: Loss of main condenser (primary system intact).

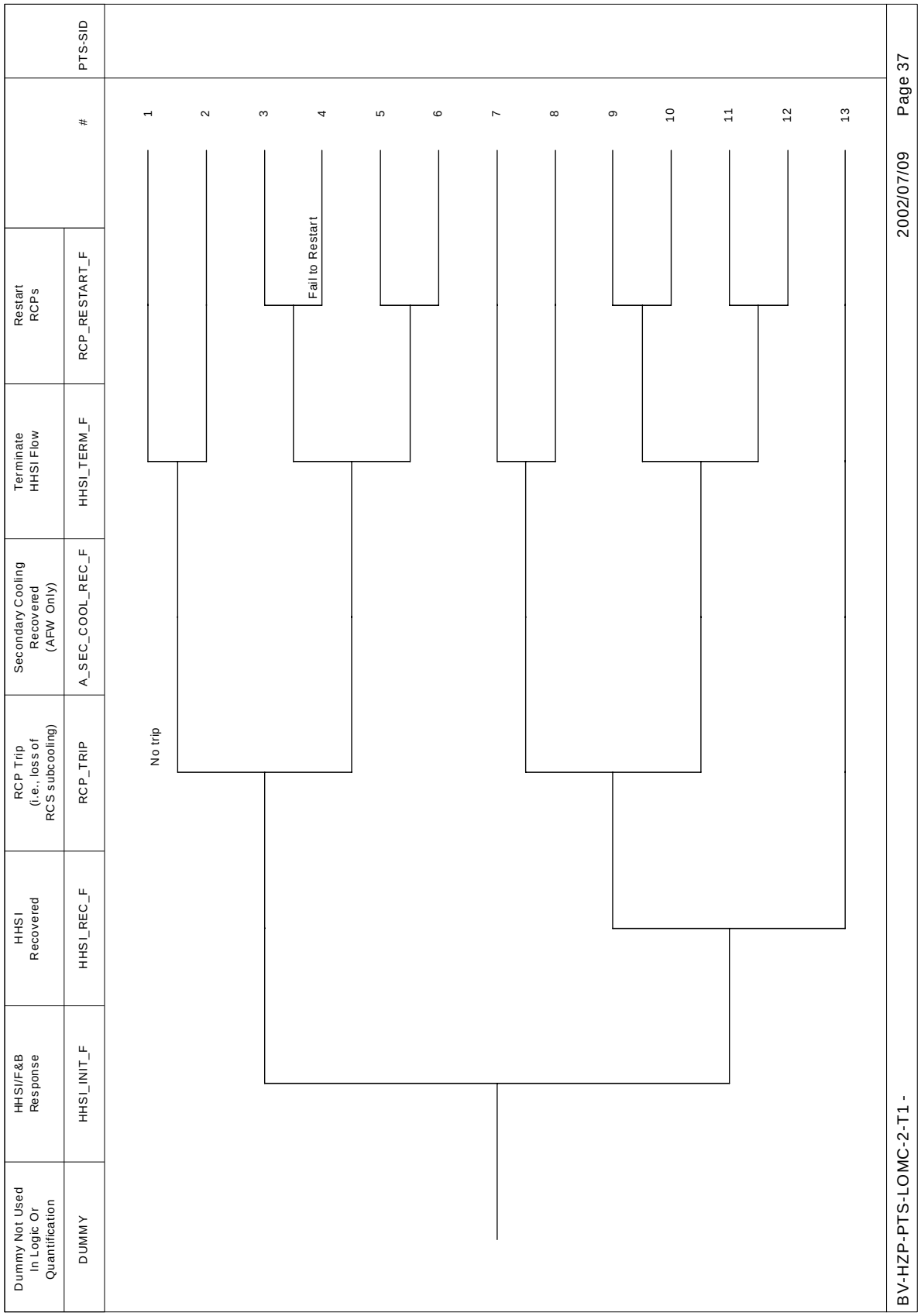

Figure 4.126. Beaver Valley -HZP-LOMC-2-T1: Loss of main condenser–primary system intact (HHSI not F&B).

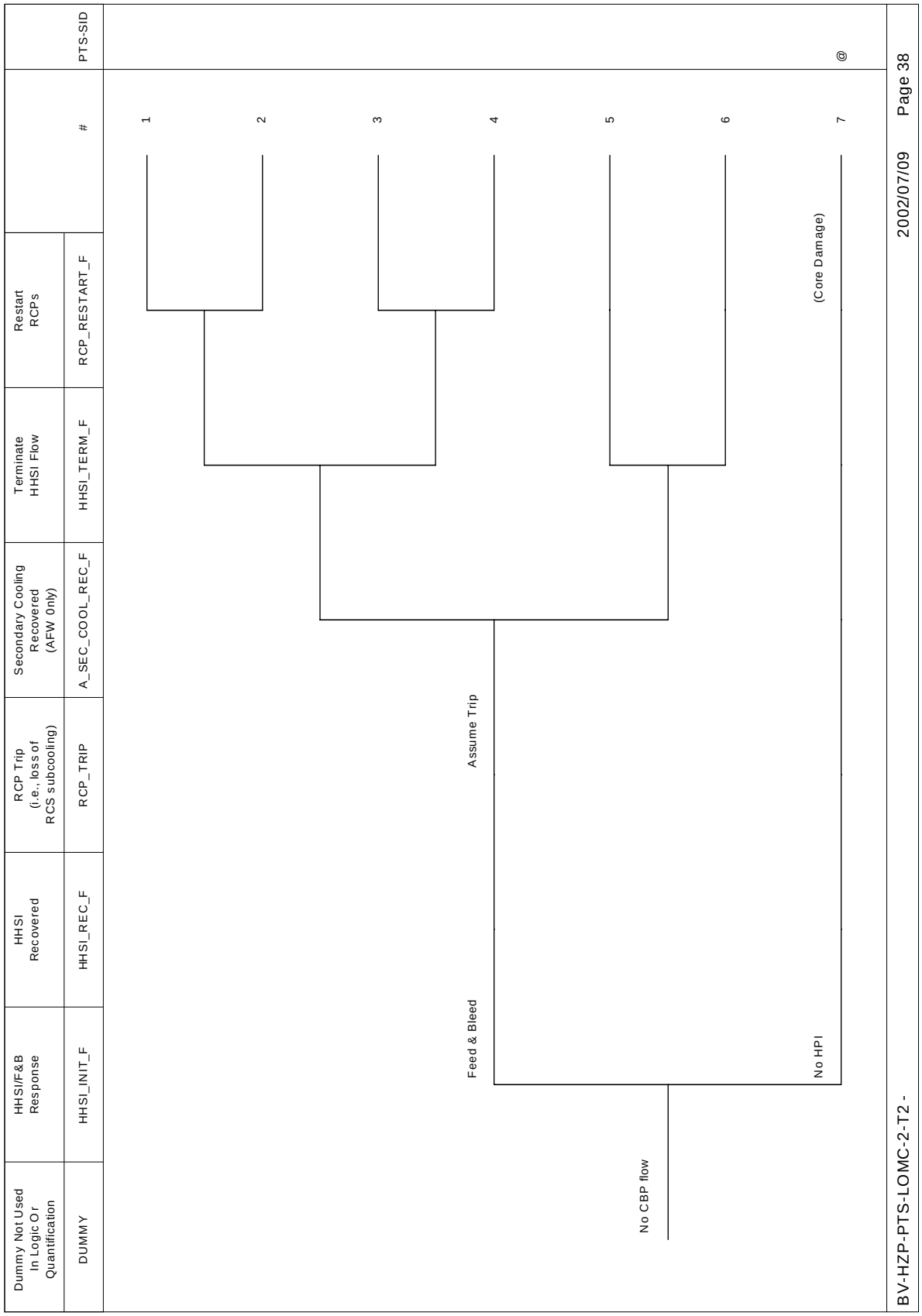

Figure 4.127. Beaver Valley -HZP-LOMC-2-T2: Loss of main condenser–primary system intact (HHSI F&B).

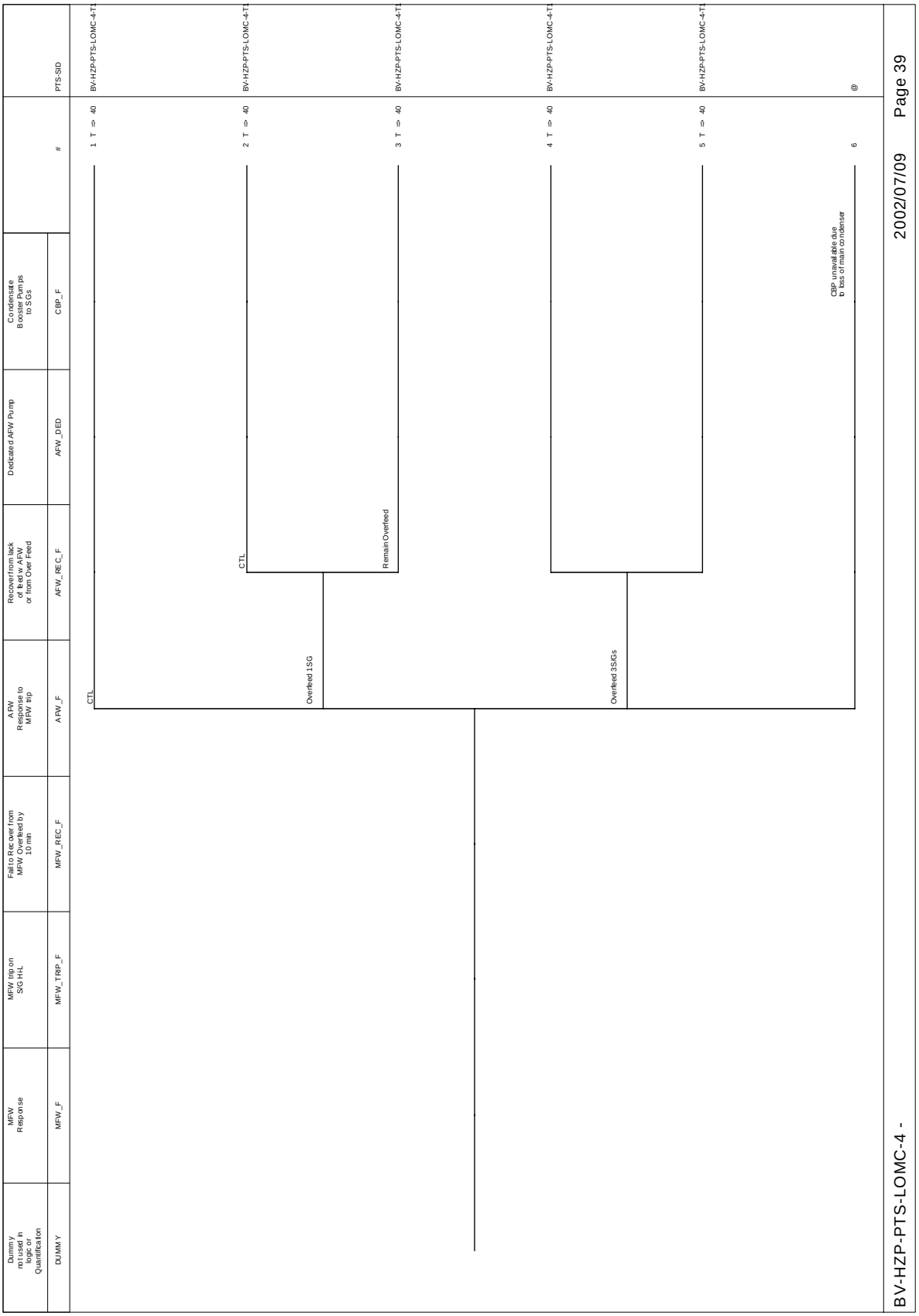

Figure 4.128. Beaver Valley -HZP-LOMC-4: Loss of main condenser (at least one SRV initially open).

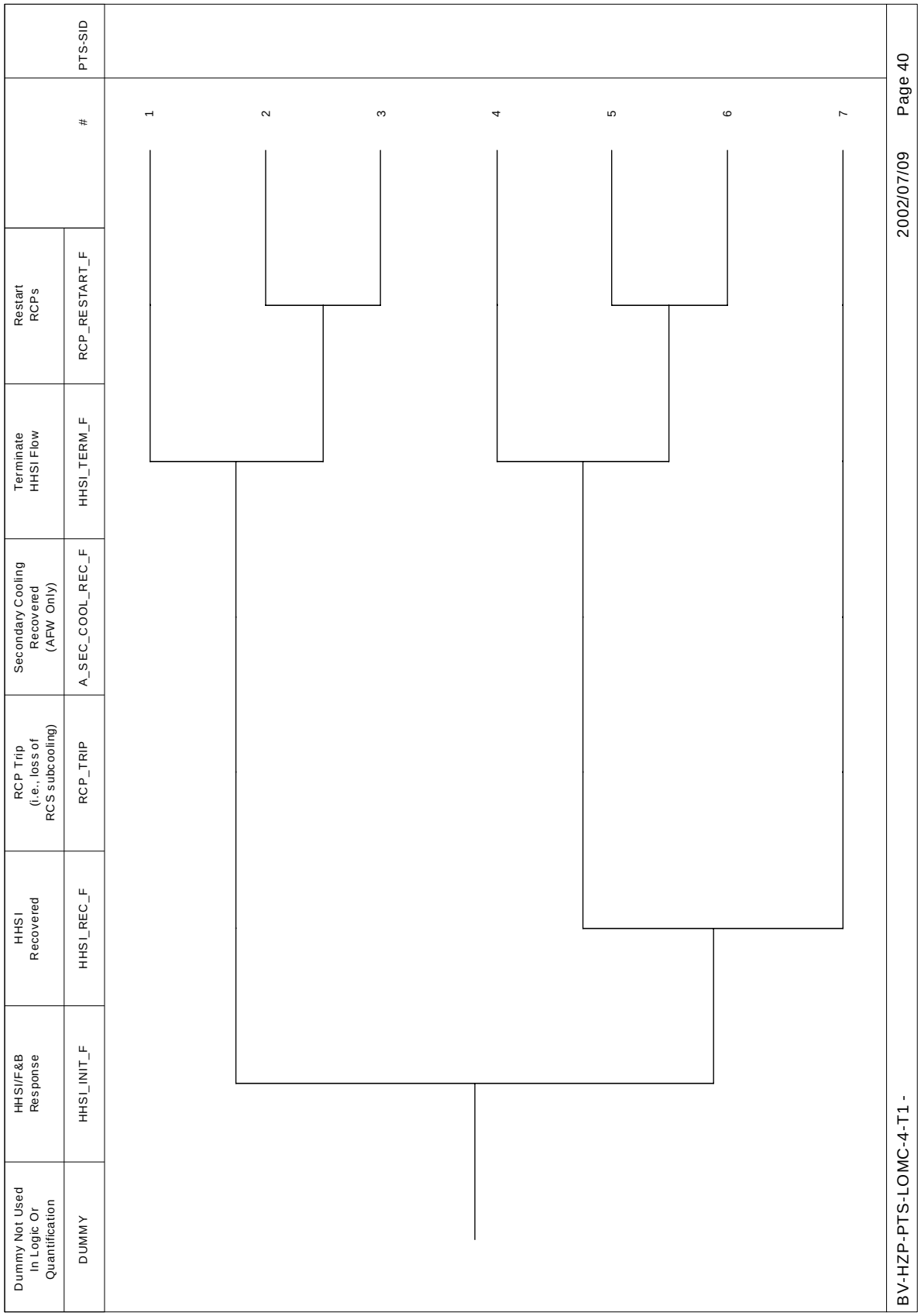

Figure 4.129. Beaver Valley -HZP-LOMC-4-T1: Loss of main condenser–at least one SRV initially open (HHSI not F&B).

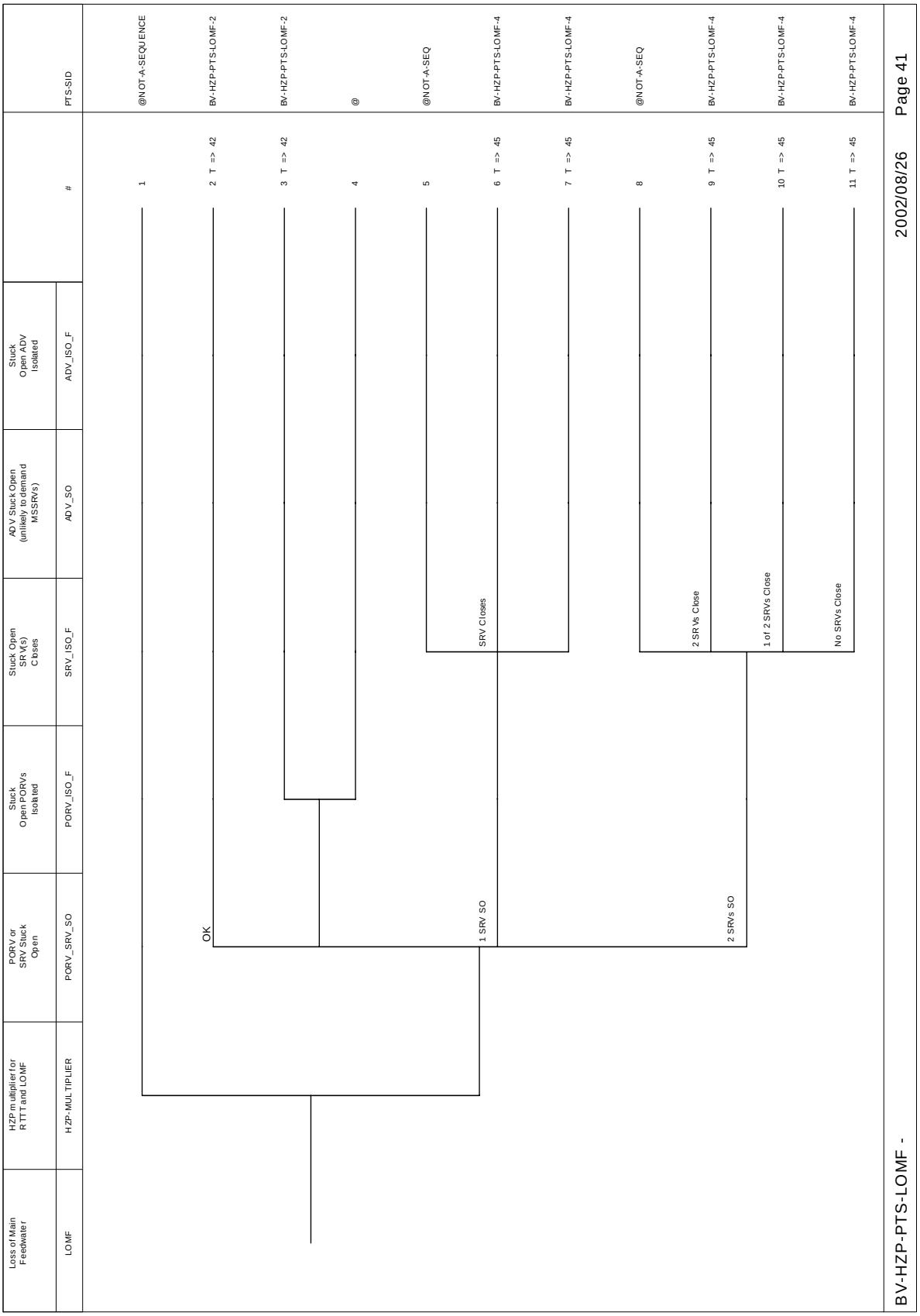

Figure 4.130. Beaver Valley -HZP-LOMF: Loss of main feedwater.

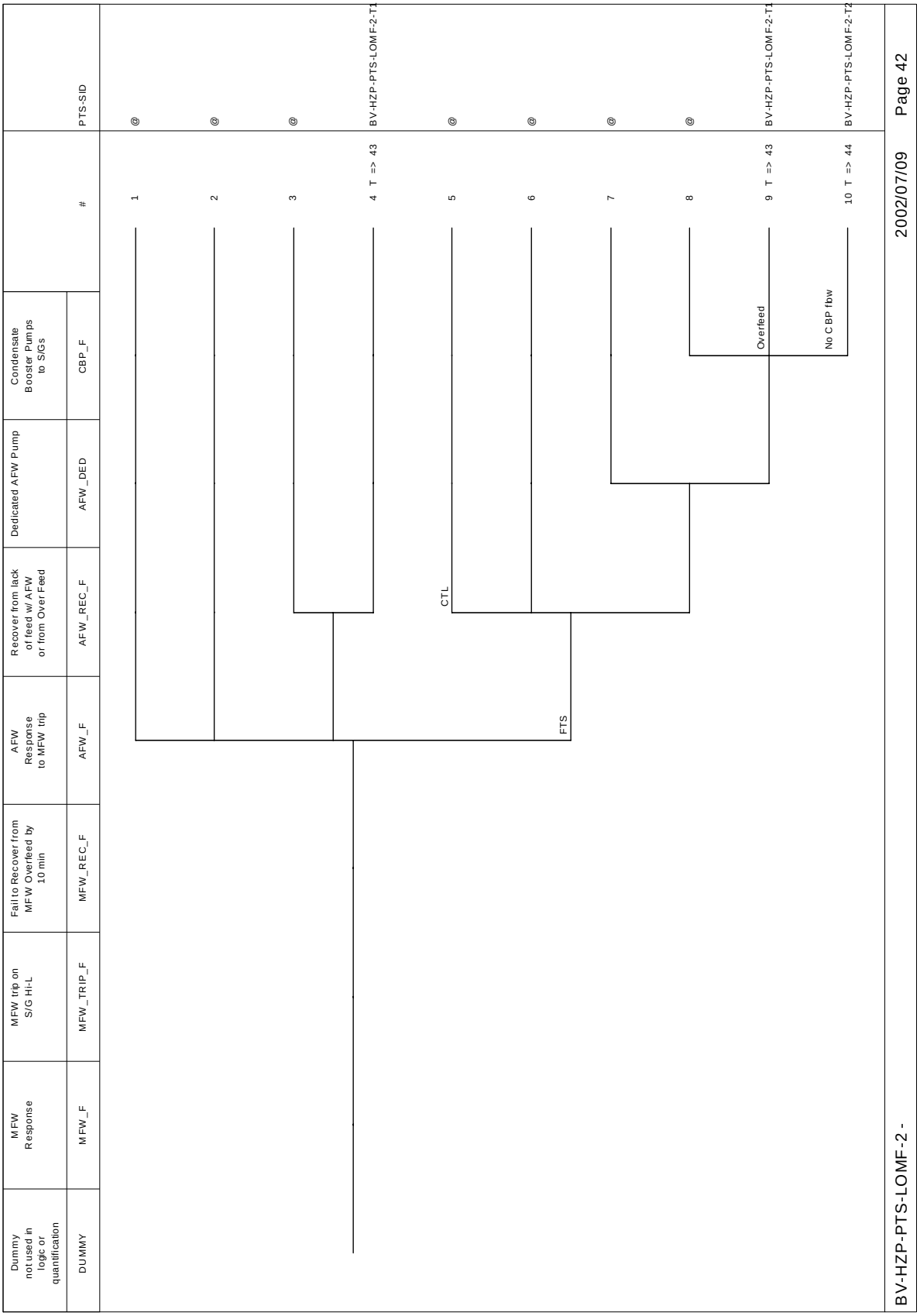

Figure 4.131. Beaver Valley -HZP-LOMF-2: Loss of main feedwater (primary system intact).

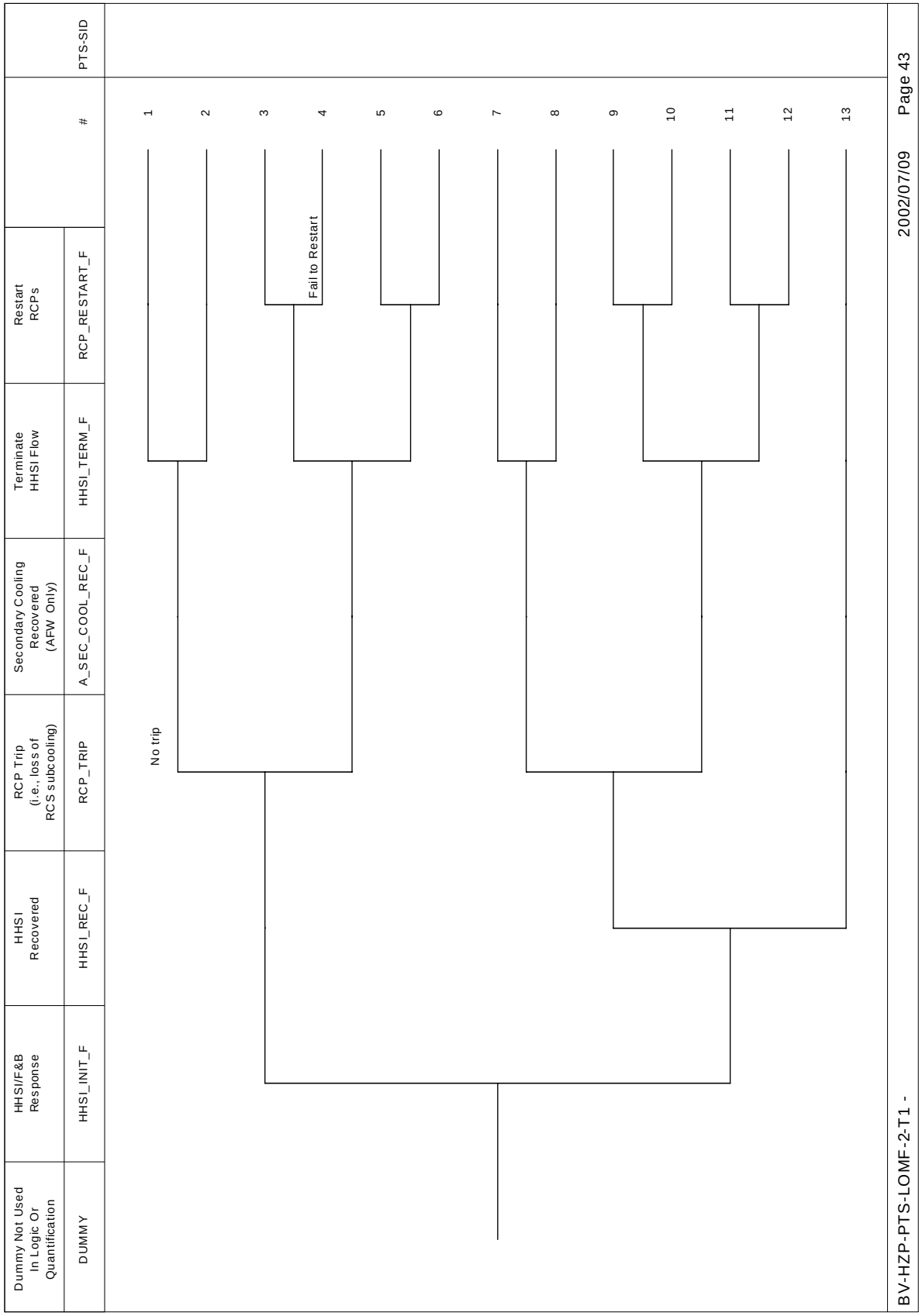

Figure 4.132. Beaver Valley -HZP-LOMF-2-T1: Loss of main feedwater–primary system intact (HHSI not F&B).

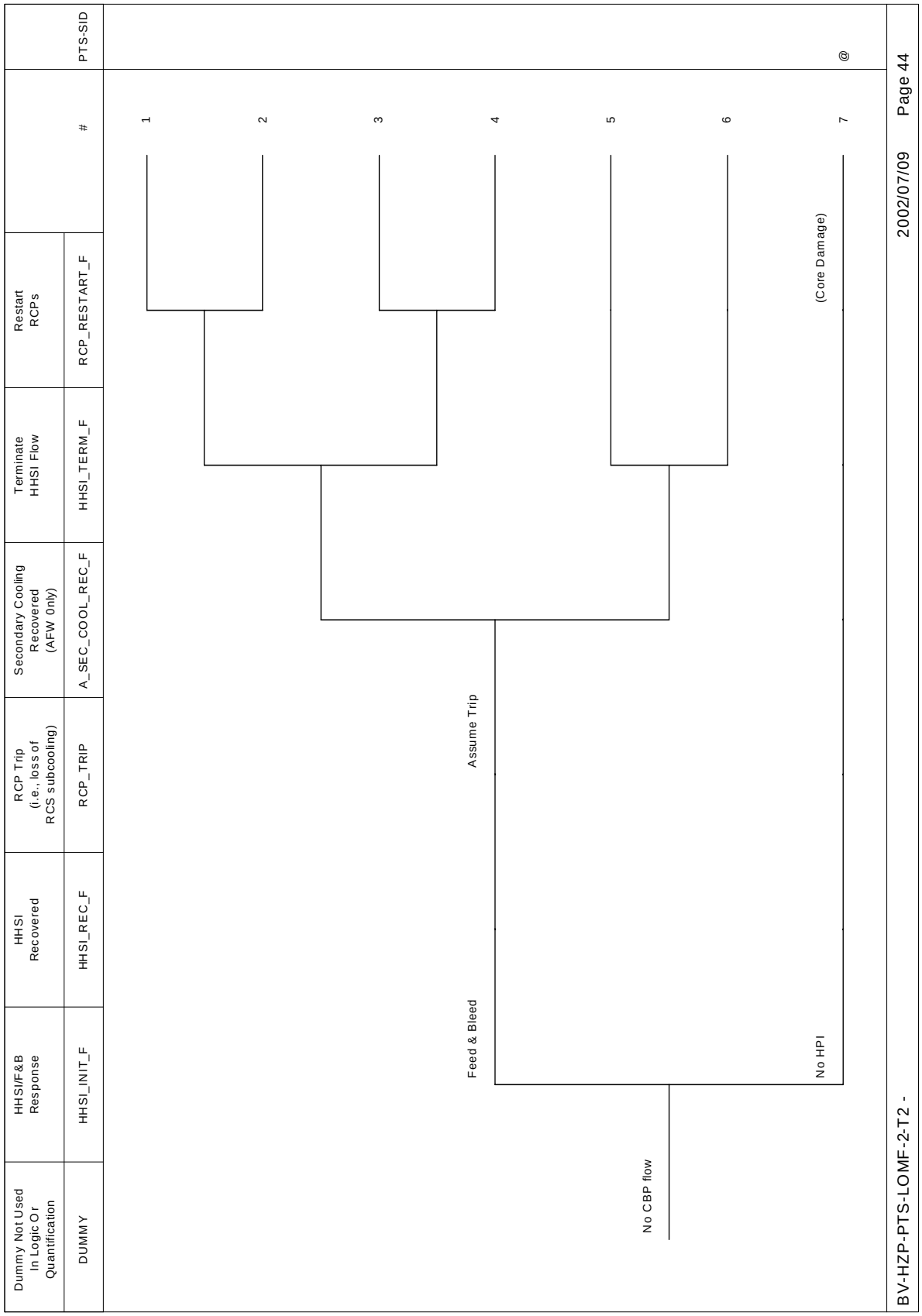

Figure 4.133. Beaver Valley -HZP-LOMF-2-T2: Loss of main feedwater–primary system intact (HHSI F&B).

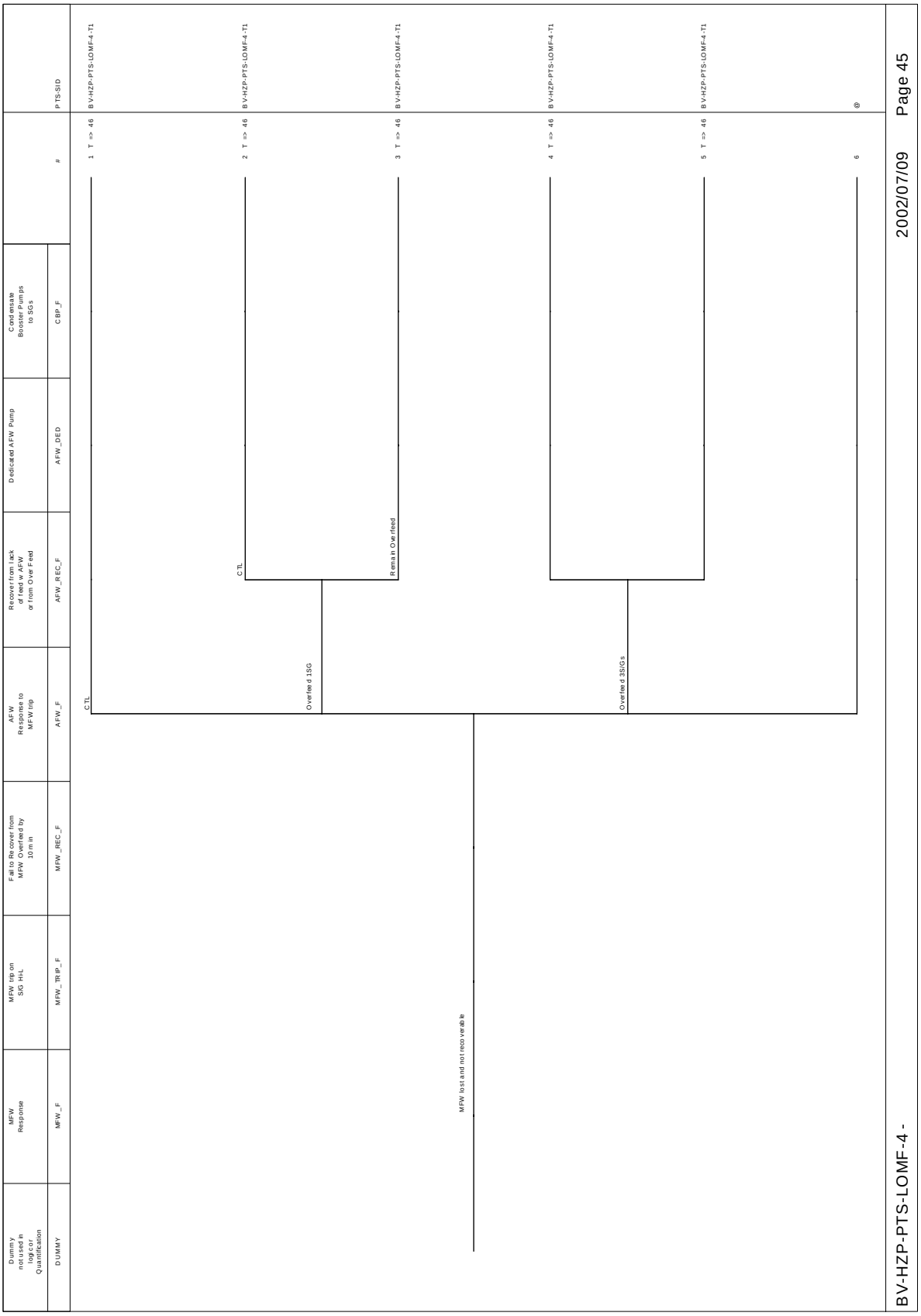

Figure 4.134. Beaver Valley -HZP-LOMF-4: Loss of main feedwater (at least one SRV initially open).

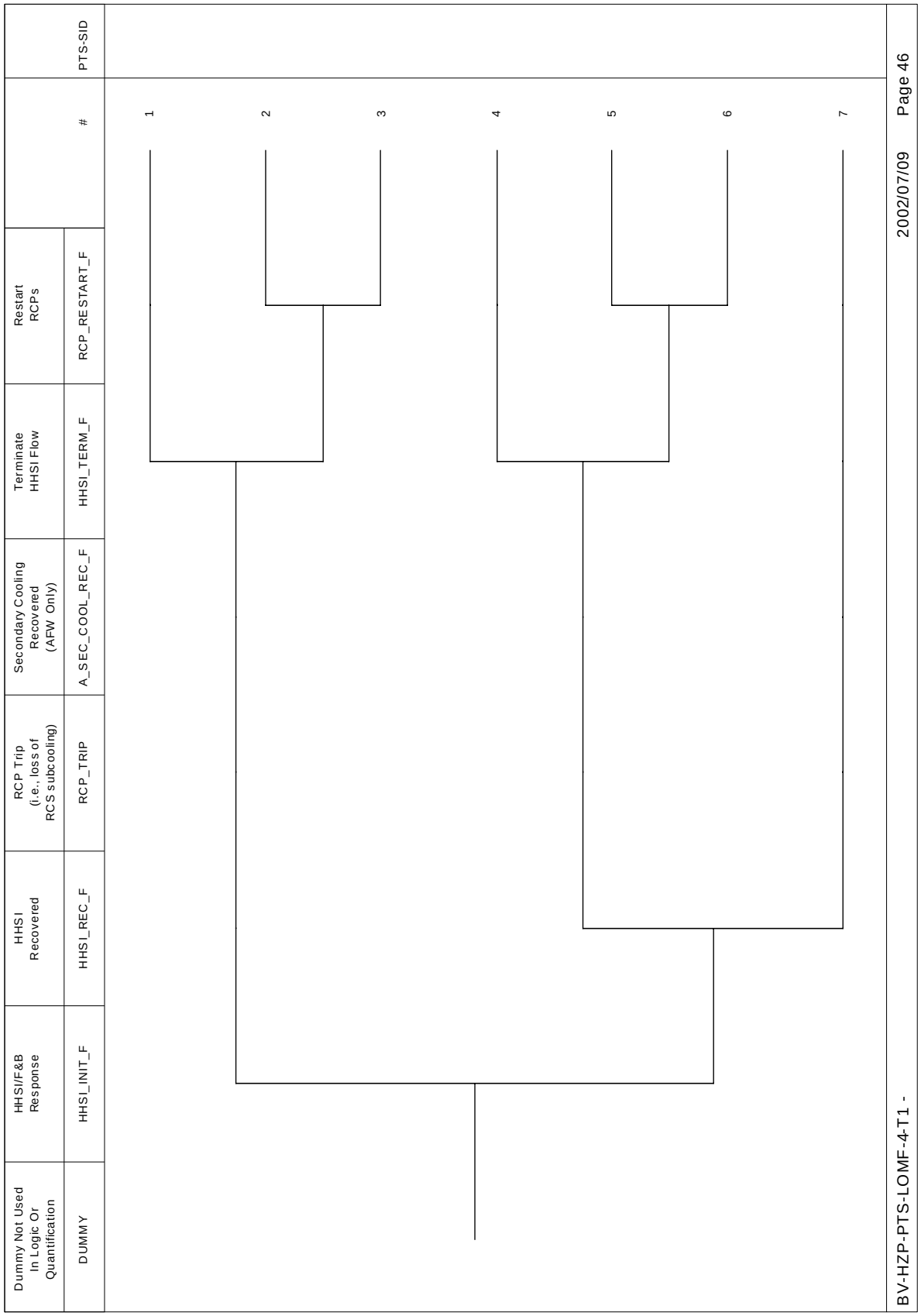

Figure 4.135. Beaver Valley -HZP-LOMF-4-T1: Loss of main feedwater–at least one SRV initially open (HHSI not F&B).

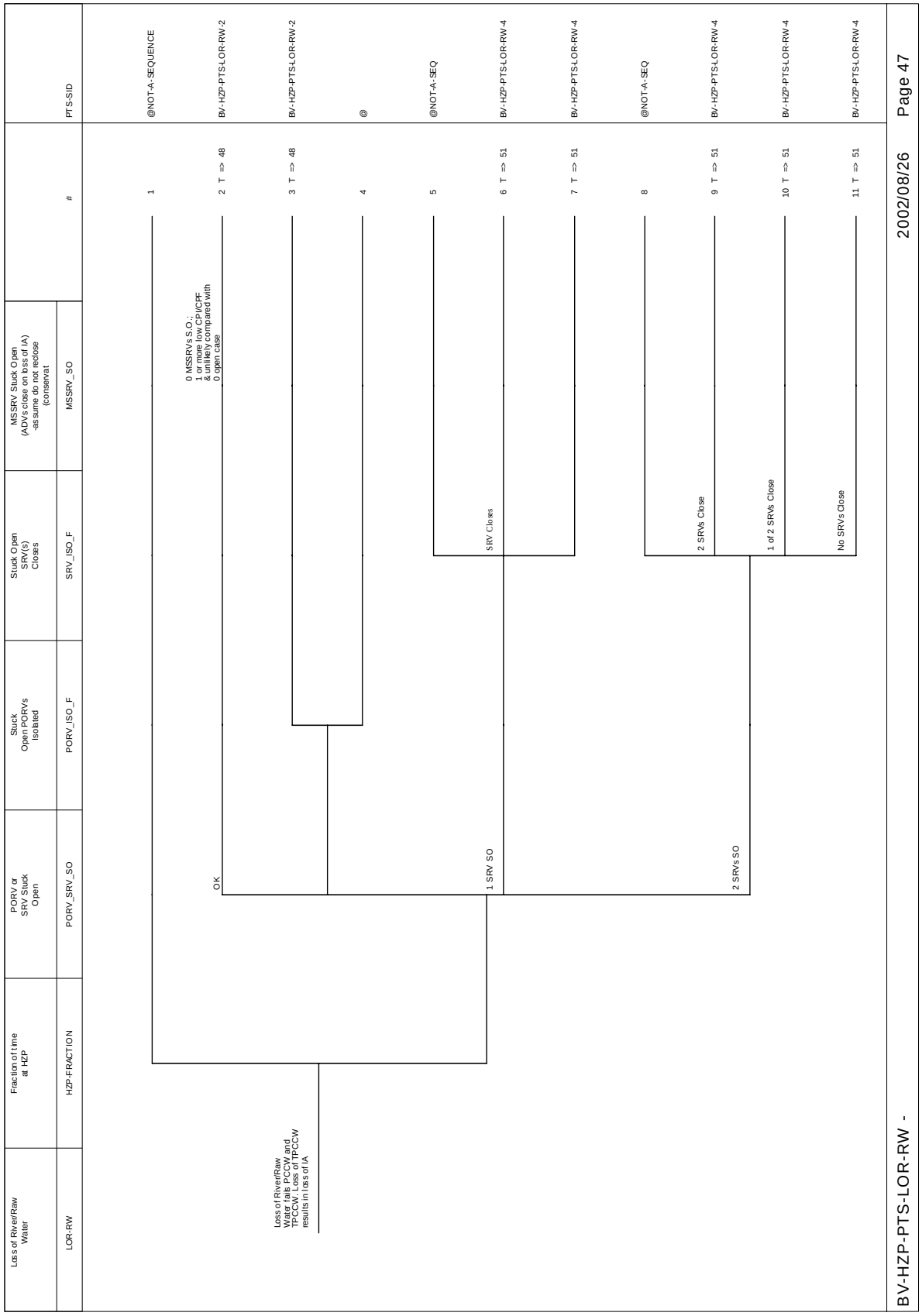

Figure 4.136. Beaver Valley -HZP-LOR-RW: Loss of river/raw water.

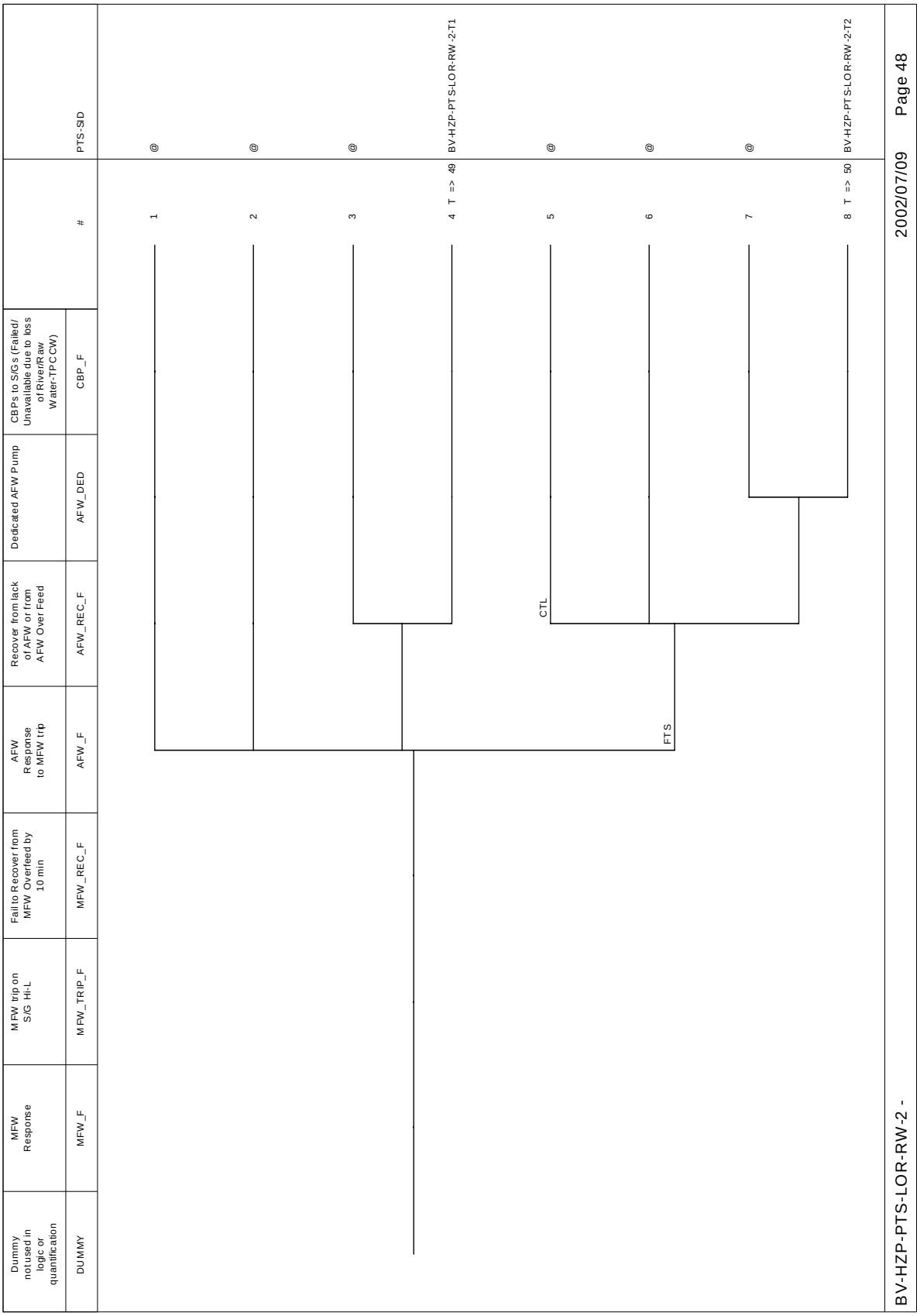

Figure 4.137. Beaver Valley -HZP-LOR-RW-2: Loss of river/raw water (primary system intact).

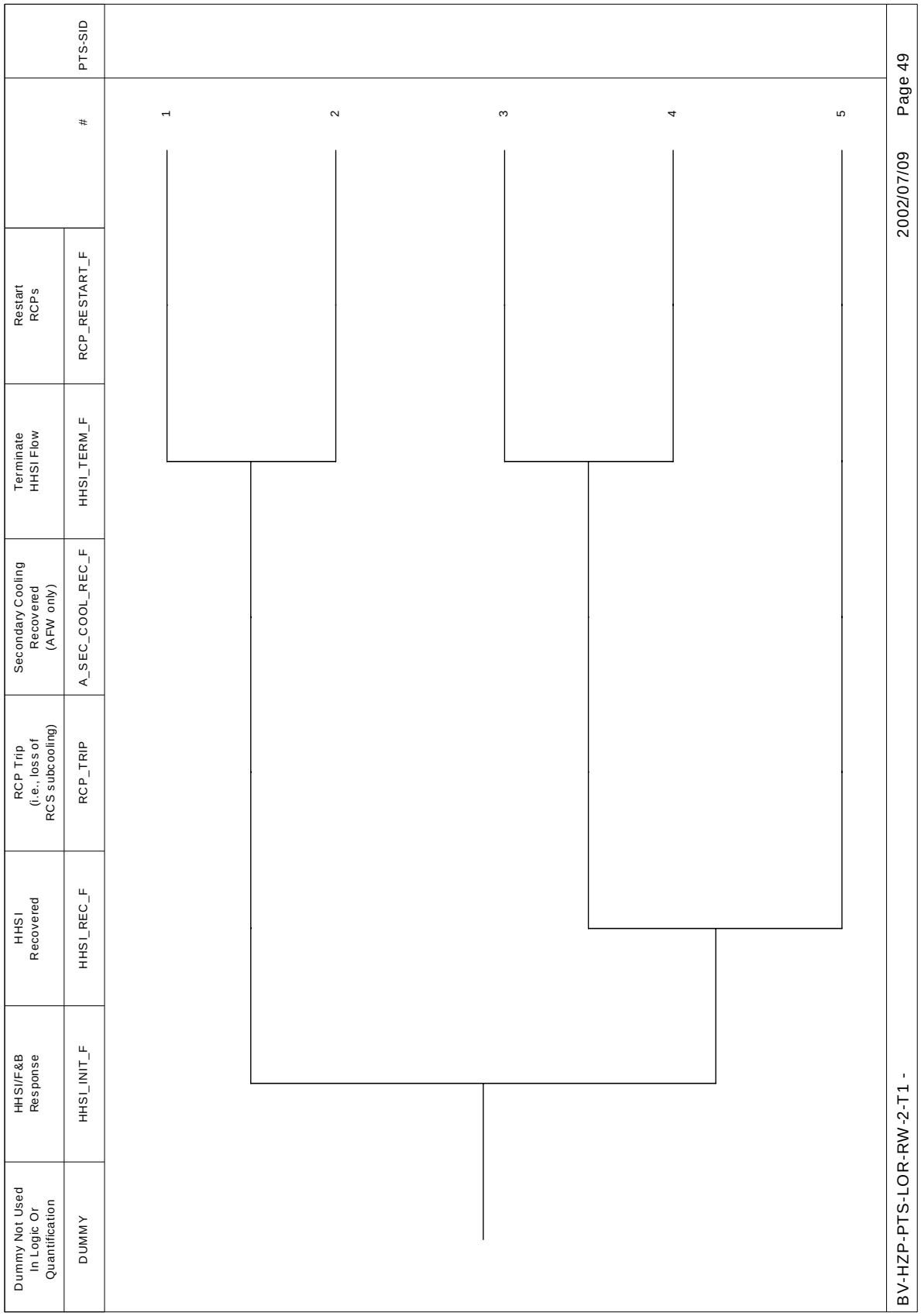

Figure 4.138. Beaver Valley -HZP-LOR-RW-2-T1: Loss of river/raw water–primary system intact (HHSI not F&B).

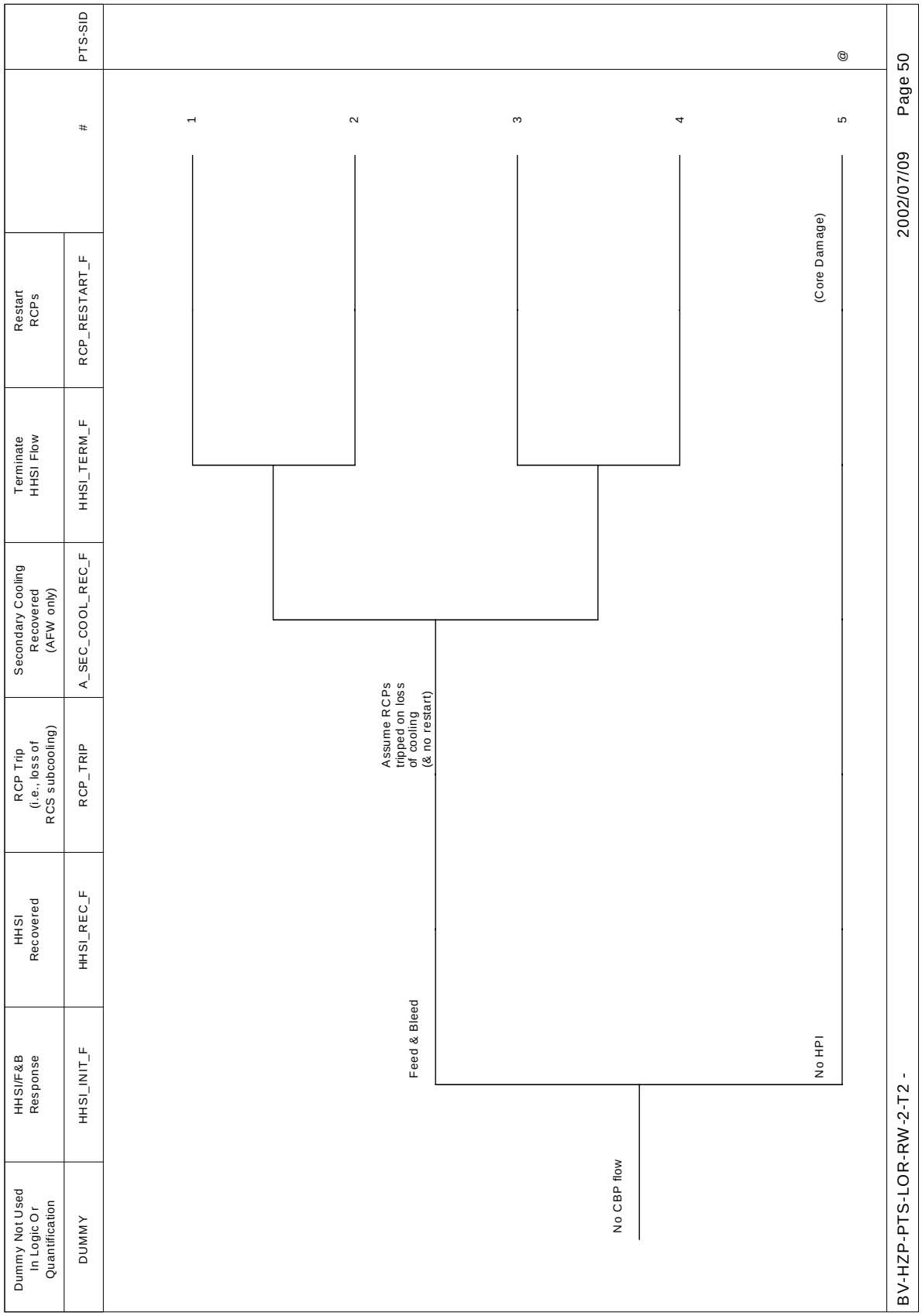

Figure 4.139. Beaver Valley -HZP-LOR-RW-2-T2: Loss of river/raw water–primary system intact (HHSI F&B).

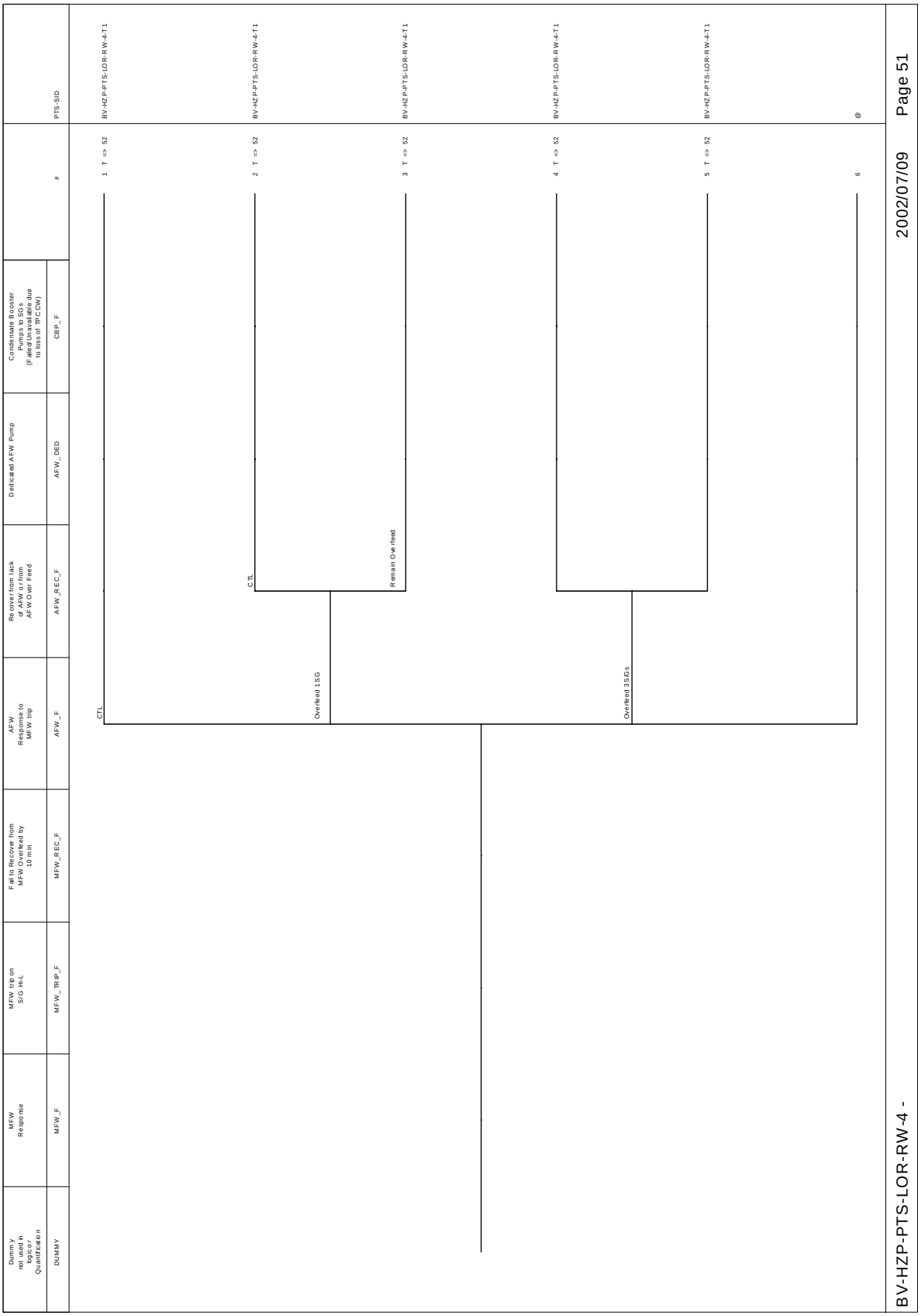

Figure 4.140. Beaver Valley -HZP-LOR-RW-4: Loss of river/raw water (at least one SRV initially open).

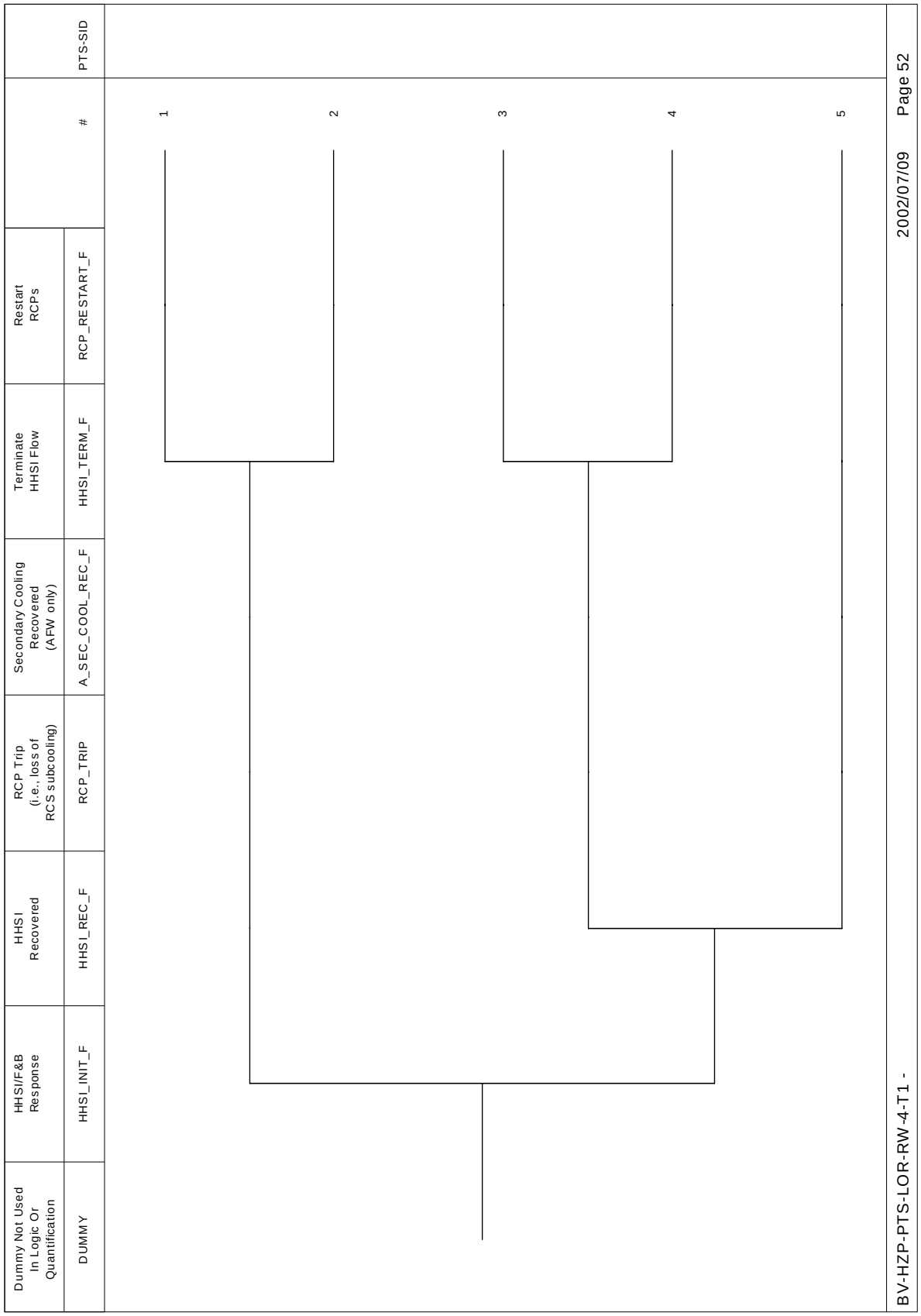

Figure 4.141. Beaver Valley -HZP-LOR-RW-4-T1: Loss of river/raw water–at least one SRV initially open (HHSI not F&B).

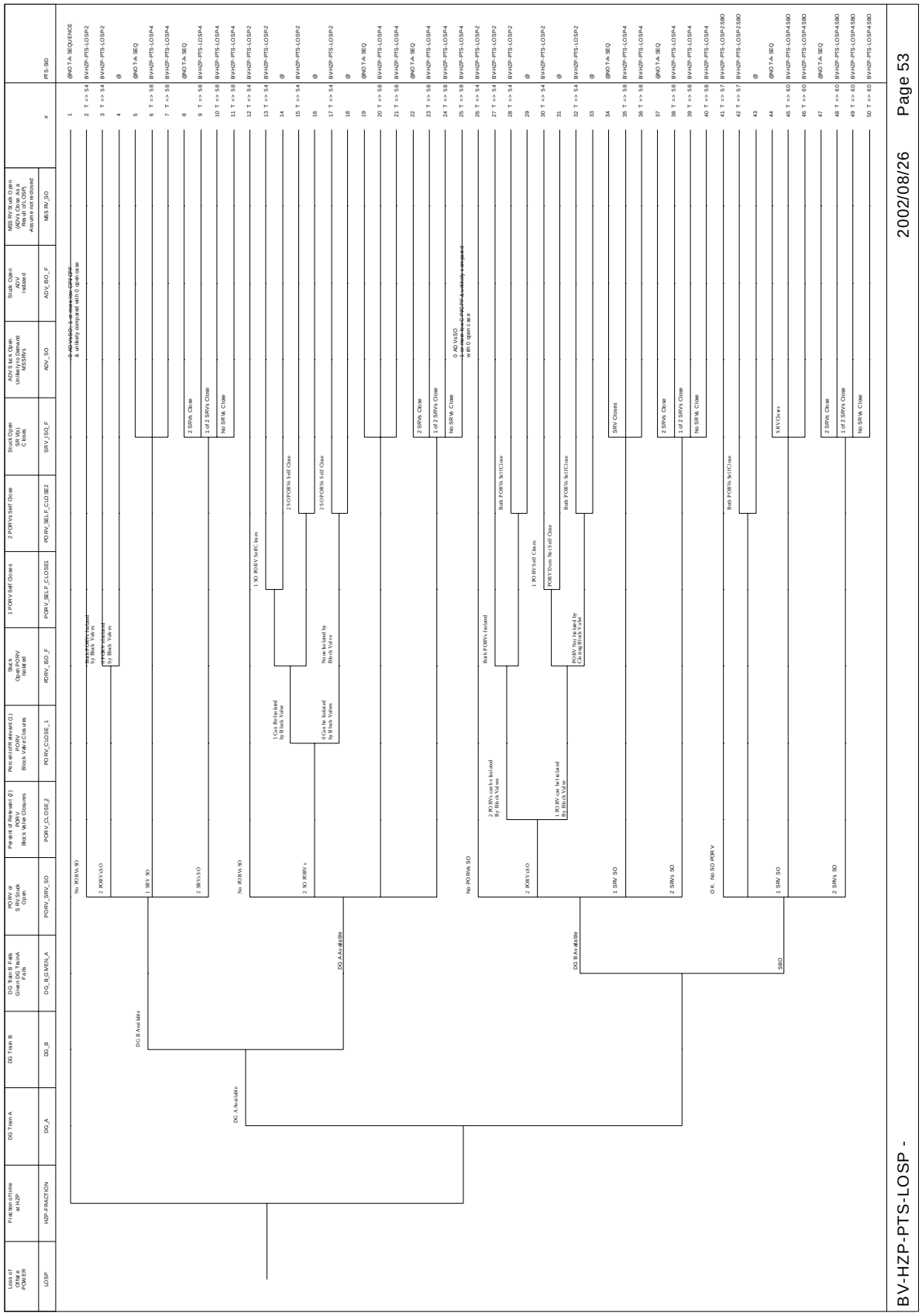

Figure 4.142. Beaver Valley -HZP-LOSP: Loss of offsite power.

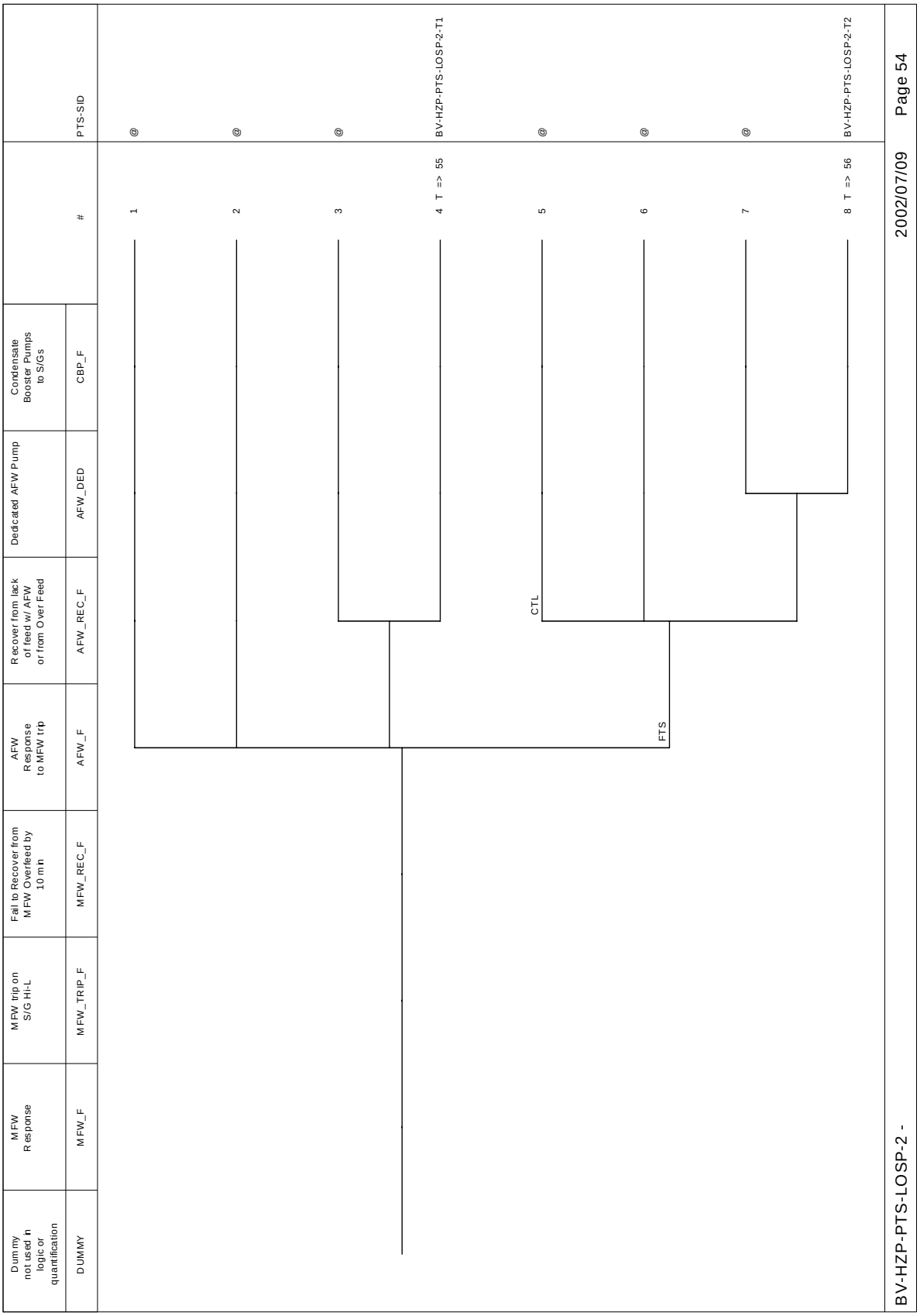

Figure 4.143. Beaver Valley -HZP-LOSP-2: Loss of offsite power (primary system intact).

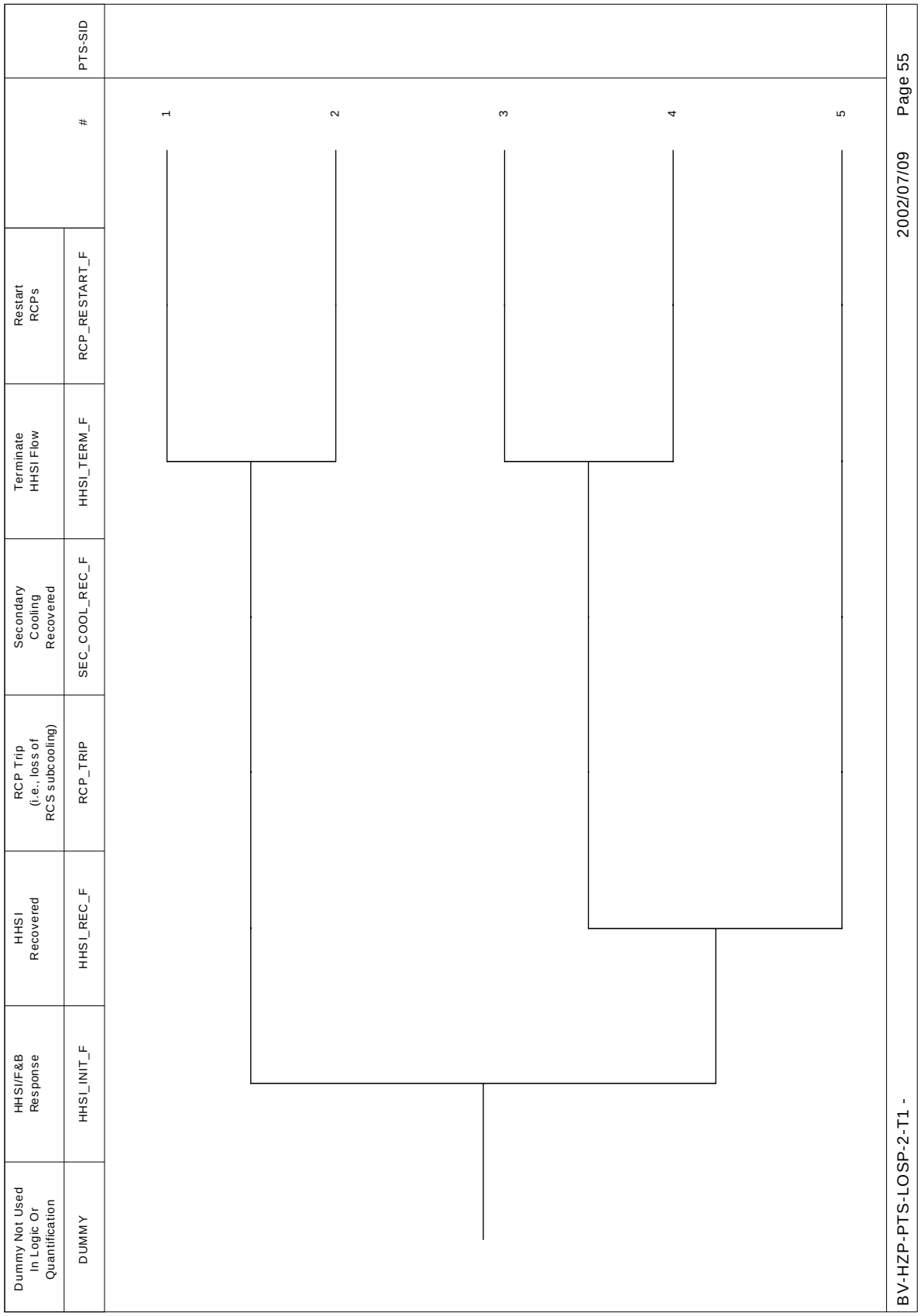

Figure 4.144. Beaver Valley -HZP-LOSP-2-T1: Loss of offsite power–primary system intact (HHSI not F&B).

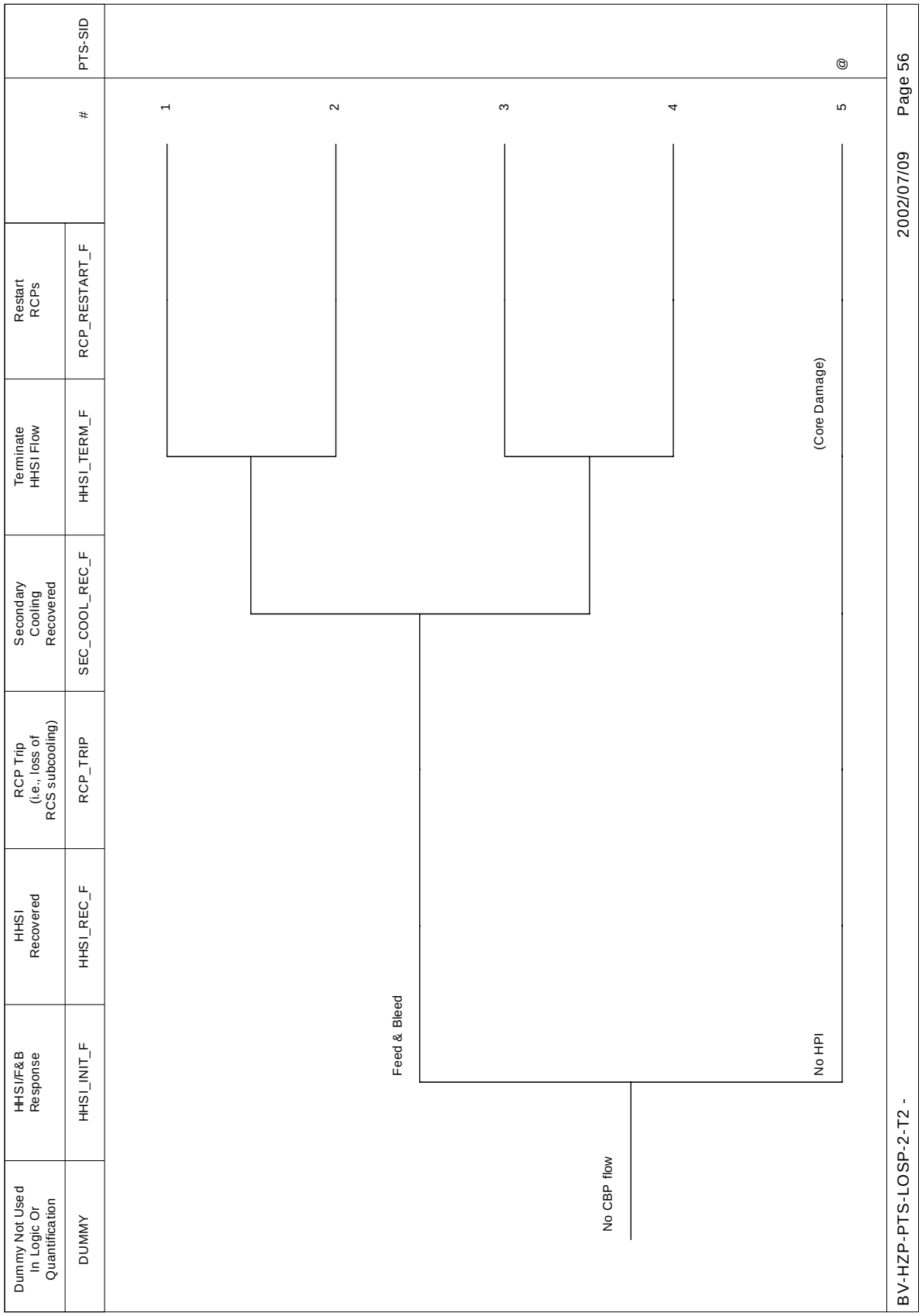

Figure 4.145. Beaver Valley -HZP-LOSP-2-T2: Loss of offsite power–primary system intact (HHSI F&B).

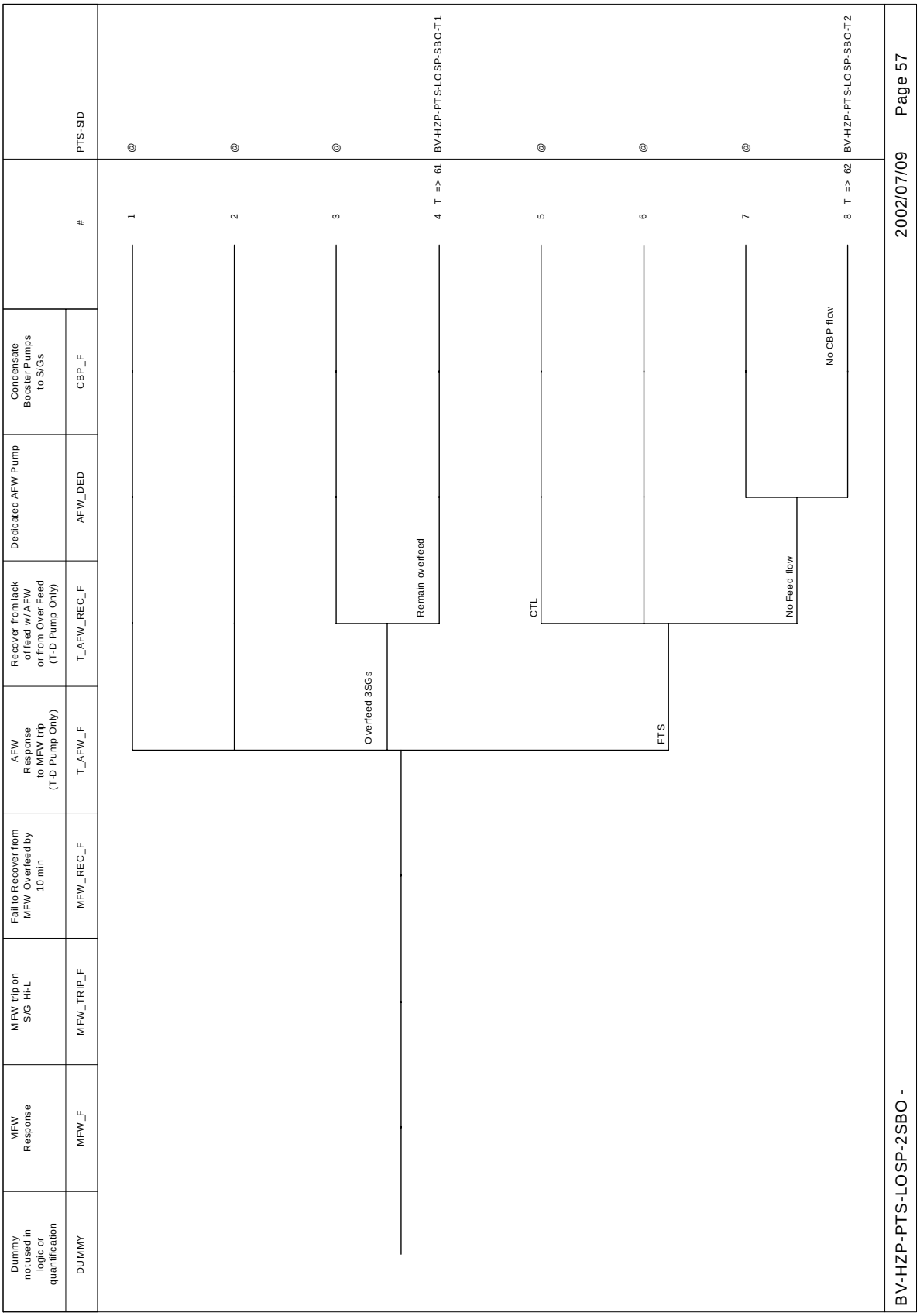

Figure 4.146. Beaver Valley -HZP-LOSP-2SBO: Loss of offsite power (station blackout)–primary system intact.

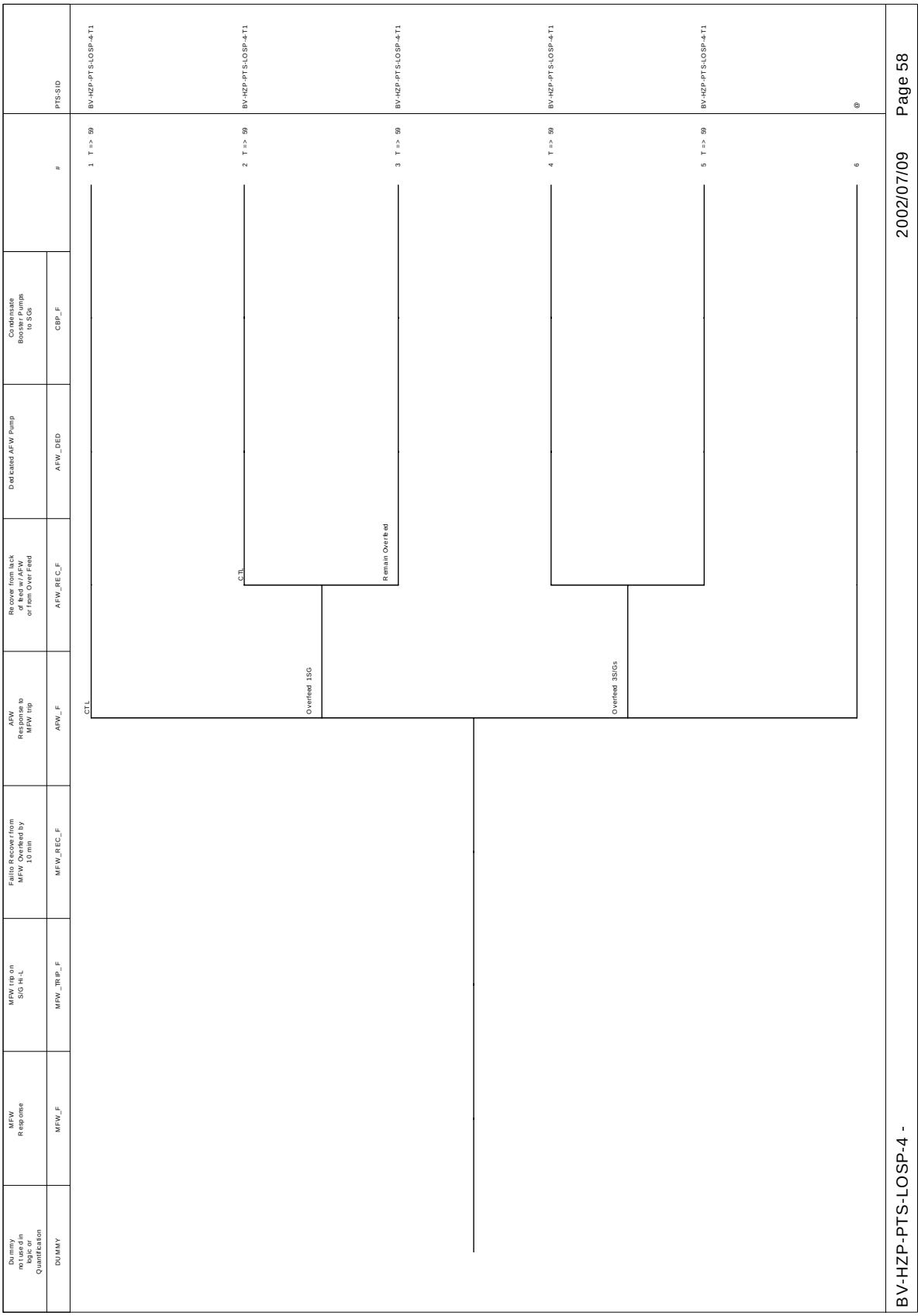

Figure 4.147. Beaver Valley -HZP-LOSP-4: Loss of offsite power (at least one SRV initially open).

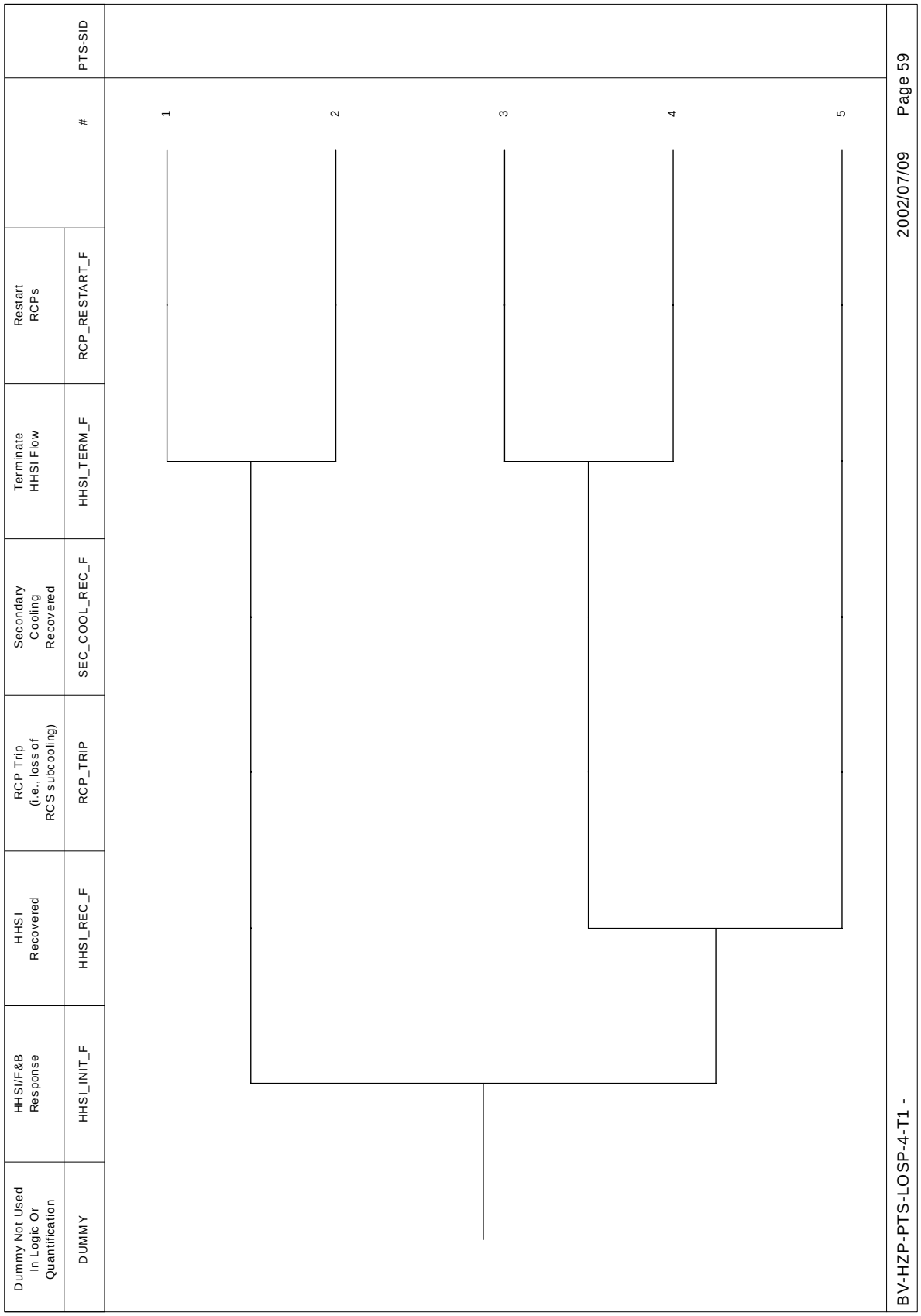

Figure 4.148. Beaver Valley -HZP-LOSP-4-T1: Loss of offsite power–at least one SRV initially open (HHSI not F&B).

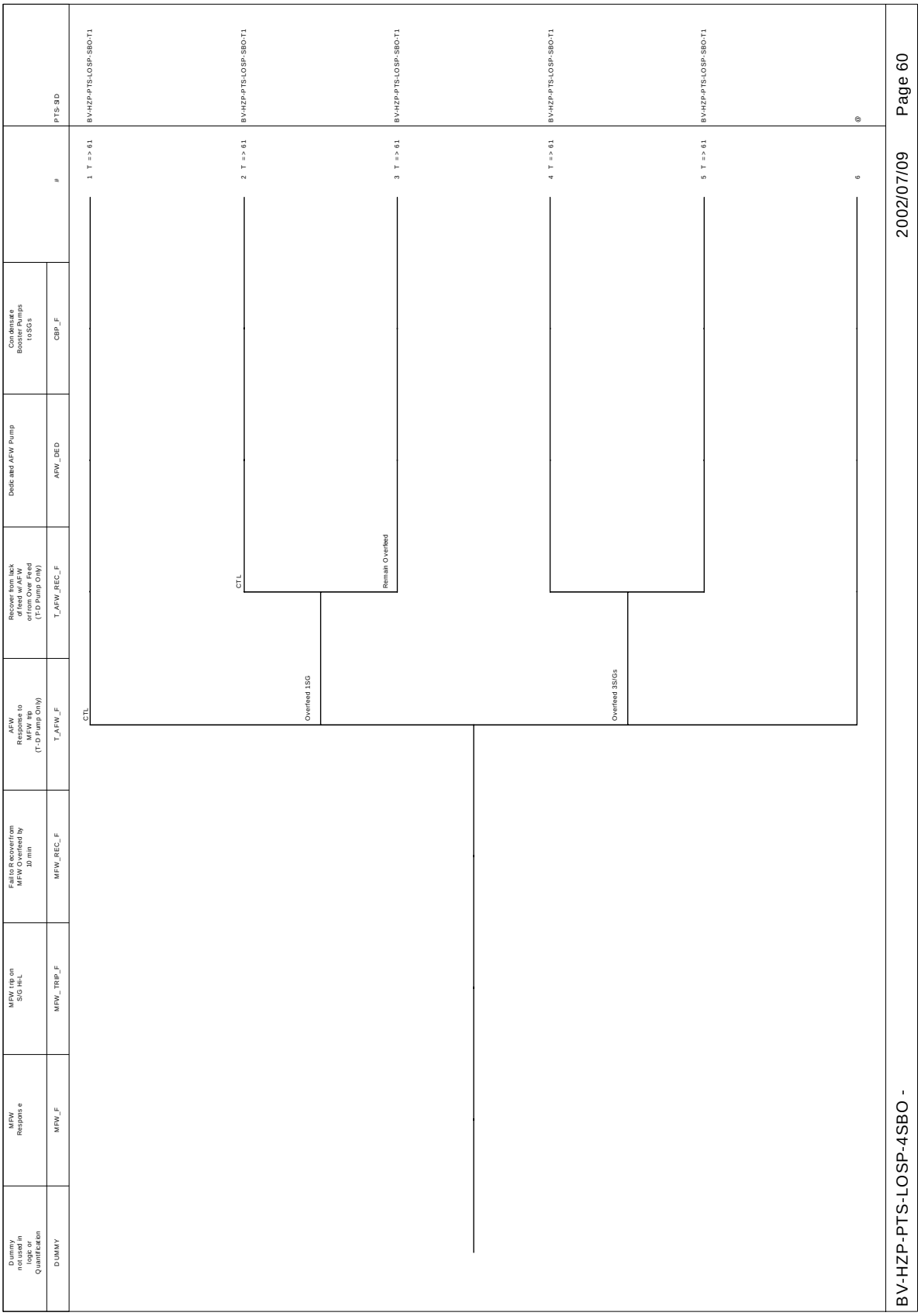

Figure 4.149. Beaver Valley -HZP-LOSP-4SBO: Loss of offsite power (station blackout)–at least one SRV initially open.

Dummy Not Used In Logic Or Quantification	HHSI/F&B Response	HHSI Recovered	RCP Trip (i.e., loss of RCS subcooling)	Secondary Cooling Recovered	Terminate HHSI Flow	Restart RCPs		
DUMMY	HHSI_INIT_F	HHSI_REC_F	RCP_TRIP	SEC_COOL_REC_F	HHSI_TERM_F	RCP_RESTART_F	#	PTS-SID
							1	

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Figure 4.150. Beaver Valley -HZP-LOSP-SBO-T1: Loss of offsite power (station blackout)–primary system intact or at least one SRV initially open (HHSI not F&B).

Dummy Not Used In Logic Or Quantification	HHSI/F&B Response	HHSI Recovered	RCP Trip (i.e., loss of RCS subcooling)	Secondary Cooling Recovered	Terminate HHSI Flow	Restart RCPs		
DUMMY	HHSI_INIT_F	HHSI_REC_F	RCP_TRIP	SEC_COOL_REC_F	HHSI_TERM_F	RCP_RESTART_F	#	PTS-SID
No CBP flow	No HPI					(Core Damage)	1	@

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Figure 4.151. Beaver Valley -HZP-LOSP-SBO-T2: Loss of offsite power (station blackout)–primary system intact or at least one SRV initially open (HHSI F&B).

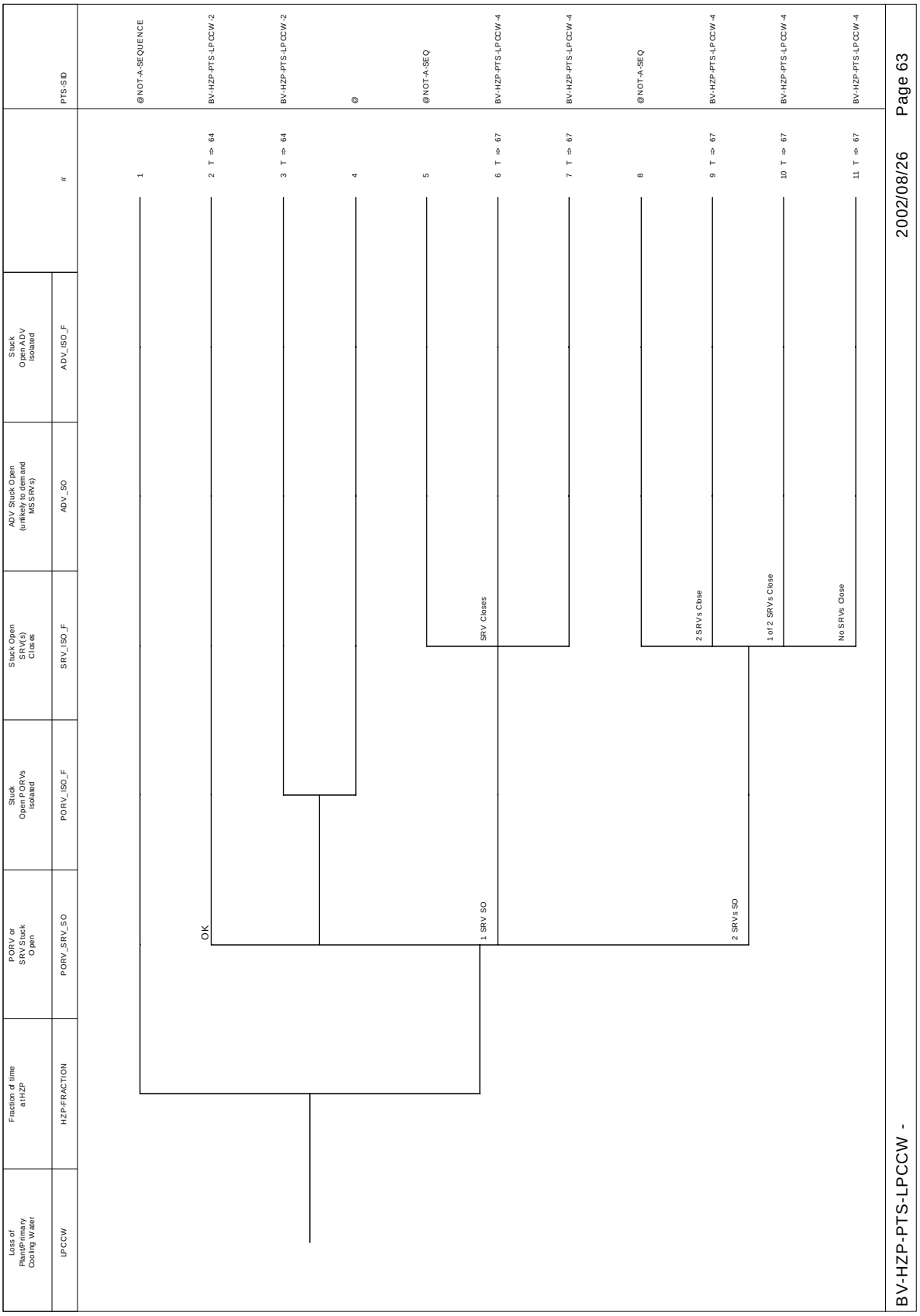

Figure 4.152. Beaver Valley -HZP-LPCCW: Loss of (reactor) primary component cooling water.

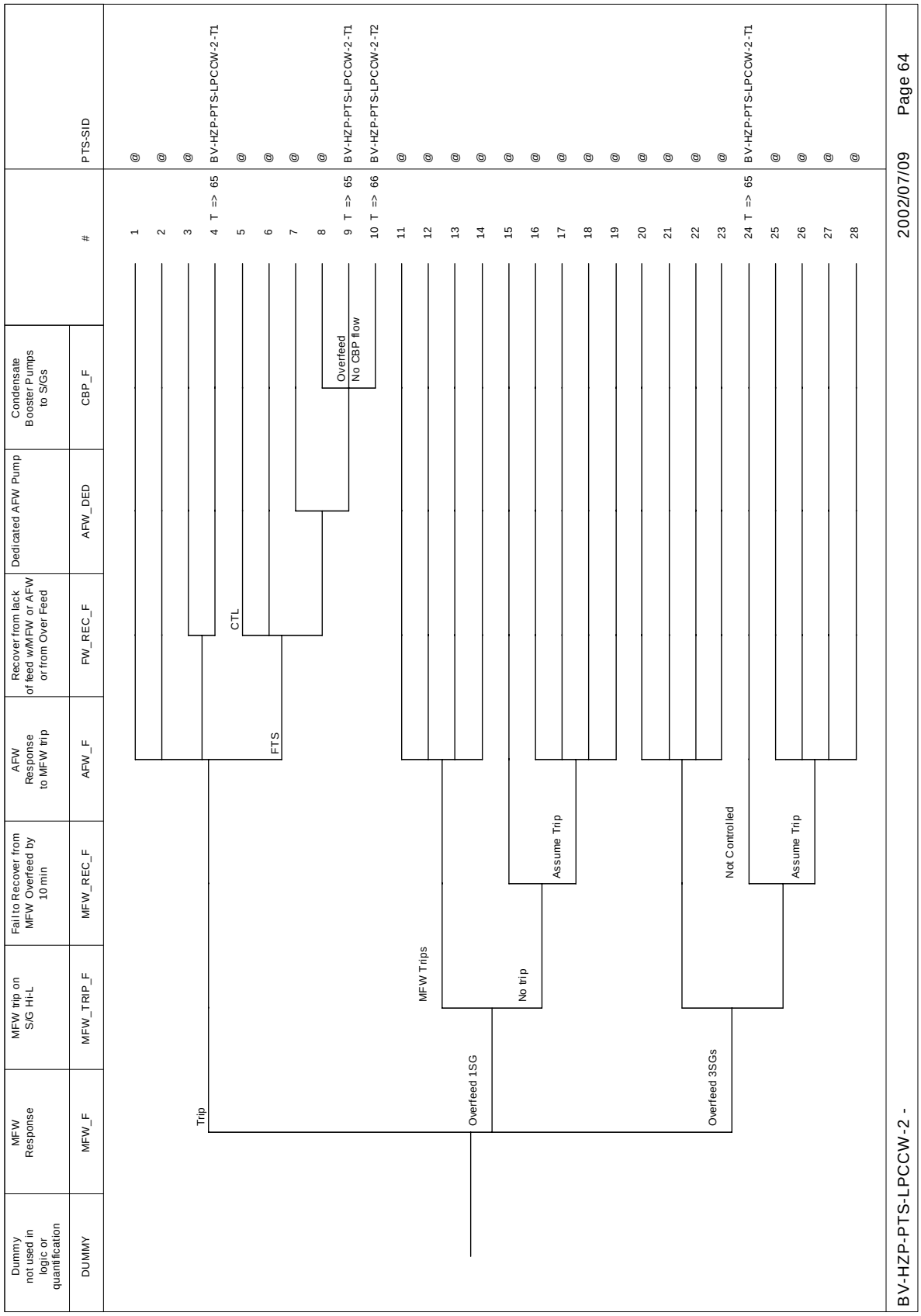

Figure 4.153. Beaver Valley -HZP-LPCCW-2: Loss of (reactor) primary component cooling water (primary system intact).

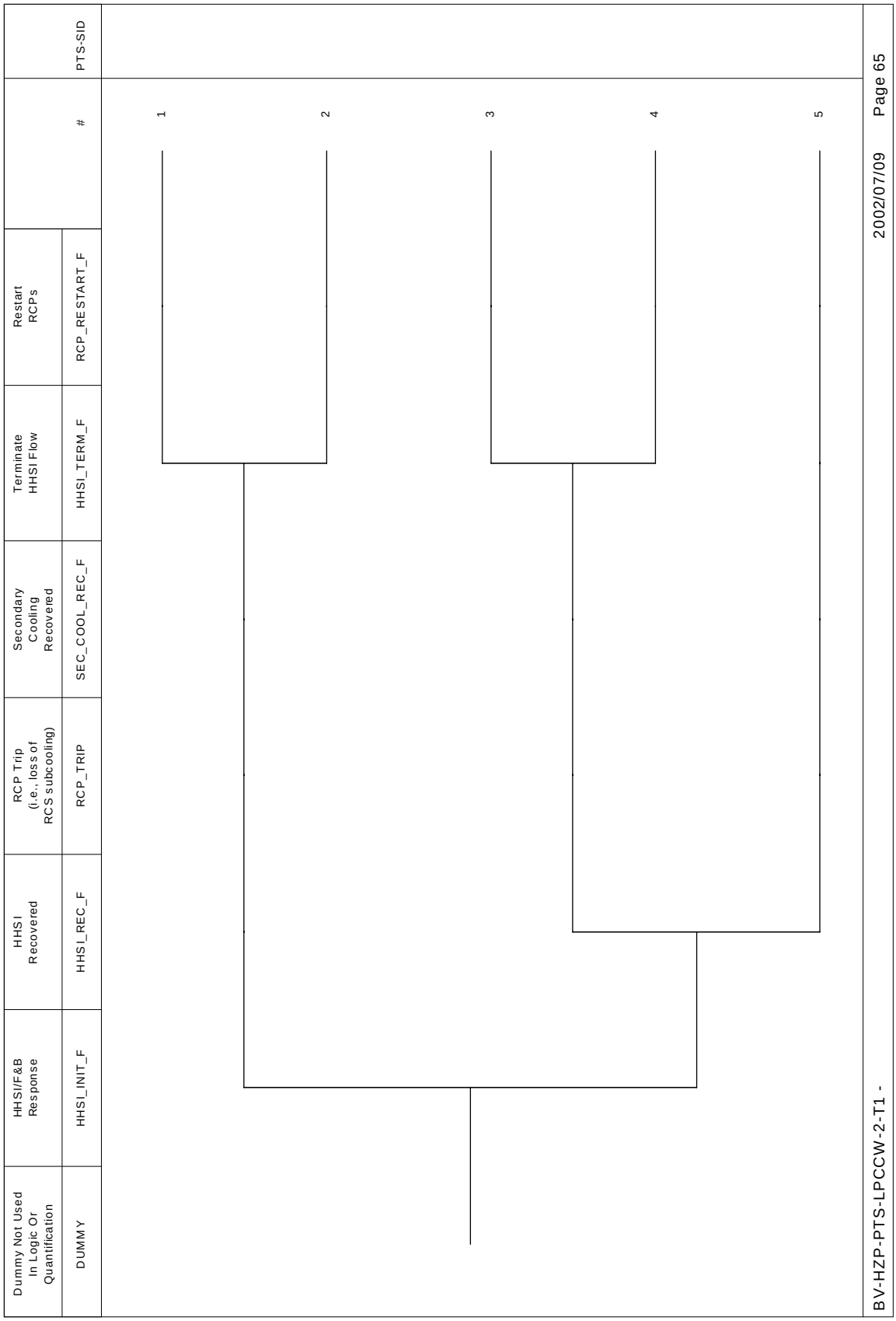

Figure 4.154. Beaver Valley -HZP-LPCCW-2-T1: Loss of (reactor) primary component cooling water–primary system intact (HHSI not F&B).

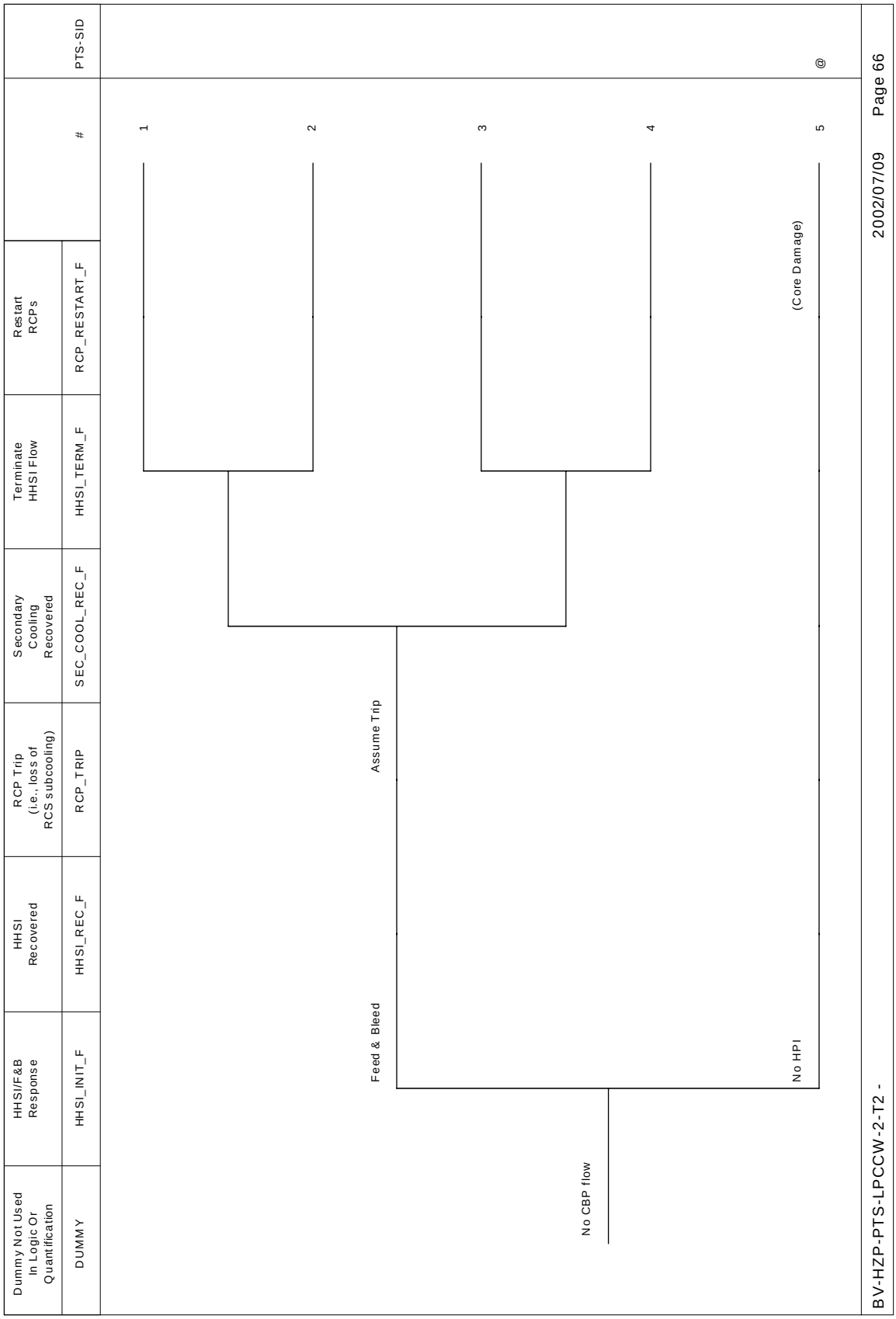

Figure 4.155. Beaver Valley -HZP-LPCCW-2-T2: Loss of (reactor) primary component cooling water–primary system intact (HHSI F&B).

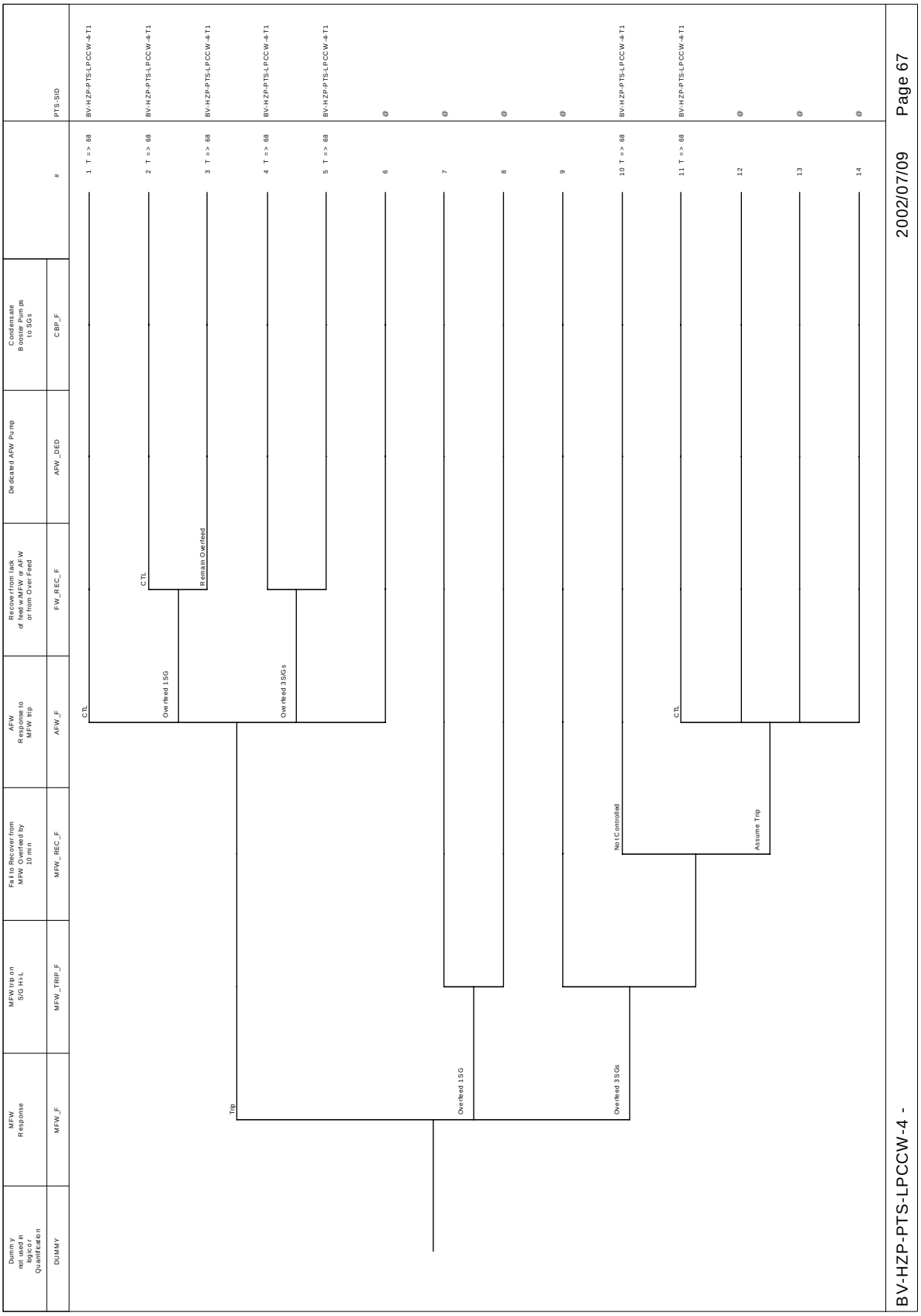

Figure 4.156. Beaver Valley -HZP-LPCCW-4: Loss of (reactor) primary component cooling water (at least one SRV initially open).

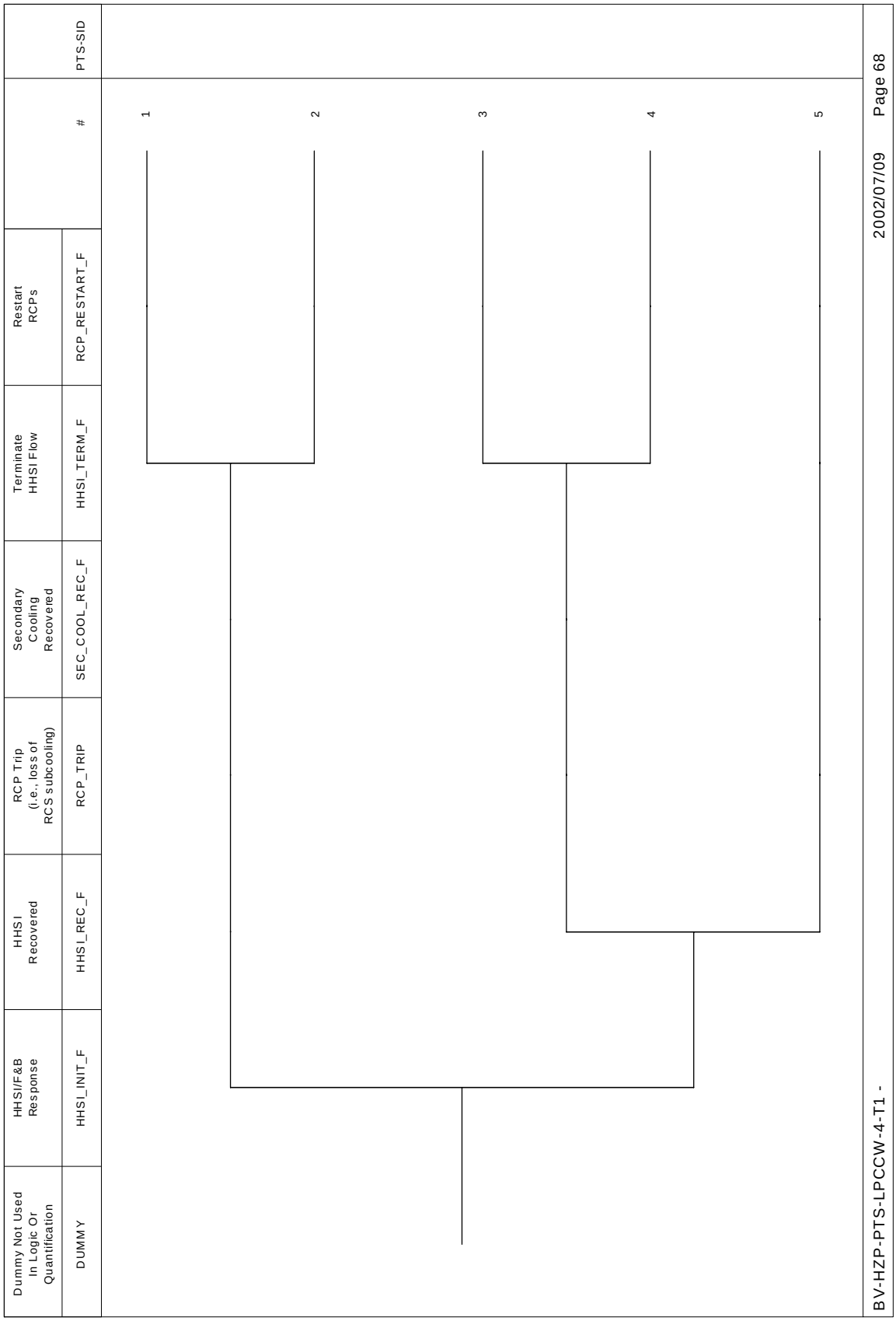

Figure 4.157. Beaver Valley -HZP-LPCCW-4-T1: Loss of (reactor) primary component cooling water–at least one SRV initially open (HHSI not F&B).

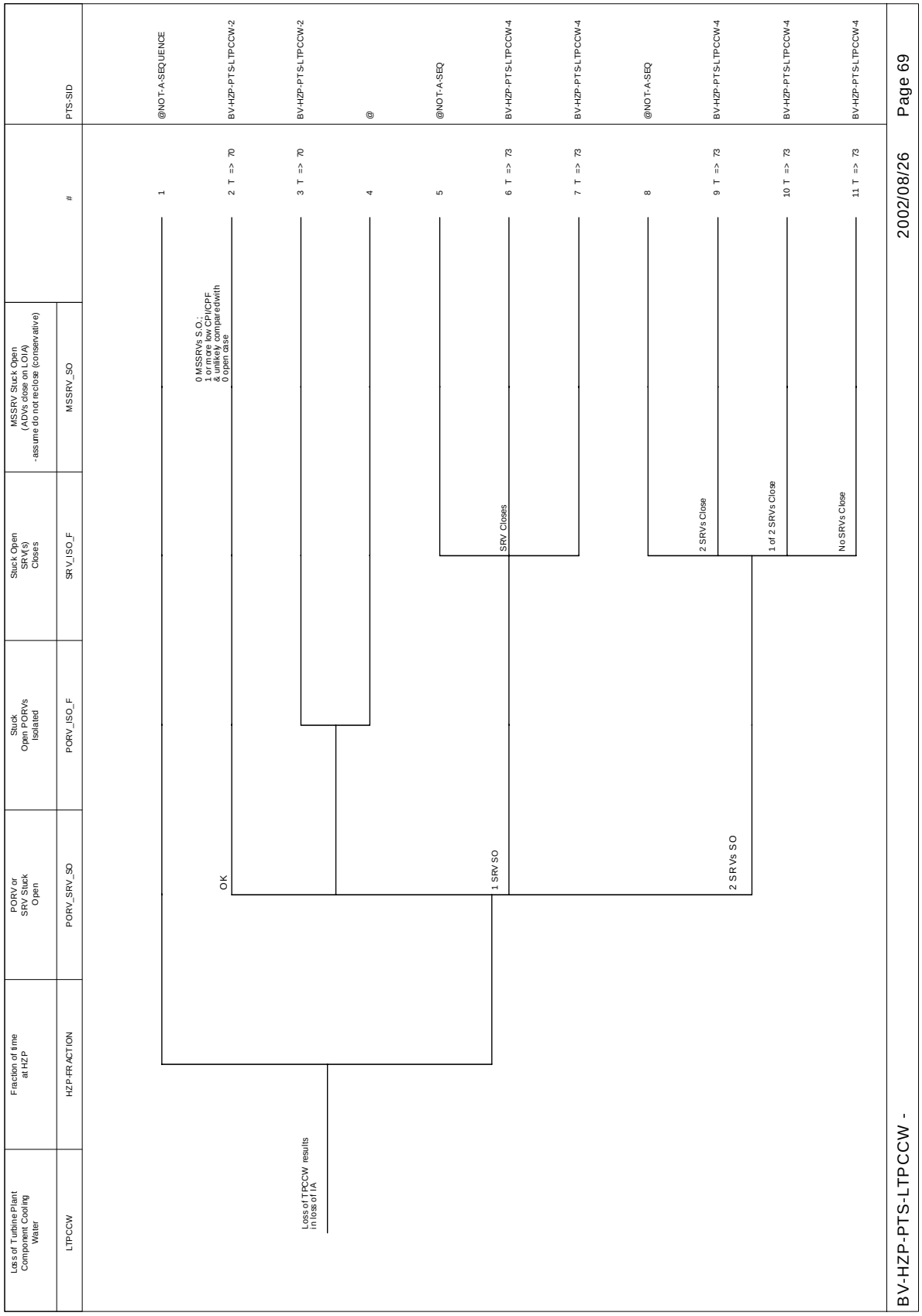

Figure 4.158. Beaver Valley -HZP-LTPCCW: Loss of turbine plant component cooling water.

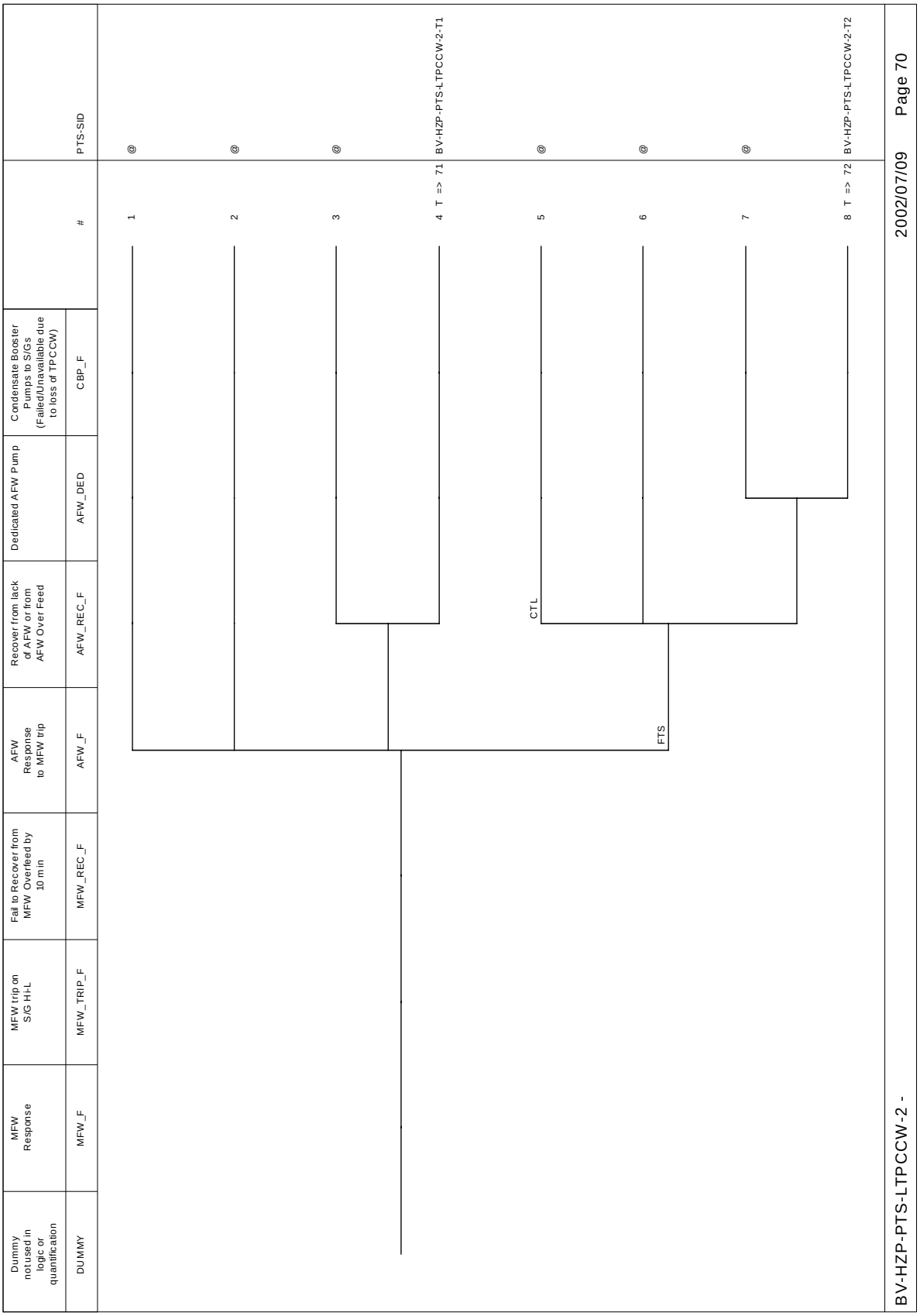

Figure 4.159. Beaver Valley -HZP-LTPCCW-2: Loss of turbine plant component cooling water (primary system intact).

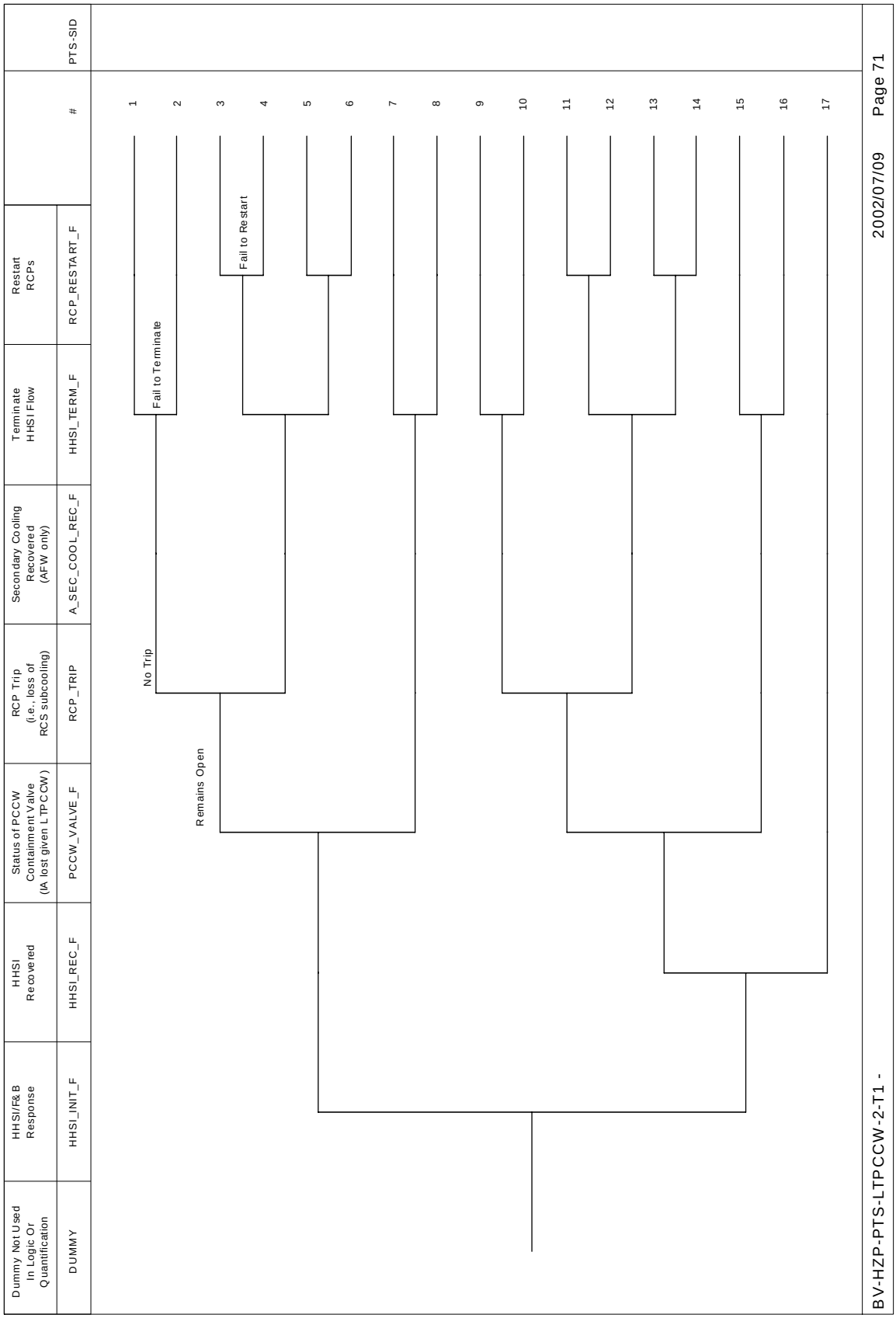

Figure 4.160. Beaver Valley -HZP-LTPCCW-2-T1: Loss of turbine plant component cooling water–primary system intact (HHSI not F&B).

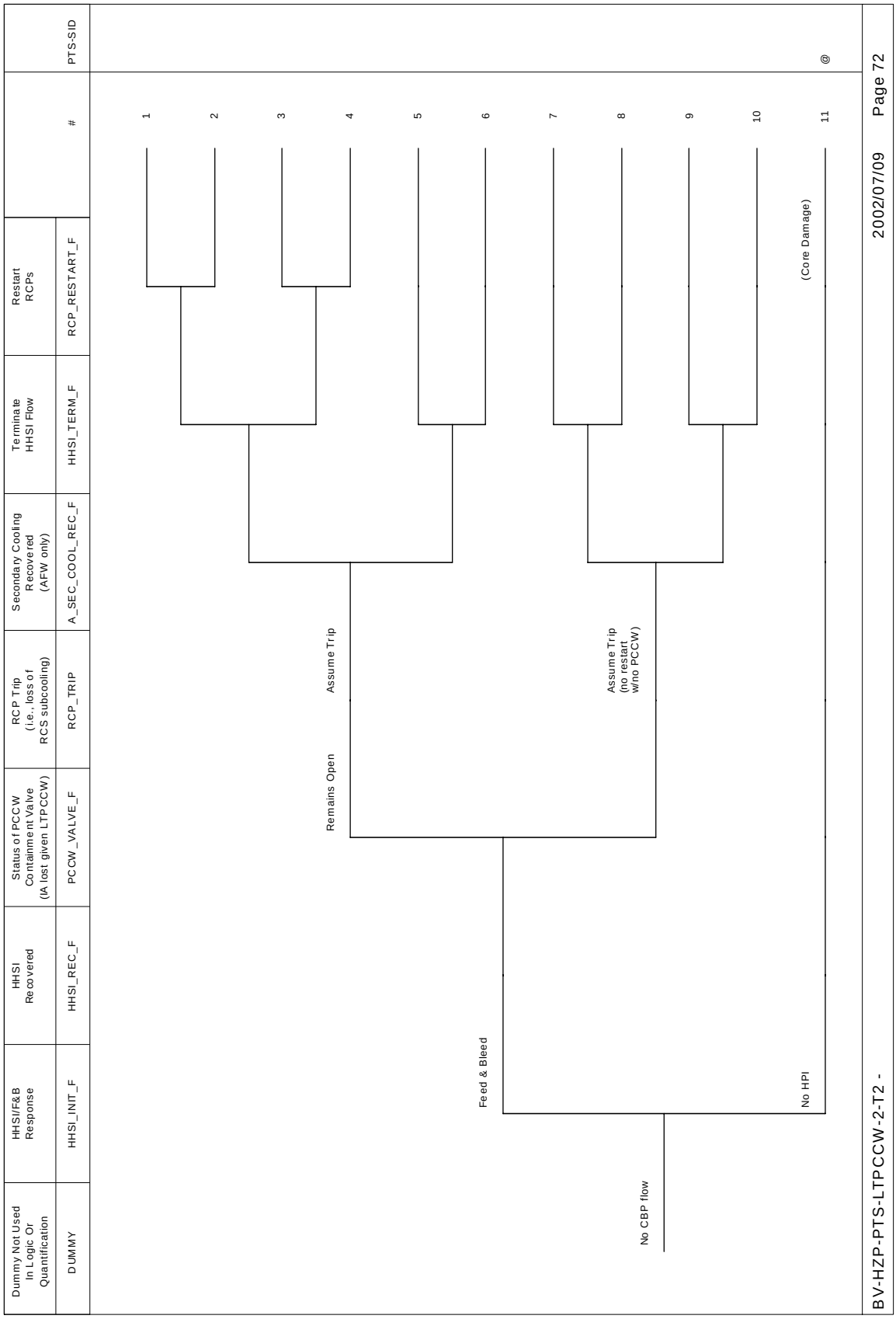

Figure 4.161. Beaver Valley -HZP-LTPCCW-2-T2: Loss of turbine plant component cooling water–primary system intact (HHSI not F&B).

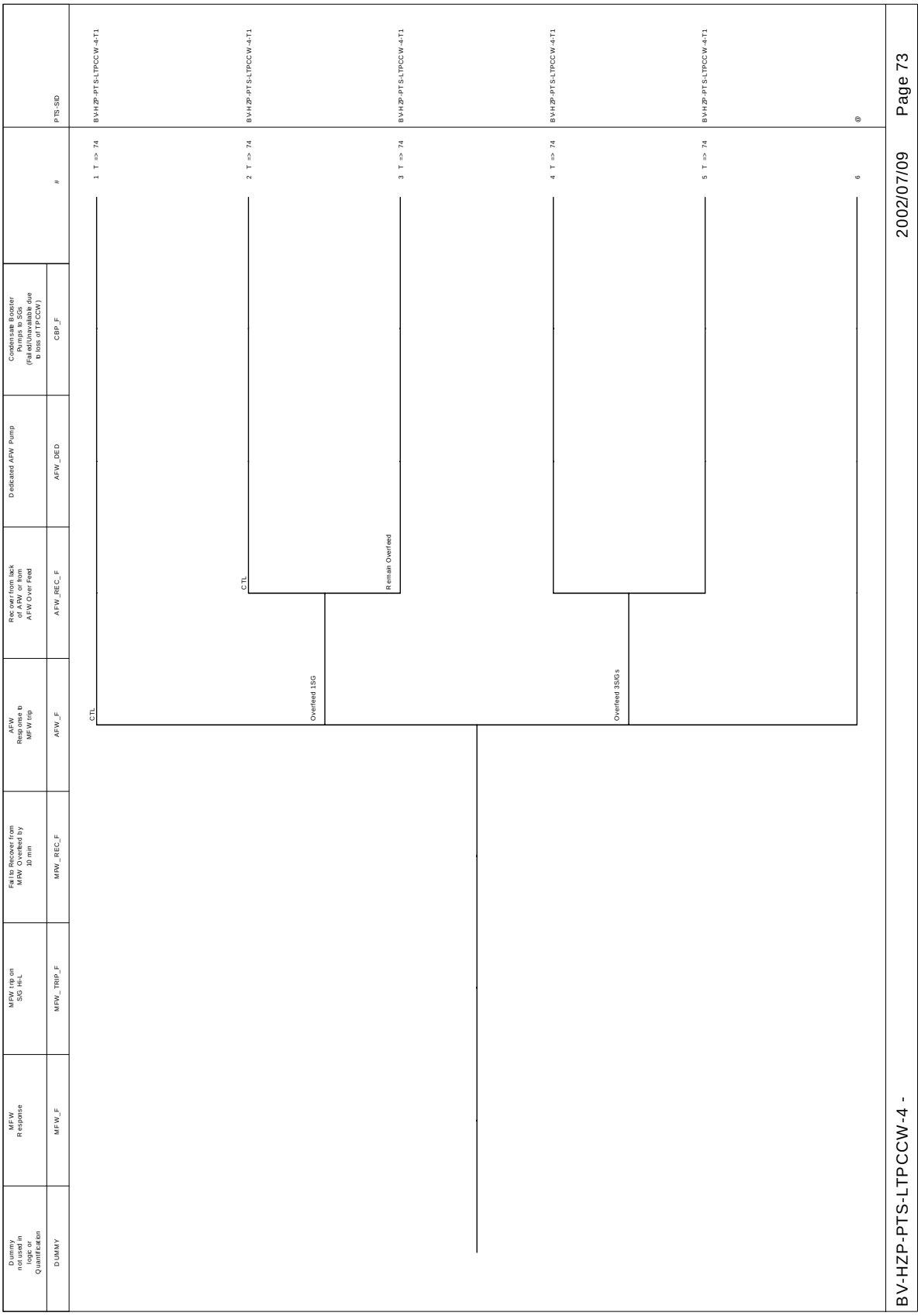

Figure 4.162. Beaver Valley -HZP-LTPCCW-4: Loss of turbine plant component cooling water (at least one SRV initially open).

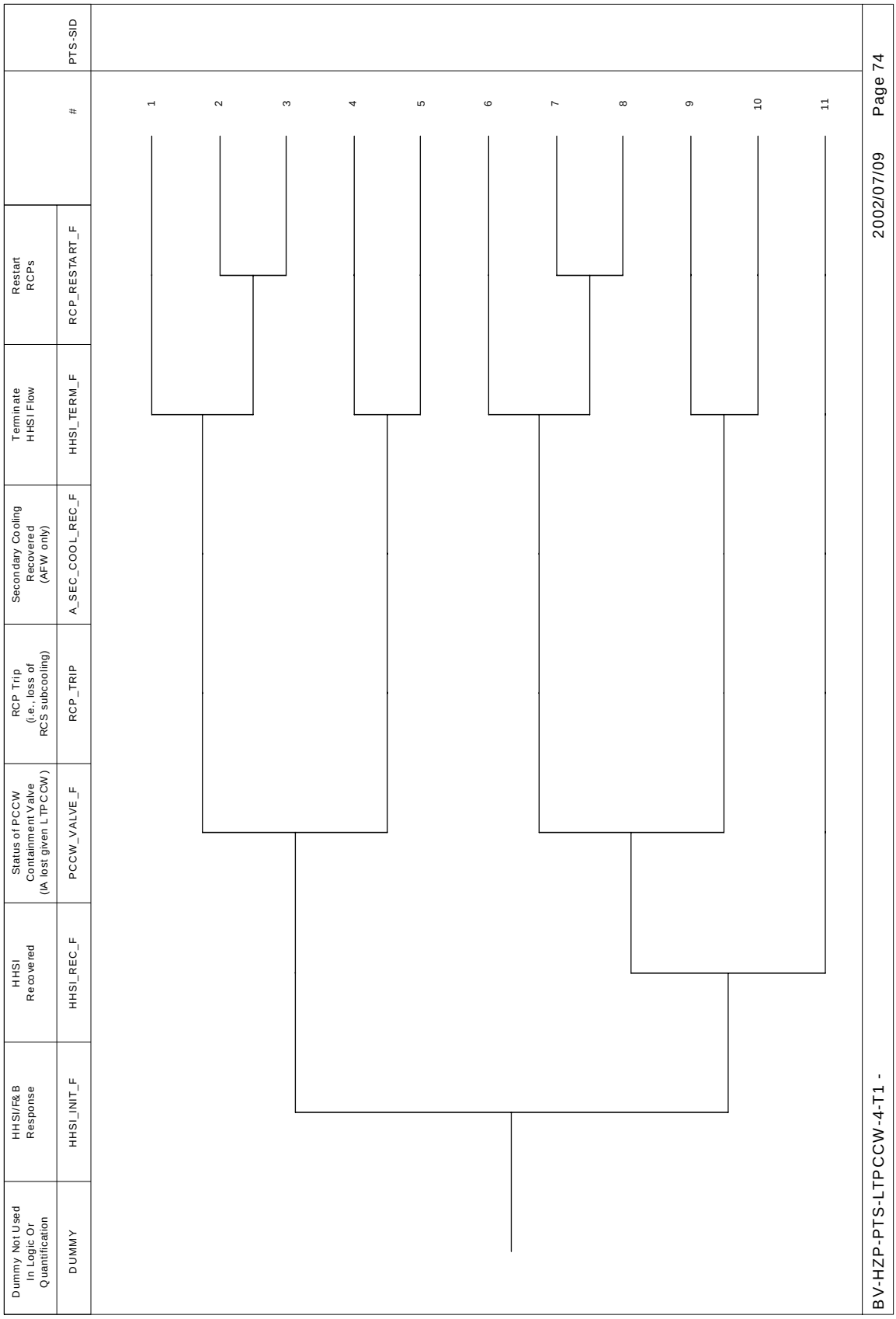

Figure 4.163. Beaver Valley -HZP-LTPCCW-4-T1: Loss of turbine plant component cooling water–at least one SRV initially open (HHSI not F&B).

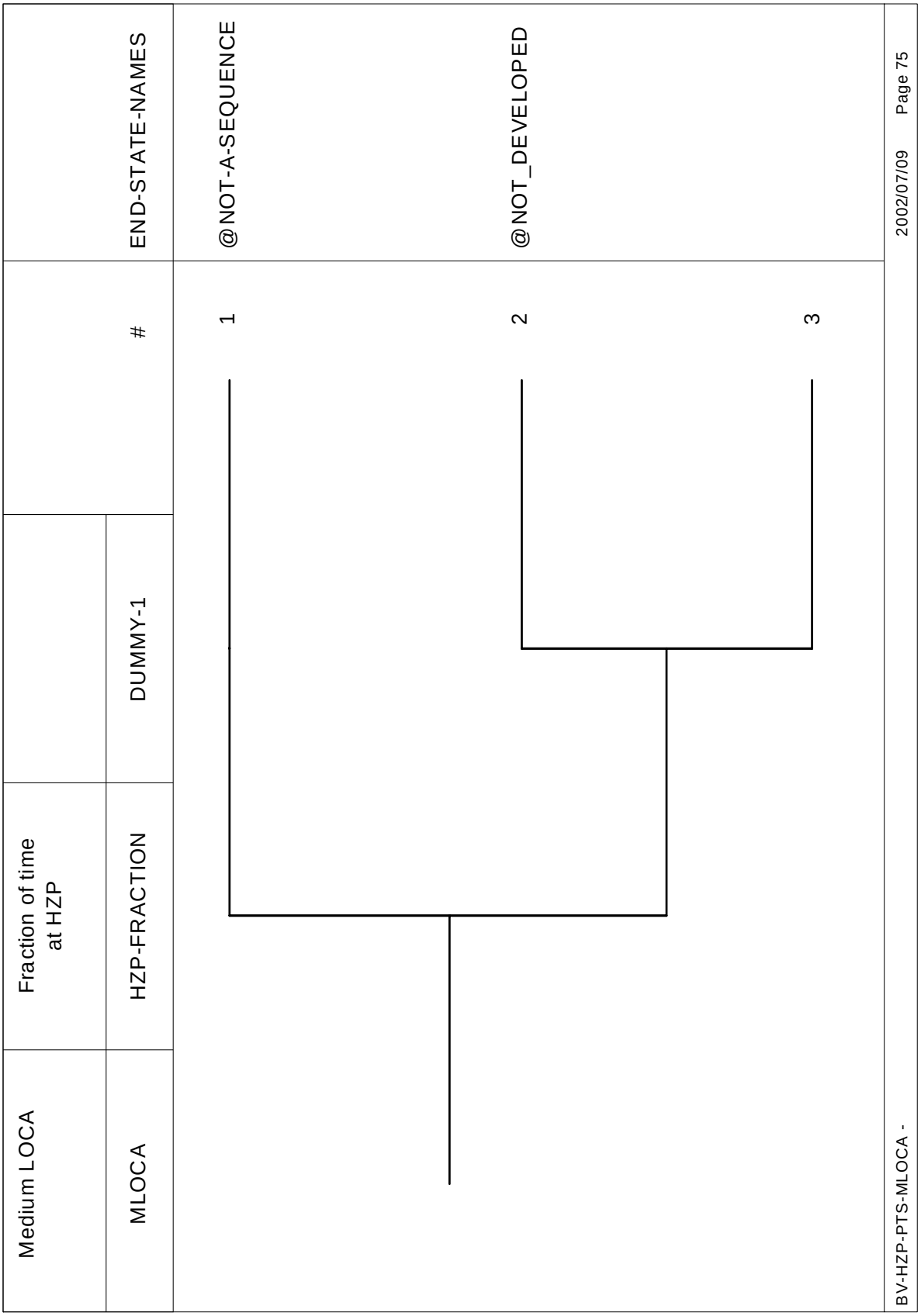

Figure 4.164. Beaver Valley -HZP-MLOCA: Medium LOCA.

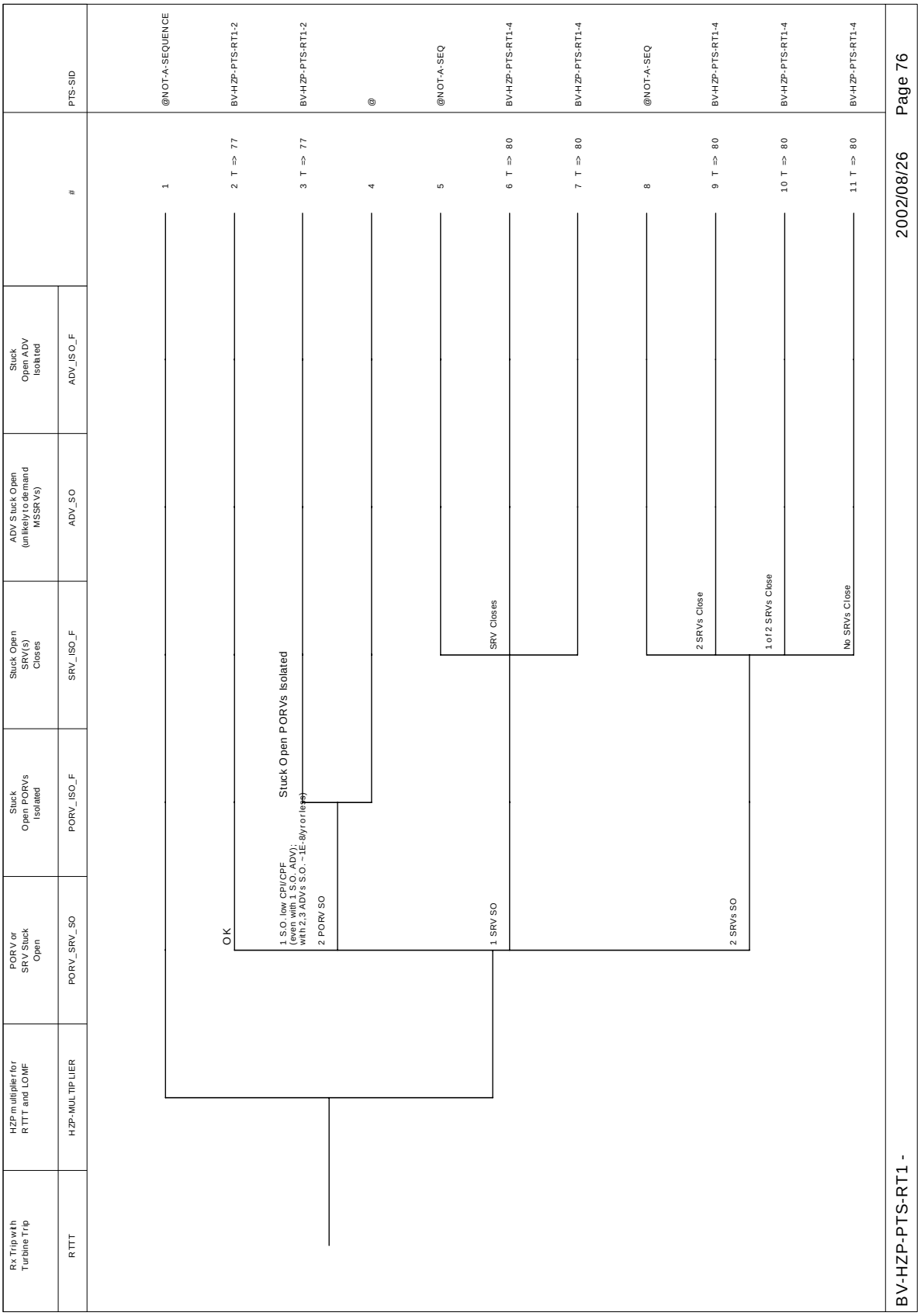

Figure 4.165. Beaver Valley -HZP-RT1: Reactor trip with turbine trip.

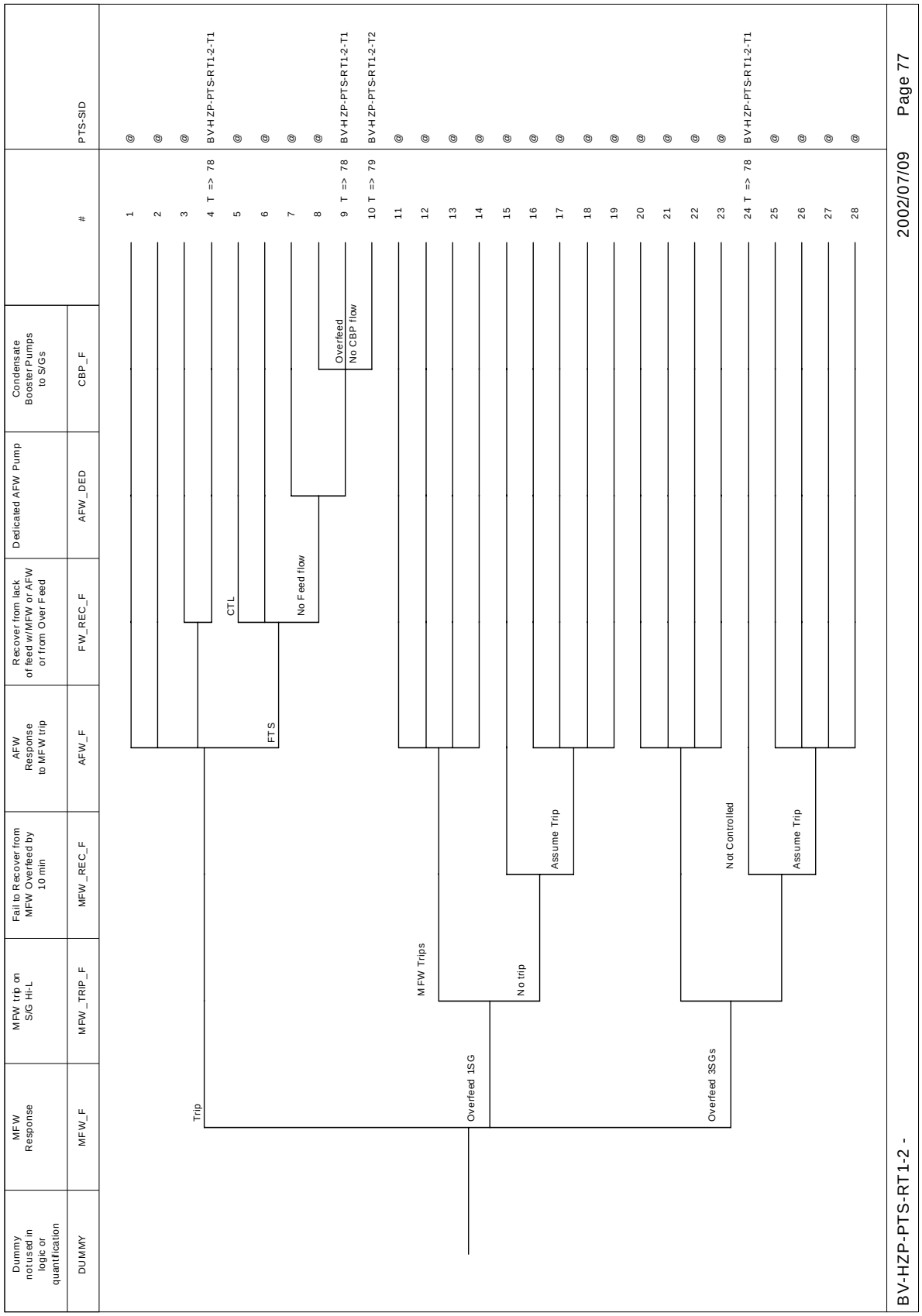

Figure 4.166. Beaver Valley -HZP-RT1-2: Reactor trip with turbine trip (primary system intact).

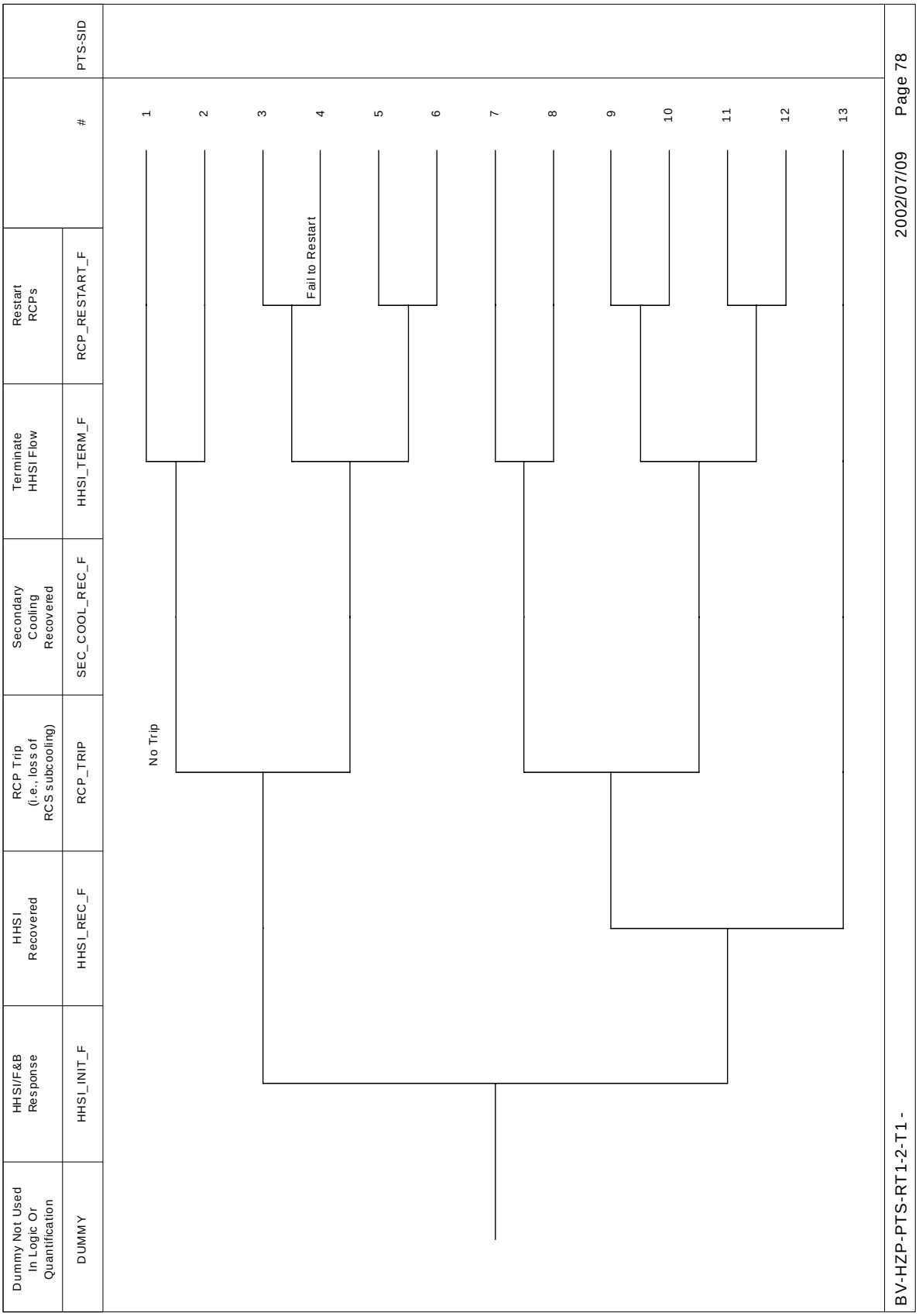

Figure 4.167. Beaver Valley -HZP-RT1-2-T1: Reactor trip with turbine trip–primary system intact (HHSI not F&B).

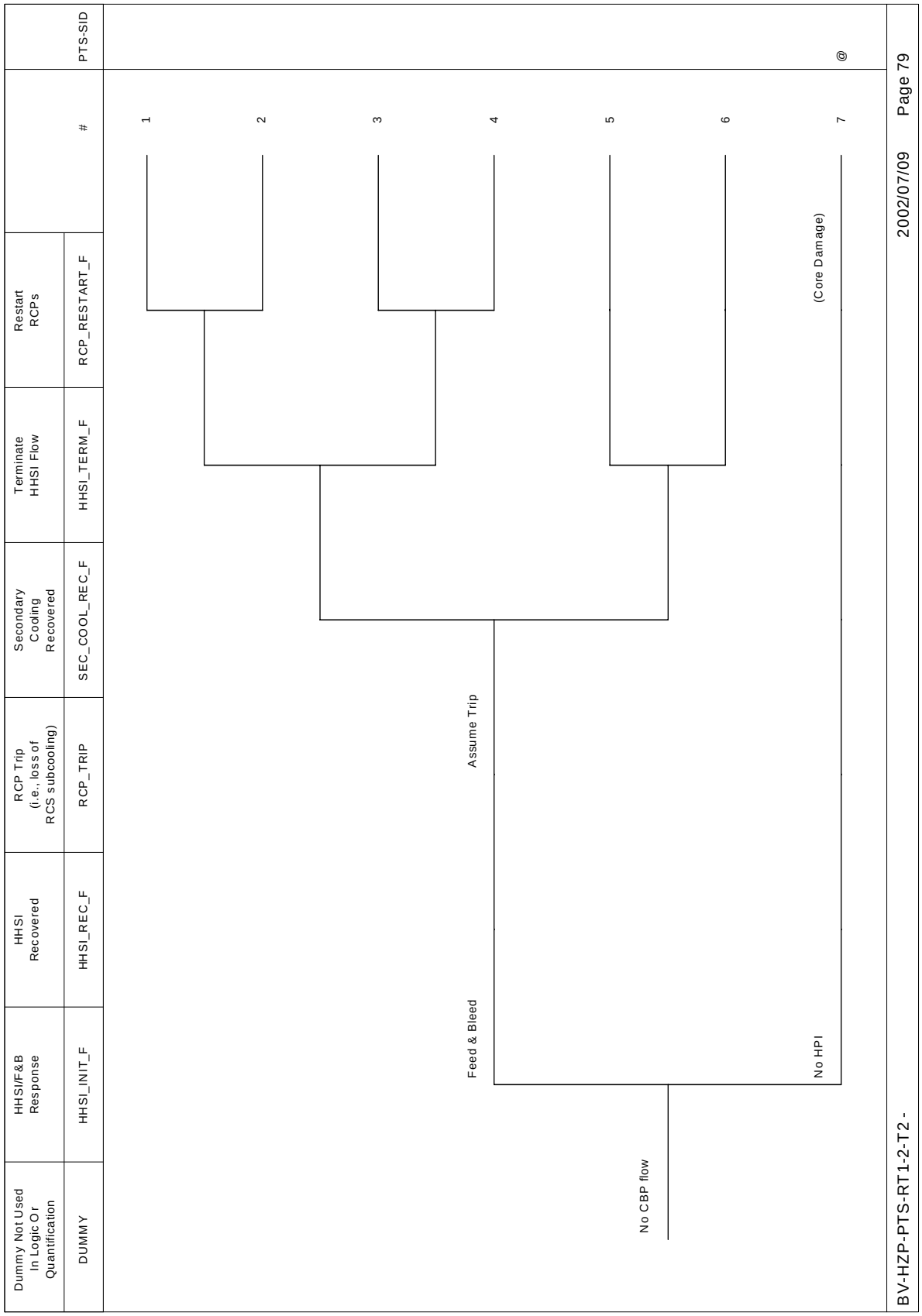

Figure 4.168. Beaver Valley -HZP-RT1-2-T2: Reactor trip with turbine trip–primary system intact (HHSI F&B).

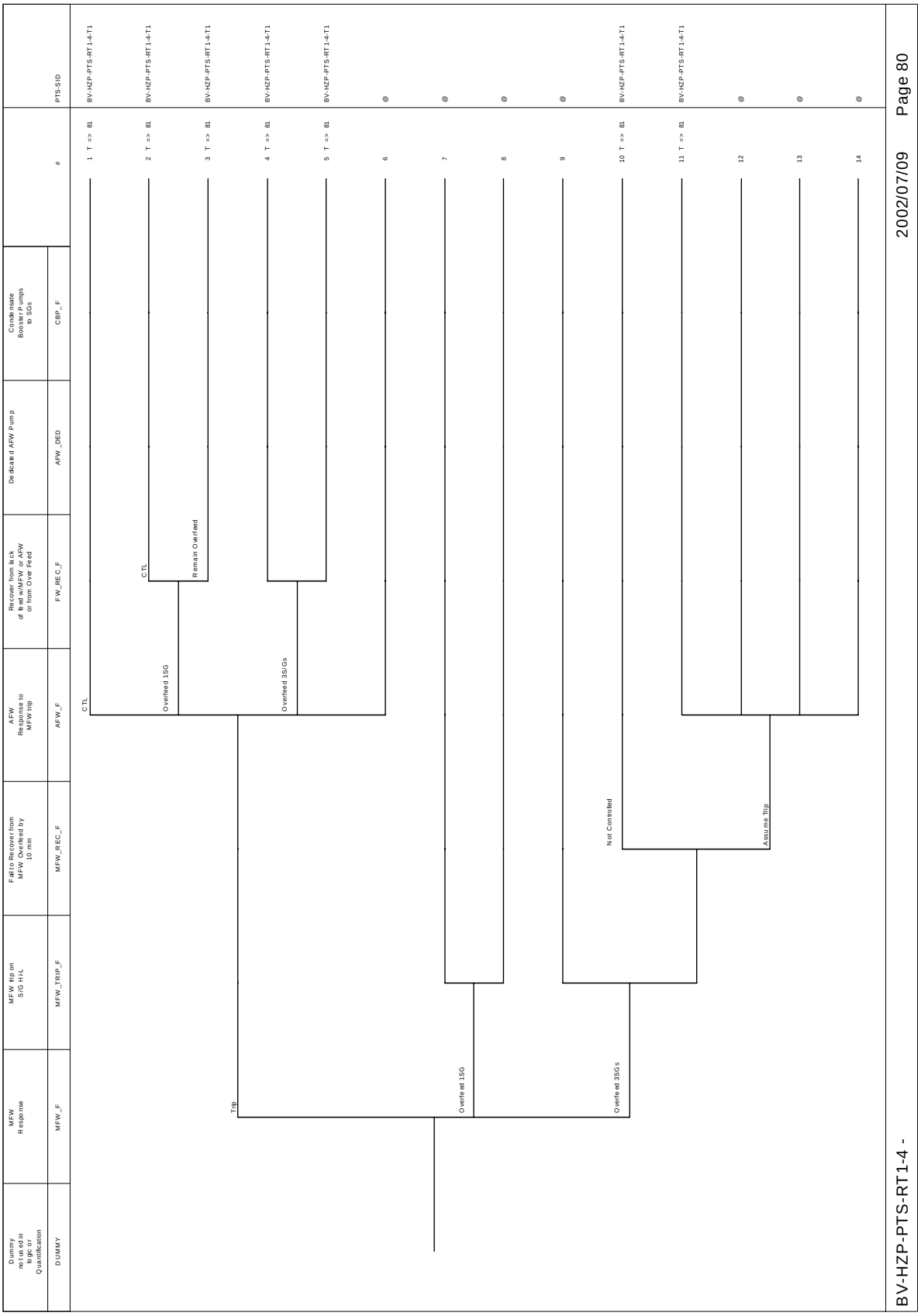

Figure 4.169. Beaver Valley -HZP-RT1-4: Reactor trip with turbine trip (at least one SRV initially open.

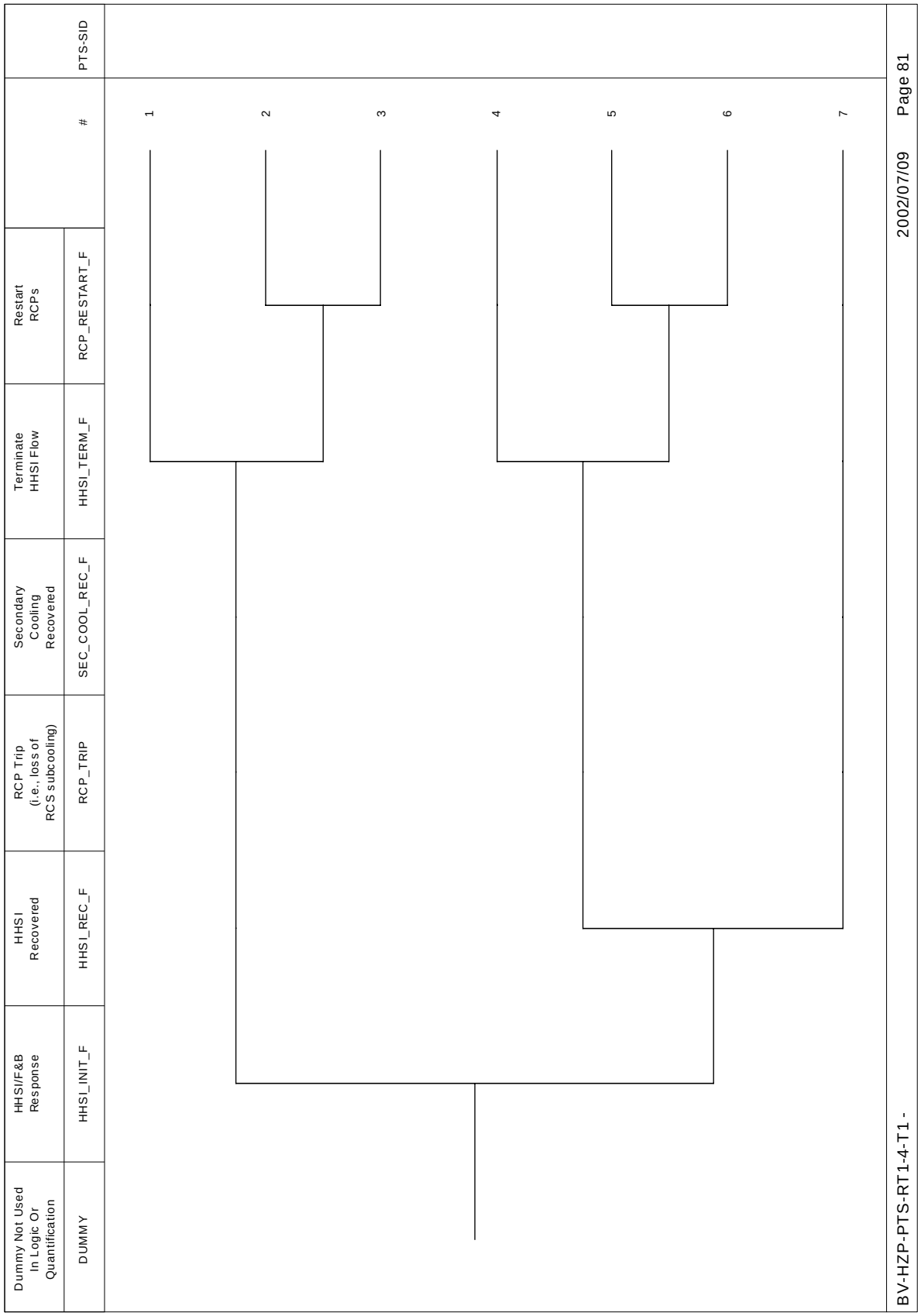

Figure 4.170. Beaver Valley -HZP-RT1-4-T1: Reactor trip with turbine trip–at least one SRV initially open (HHSI not F&B).

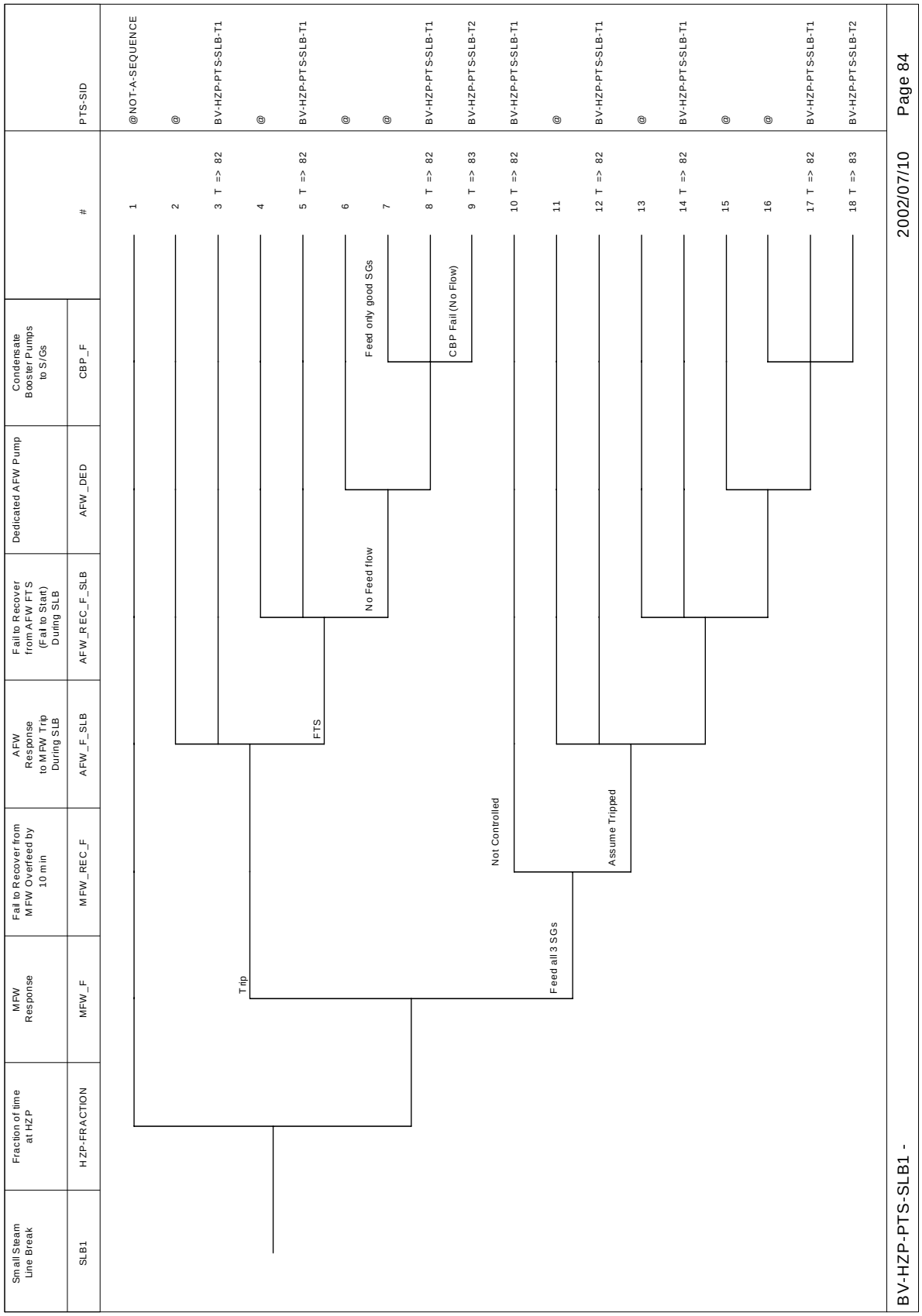

Figure 4.171. Beaver Valley -HZP-SLB1: Small steam line break.

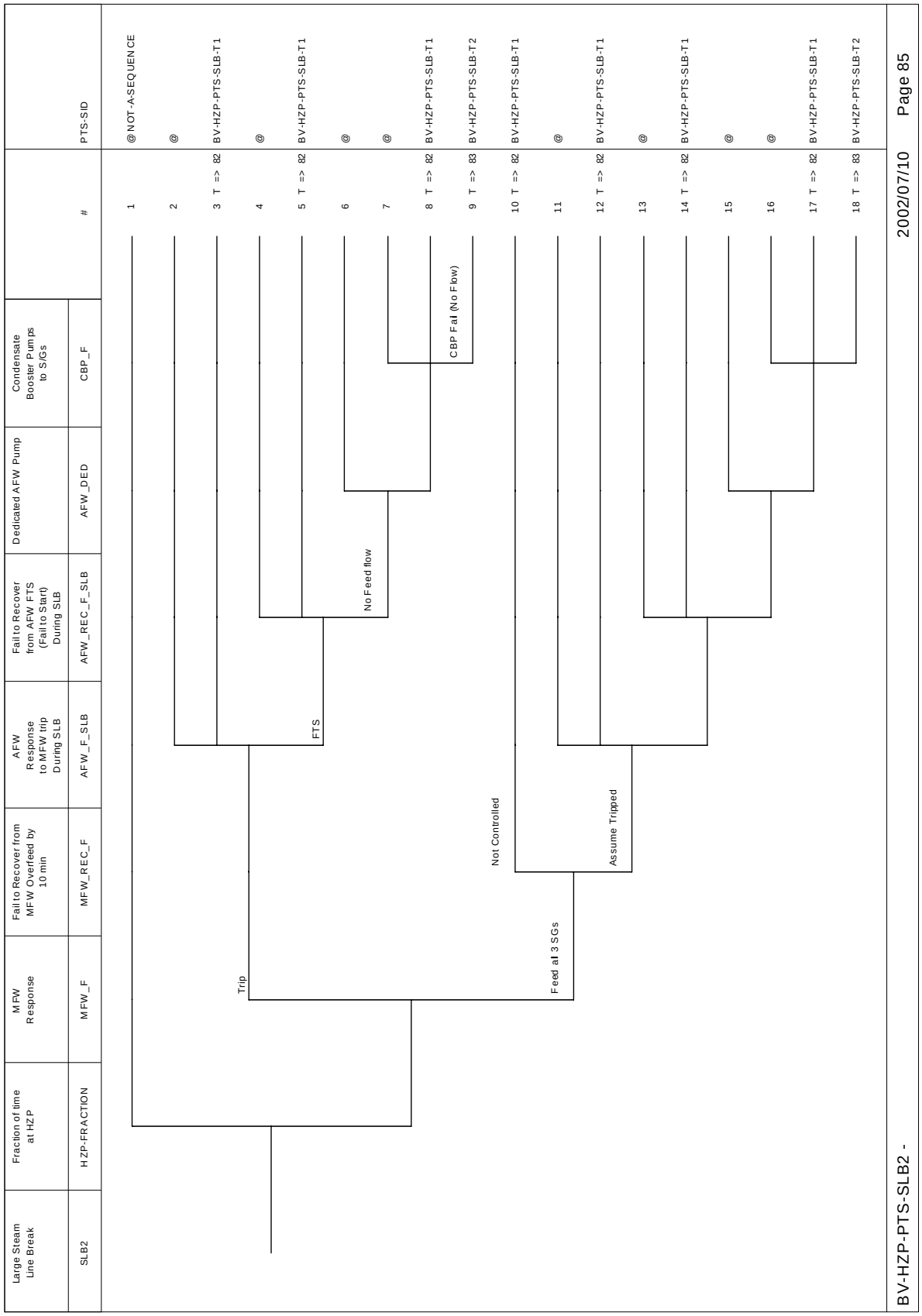

Figure 4.172. Beaver Valley -HZP-SLB2: Large steam line break.

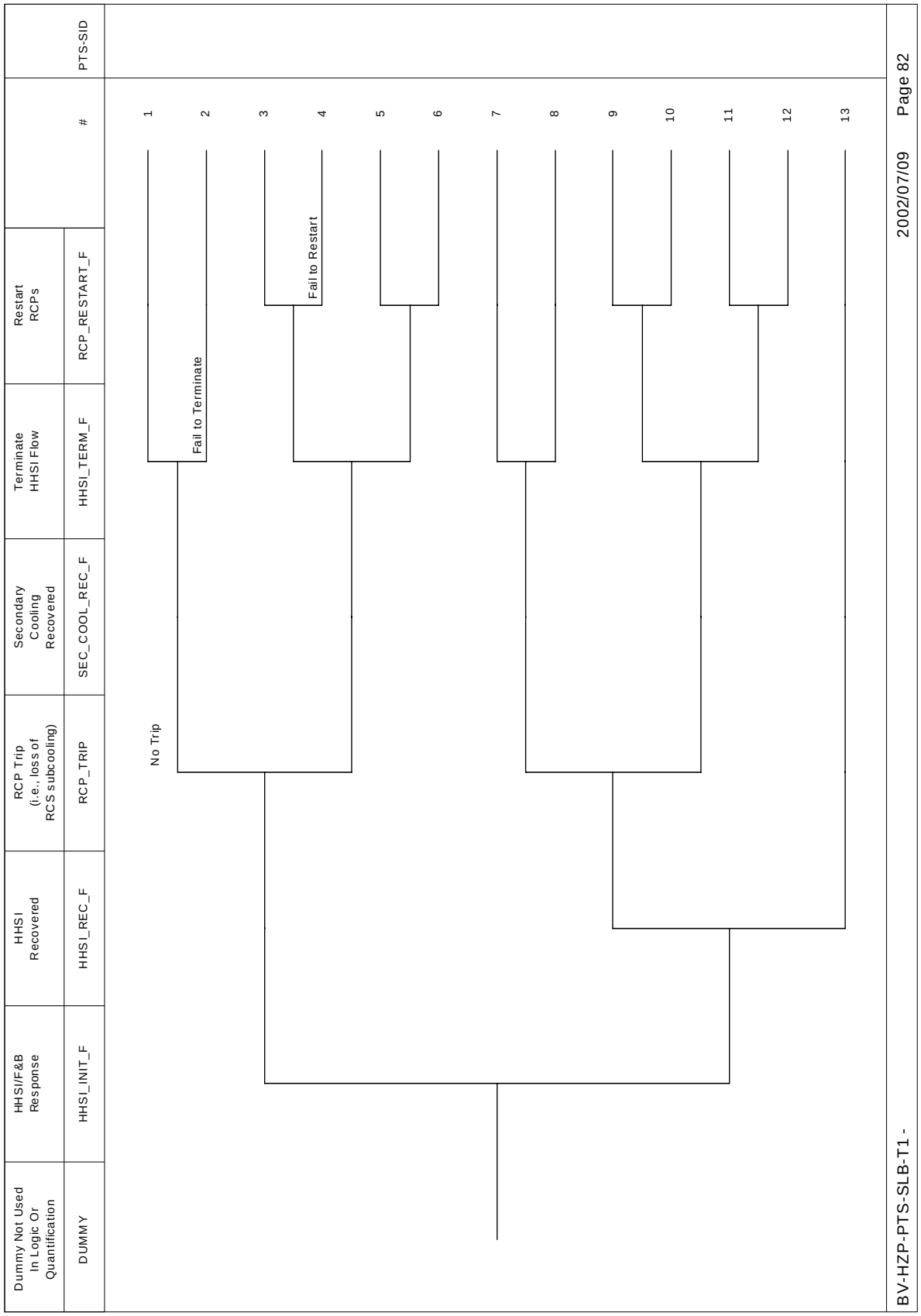

Figure 4.173. Beaver Valley -HZP-SLB-T1: Steam line break (HHSI not F&B).

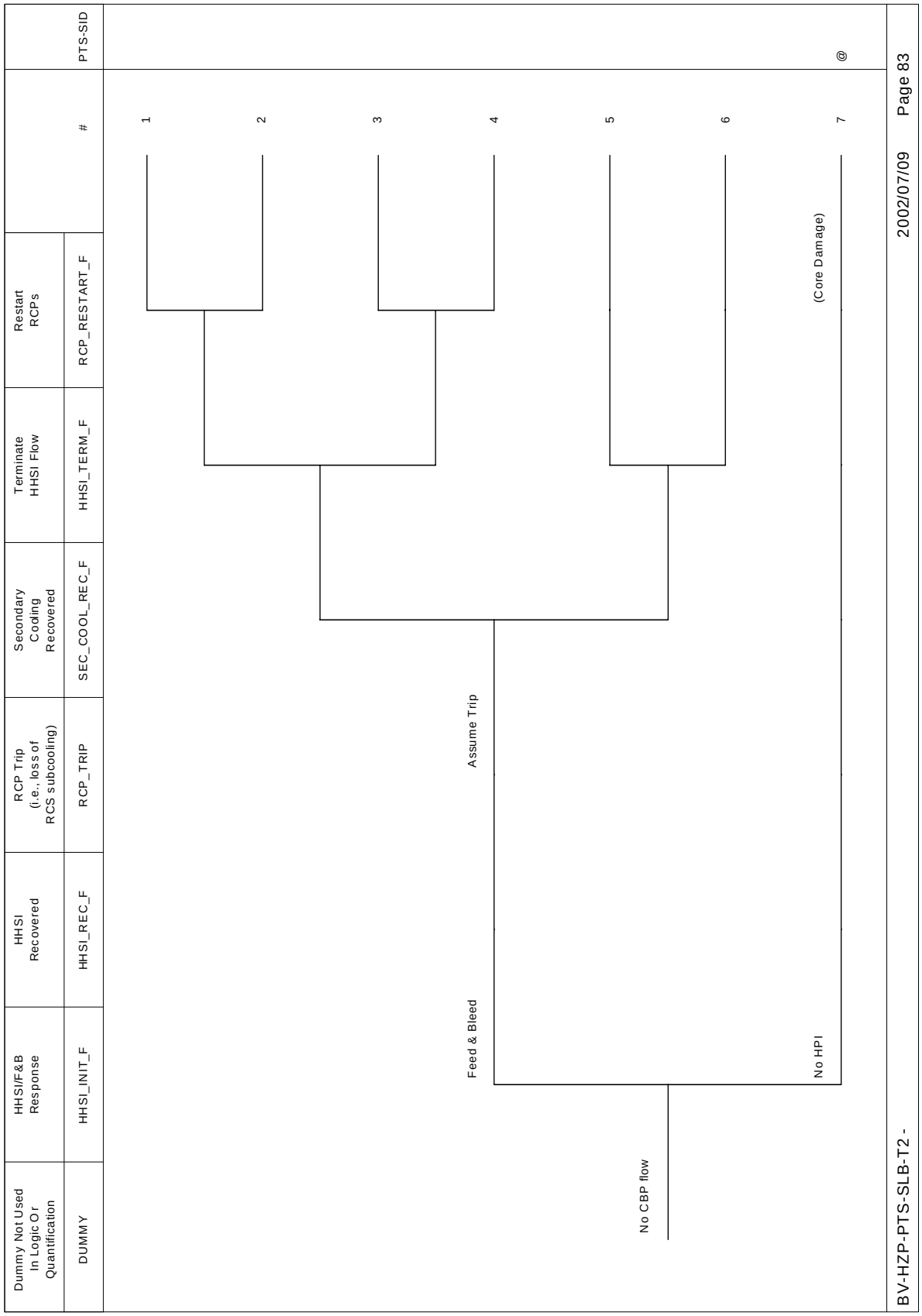

Figure 4.174. Beaver Valley -HZP-SLB-T2: Steam line break (HHSI F&B).

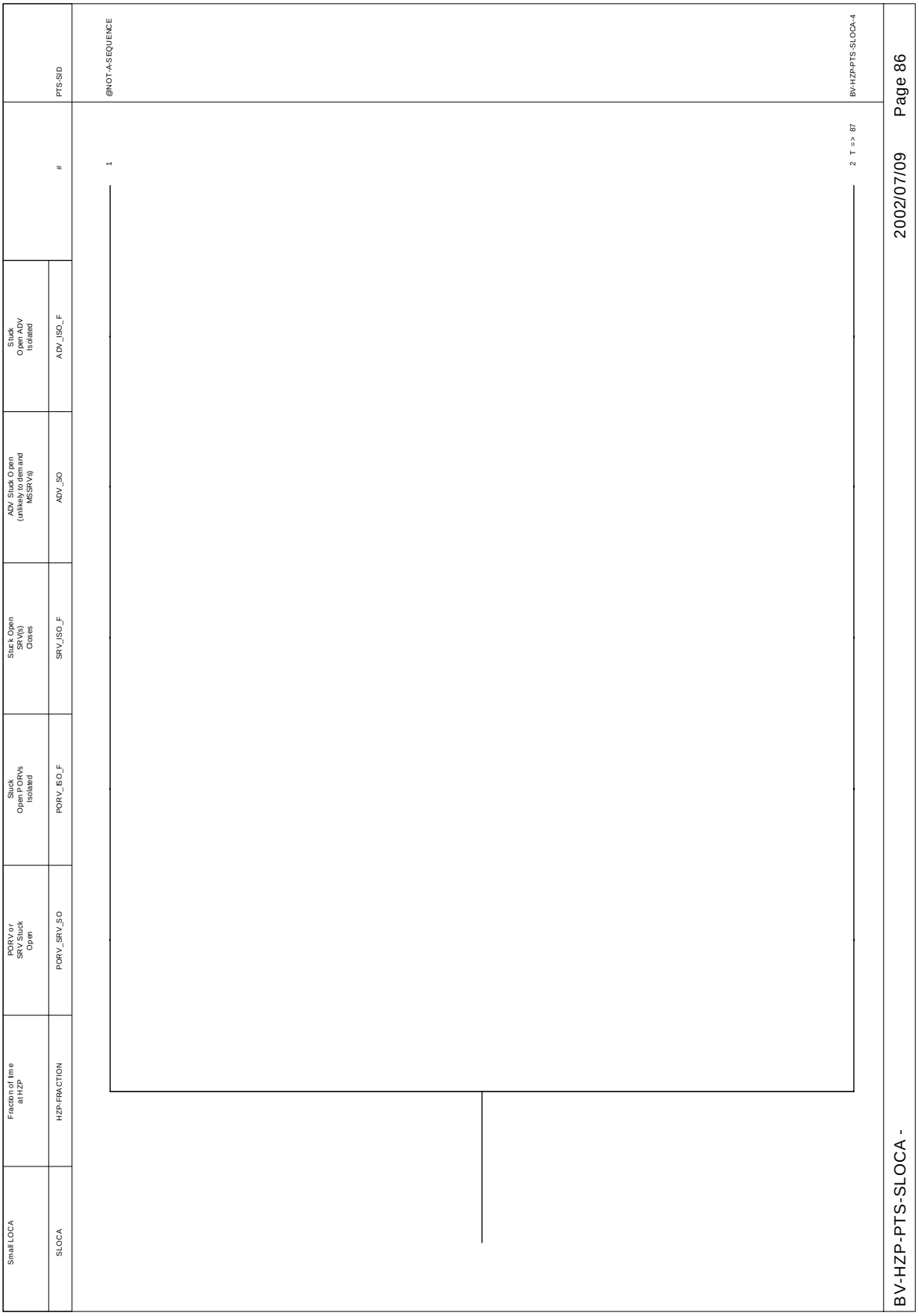

Figure 4.175. Beaver Valley -HZP-SLOCA: Small LOCA.

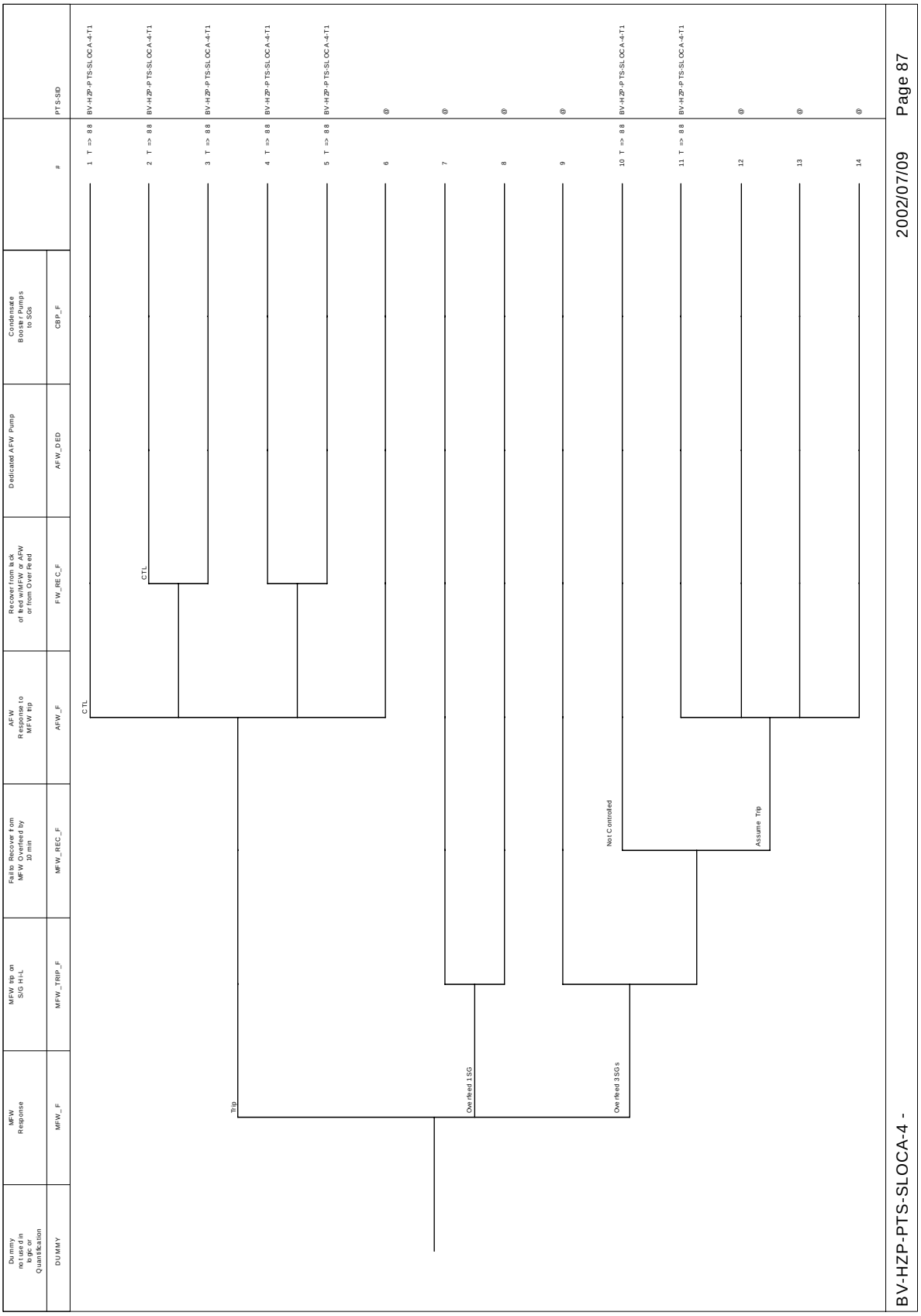

Figure 4.176. Beaver Valley -HZP-SLOCA-4: Small LOCA (primary system open).

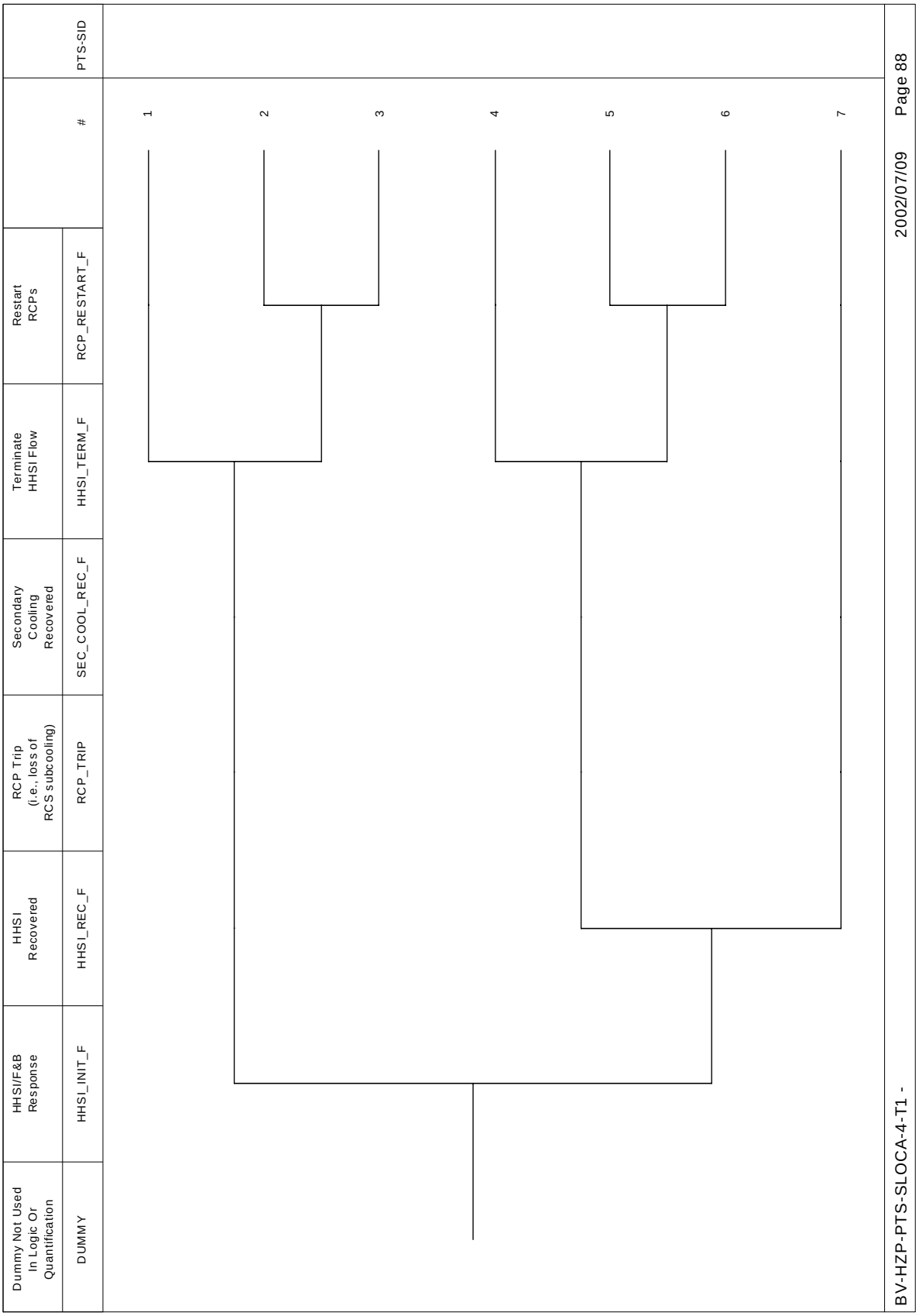

Figure 4.177. Beaver Valley -HZP-SLOCA-4-T1: Small LOCA–primary system open (HHSI not F&B).

Table 4.1. Event tree linkage rules for Beaver Valley power or HZP event trees.

```
| ET rules for BV model
| Last modified August 23, 2002, 11:50 am

| --- Rule for AC Bus (AC_BUS) Top ----------------------------------------

| This rule splits the probability of AC bus failure equally between the four
| AC buses (note that the event /RED gets replaced by RED in the recovery
| rules applied later)

| Top branch - 120V AC Red Bus fails
| 1st failure branch - 120V AC White Bus fails
| 2nd failure branch - 120V AC Blue Bus fails
| 3rd failure branch - 120V AC Yellow Bus fails

if always then
  /AC_BUS    = RED;
   AC_BUS[1] = WHITE;
   AC_BUS[2] = BLUE;
   AC_BUS[3] = YELLOW;
endif
| ---------------------------------------------------------------------

| --- Rule for DC Bus (DC_BUS) Top ----------------------------------------
| This rule splits the probability of DC bus failure equally between the two
| DC buses (note that the event /ORANGE gets replaced by ORANGE in the
| recovery rules applied later)

if always then
  /DC_BUS = ORANGE;
   DC_BUS = PURPLE;
endif
| ---------------------------------------------------------------------

| --- Rule for DG A (DG_A) Top ---------------------------------------------
| No rule required for failure of DG_A.  It is a binary question
| establishing the status of DG_A with no variations due to prior failures.
| ---------------------------------------------------------------------

| --- Rule for DG B (DG_B) Top ---------------------------------------------
| No rule required for failure of DG_B.  It is a binary question
| establishing the status of DG_B with no variations due to prior failures.
| ---------------------------------------------------------------------

| --- Rule for DG B given DG A (DG_B_GIVEN_A) Top --------------------------
| No rule required for failure of DG_B given failure of DG_A.  It is a
```

Table 4.1. Event tree linkage rules for Beaver Valley power or HZP event trees.

```
| binary question establishing the status of DG_B given DG_A with no
| variations due to prior failures.
| ---------------------------------------------------------------------

| --- Rule for primary-side pressure control (PORV_SRV_SO_ORGE) Top --------
| Top branch - no open primary-side valves
| 1st failure branch - stuck open PORV
| 2nd failure branch - stuck open SRV
| Loss of 125V DC Purple prohibits 1 PORV from opening
| Loss of 125V DC Orange prohibits 2 PORVs from opening
| (Remember, /ORANGE get replaced with ORANGE in the recovery rules
| applied later, so cannot have 2 PORVs stuck open.)
|   NOTE:  Logic used to substitute for case where AC Blue Bus lost,
|   prohibiting 2 PORVs from opening.

if always then
   /PORV_SRV_SO_ORGE      = PORV-2-FT;
   PORV_SRV_SO_ORGE[1]   = SRV_SO;
   PORV_SRV_SO_ORGE[2]   = SRV_SO_2;
endif
| ---------------------------------------------------------------------

| --- Rule for primary-side pressure control (PORV_SRV_SO) Top -------------
| Top branch - no open primary-side valves
| 1st failure branch - 2 stuck open PORVs
| 2nd failure branch - 1 stuck open SRV
| 3rd failure branch - 2 stuck open SRVs

if always then
  /PORV_SRV_SO    = PORV-1-FT;
   PORV_SRV_SO[1] = PORV_SO_2;
   PORV_SRV_SO[2] = SRV_SO;
   PORV_SRV_SO[3] = SRV_SO_2;
endif
| ---------------------------------------------------------------------

| --- Rule for PORV isolation (PORV_ISO_F) Top ----------------------------
| Same event used to model PORV block valve closure for all conditions.
| No rule required for PORV-ISO_F.  It is a binary question
| establishing the status of closure of the PORV block valves with no
| variations due to prior failures.
| ---------------------------------------------------------------------

| --- Rule for number (fraction) of 2 PORVs that can be isolated------------
| (PORV_CLOSE_2) Top -----------------------------------------------------
```

Table 4.1. Event tree linkage rules for Beaver Valley power or HZP event trees.

```
| No rule required for PORV_CLOSE_2.  It is a binary question
| establishing the fraction of 2 PORV combinations that can be closed with
| no variations due to prior failures.
| ---------------------------------------------------------------------

| --- Rule for number (fraction) of 1 PORVs that can be isolated------------
| (PORV_CLOSE_1) Top -----------------------------------------------------
| No rule required for PORV_CLOSE_1.  It is a binary question
| establishing the fraction of 1 PORV combinations that can be closed with
| no variations due to prior failures.
| ---------------------------------------------------------------------

| --- Rule for 1 PORV self closing (PORV_SELF_CLOSE_1) Top -----------------
| No rule required for PORV_SELF_CLOSE_1.  It is a binary question
| establishing the status of the self closure of 1 SO PORV with no
| variations due to prior failures.
| ---------------------------------------------------------------------

| --- Rule for 2 PORVs self closing (PORV_SELF_CLOSE_2) Top ----------------
| No rule required for PORV_SELF_CLOSE_2.  It is a binary question
| establishing the status of the self closure of 2 SO PORV with no
| variations due to prior failures.
| ---------------------------------------------------------------------

| --- Rules for stuck-open SRV(s) reclosing (SRV_ISO_F) Top ----------------

if SRV_SO then
   /SRV_ISO_F = DUMMY;
    SRV_ISO_F[1] = SSRV_ISO_F_1-FT;
    SRV_ISO_F[2] = SRV_ISO_F_1-FT;
|
|Top branch - both SO primary SRVs reclose
|1st failure branch - 1 of 2 SO primary SRVs reclose (2 combinations)
|2nd failure branch - 2 SO primary SRVs reclose
|
elsif SRV_SO_2 then
   /SRV_ISO_F = DUMMY;
    SRV_ISO_F[1] = SRV_ISO_F_0-FT;
    SRV_ISO_F[2] = SRV_ISO_F_1OF2-FT;
    SRV_ISO_F[3] = SRV_ISO_F_2-FT;
endif
| ---------------------------------------------------------------------

| --- Rule for stuck-open ADVs (ADV_SO) Top --------------------------------
| No rule required.  Top event never asked in event tree development.
```

Table 4.1. Event tree linkage rules for Beaver Valley power or HZP event trees.

```
| ---------------------------------------------------------------------------

| --- Rule for isolation of stuck-open ADVs (ADV_ISO_F) Top ----------------
| No rule required.  Top event never asked in event tree development.
| ---------------------------------------------------------------------------

| --- Rule for stuck-open main steam SRVs (MSSRV_SO) Top -------------------
| No rule required.  Top event never asked in event tree development.
| ---------------------------------------------------------------------------

| --- Rule for main feedwater response (MFW_F) Top -------------------------
| There are two cases.  One where the initiator is a steamline break, the
| other involves all other initiators.  For the steamline break:
| Top branch    - MFW trips as designed
| Bottom branch - MFW overfeeds 3 SGs
|
| For the other initiators (LOAC, LOCAIR, LPCCW, and RTTT):
| Top branch - MFW trips as designed
| 1st failure branch - MFW overfeeds 1 SG
| 2nd failure branch - MFW overfeeds 3 SGs

if init(SLB1) + init(SLB2) then
   /MFW_F = MFW-FT-SLB;
    MFW_F = MFW-FT-SLB;
else
   /MFW_F    = MFW-FT;
    MFW_F[1] = MFW_1_OF;
    MFW_F[2] = MFW_3_OF;
endif
| ---------------------------------------------------------------------------

| --- Rule for main feedwater failure to trip on high SG level -------------
| --- (MFW_TRIP_F) Top -------------------------------
| No rule required for MFW_TRIP_F.  It is a binary question establishing
| the status of whether main feedwater has tripped on high SG level with
| no variations due to prior failures.
| ---------------------------------------------------------------------------

| --- Rule for failure to recover from main feedwater overfeed -------------
| --- (MFW_REC_F) Top ---------------------------------------------------
| No rule required for MFW_REC_F.  It is a binary question establishing
| the status of whether main feedwater overfeed has been controlled with
| no variations due to prior failures.

| ---------------------------------------------------------------------------
```

Table 4.1. Event tree linkage rules for Beaver Valley power or HZP event trees.

```
| --- Rule for failure of AFW (AFW_F) Top ----------------------------------
| If AFW doesn't fail (AFW_FAIL) and isn't controlled (AFW-FT), then it
| overfeeds either 1 (single failure) or 3 SGs (cc failure)
| Top branch - AFW functions as designed
| 1st failure branch - AFW overfeeds 1 SG
| 2nd failure branch - AFW overfeeds 3 SGs
| 3rd failure branch - AFW fails to provide flow
| If either DG_A or DG_B fails, then one MDP is unavailable
| If LODC occurs, then one MDP is unavailable

if init(LODC) + DG_A + DG_B then
  /AFW_F    = AFW-MDP-FT;
   AFW_F[1] = AFW_MDP_1_OF;
   AFW_F[2] = AFW_MDP_3_OF;
   AFW_F[3] = AFW_MDP_FAIL;
else
  /AFW_F    = AFW-FT;
   AFW_F[1] = AFW_1_OF;
   AFW_F[2] = AFW_3_OF;
   AFW_F[3] = AFW_FAIL;
endif
| ---------------------------------------------------------------------------

| --- Rule for failure to recover feedwater (FW_REC_F) Top -----------------
if (init(RTTT) + init(SGTR) + init(SLOCA)) * (AFW_1_OF + AFW_3_OF) then
/FW_REC_F = FW_REC_FT-T-AB;
FW_REC_F =  FW_REC_FT-T-AB;

elsif (init(LOAC) + init(LPCCW)) * (AFW_1_OF + AFW_3_OF) then
/FW_REC_F = FW_REC_FT-T-C;
FW_REC_F =  FW_REC_FT-T-C;

elsif (init(RTTT) + init(SGTR) + init(SLOCA)) * AFW_FAIL then
/FW_REC_F = FW_REC_AB-FT;
FW_REC_F[1] =  FW_REC_FT-T-AB;
FW_REC_F[2] = FW_REC_NONE;

else
/FW_REC_F = FW_REC_C-FT;
FW_REC_F[1] =  FW_REC_FT-T-C;
FW_REC_F[2] = FW_REC_NONE;
endif
| ---------------------------------------------------------------------------
```

Table 4.1. Event tree linkage rules for Beaver Valley power or HZP event trees.

```
| --- Rule for failure of turbine driven AFW during SBO (T_AFW_F) Top ------
| Under SBO conditions, only the TDP is available
| If AFW doesn't fail (AFW_TDP_FAIL) and isn't controlled (AFW-TDP-FT),
| then it overfeeds either 1 (single failure) or 3 SGs (cc failure)
| Top branch - AFW functions as designed
| 1st failure branch - TD AFW overfeeds 1 SG
| 2nd failure branch - TD AFW overfeeds 3 SGs
| 3rd failure branch - TD AFW fails to provide flow

if always then
  /T_AFW_F    = AFW-TDP-FT;
   T_AFW_F[1] = AFW_TDP_1_OF;
   T_AFW_F[2] = AFW_TDP_3_OF;
   T_AFW_F[3] = AFW_TDP_FAIL;
endif

| ---------------------------------------------------------------------

| --- Rule for failure of aux feedwater during steamline break -------------
| --- (AFW_F_SLB) Top ----------------------------------------------------

if always then
/AFW_F_SLB = AFW_F_SLB-FT;
AFW_F_SLB[1] =  AFW_ISO_FAIL-FT;
AFW_F_SLB[2] = AFW_FAIL;
endif

| ---------------------------------------------------------------------

| --- Rule for failure to recover aux feedwater (AFW_REC_F) Top ------------

if (init(LOMC) + init(LOMF)) * (AFW_1_OF + AFW_3_OF) then
/AFW_REC_F = AFW_REC_FT-T-AB;
AFW_REC_F =  AFW_REC_FT-T-AB;

elsif (init(LODC) + DG_A + DG_B) * (AFW_MDP_1_OF + AFW_MDP_3_OF) then
  /AFW_REC_F = AFW_REC_FT-T-C;
   AFW_REC_F =  AFW_REC_FT-T-C;

elsif (init(LOIA) + init(LTPCCW) + init(LOR-RW) + init(LOSP))
* (AFW_1_OF + AFW_3_OF) then
/AFW_REC_F = AFW_REC_FT-T-C;
AFW_REC_F =  AFW_REC_FT-T-C;

elsif (init(LOMC) + init(LOMF)) * AFW_FAIL then
```

Table 4.1. Event tree linkage rules for Beaver Valley power or HZP event trees.

```
/AFW_REC_F = AFW_REC_AB-FT;
AFW_REC_F[1] =  AFW_REC_FT-T-AB;
AFW_REC_F[2] = AFW_REC_NONE;

elsif (init(LODC) + DG_A + DG_B) * AFW_MDP_FAIL then
   /AFW_REC_F = AFW_REC_C-FT;
   AFW_REC_F[1] =  AFW_REC_FT-T-C;
   AFW_REC_F[2] = AFW_REC_NONE;

elsif (init(LOIA) + init(LTPCCW) + init(LOR-RW) + init(LOSP))
* AFW_FAIL then
/AFW_REC_F = AFW_REC_C-FT;
AFW_REC_F[1] =  AFW_REC_FT-T-C;
AFW_REC_F[2] = AFW_REC_NONE;

else
/AFW_REC_F = AFW_REC_AB-FT;
AFW_REC_F[1] =  AFW_REC_FT-T-AB;
AFW_REC_F[2] = AFW_REC_NONE;
endif

| ----------------------------------------------------------------------

| --- Rule for failure to recover aux feedwater during steamline break -----
| --- (AFW_REC_F_SLB) Top ------------------------------------------------

if always then
/AFW_REC_F_SLB = AFW_REC_SLB-FT;
AFW_REC_F_SLB[1] = AFW_ISO_FAIL-FT;
AFW_REC_F_SLB[2] = AFW_REC_NONE;
endif

| ----------------------------------------------------------------------

| --- Rule for failure to recover TD aux feedwater (T_AFW_REC_F) Top -------

if init(LOSP) * (AFW_TDP_1_OF + AFW_TDP_3_OF) then
/T_AFW_REC_F = TAFW_REC_FT-T-C;
T_AFW_REC_F = TAFW_REC_FT-T-C;

elsif init(LOSP) * AFW_TDP_FAIL then
/T_AFW_REC_F = TAFW_REC_C-FT;
T_AFW_REC_F[1] =  TAFW_REC_FT-T-C;
T_AFW_REC_F[2] = AFW_REC_NONE;
endif
```

Table 4.1. Event tree linkage rules for Beaver Valley power or HZP event trees.

```
| ---------------------------------------------------------------------

| --- Rule for failure of dedicated AFW pump (AFW_DED) Top -----------------
| No rule required for failure of dedicated AFW pump.  It is a binary
| question establishing the status of the dedicated AFW pums with no
| variations due to prior failures.
| ---------------------------------------------------------------------

| --- Rule for failure of condensate booster pump (CBP_F) Top --------------

if (init(SLB2) + init(SLB1)) then
/CBP_F = CBP_SLB-FT;
CBP_F[1] = CBP_SLB-OVERFD;
CBP_F[2] = COND_FAIL;

else
/CBP_F = CBP_GEN-FT;
CBP_F[1] = CBP_GEN-OVERFD;
CBP_F[2] = COND_FAIL;
endif

| ---------------------------------------------------------------------

| --- Rule for high head safety injection (HHSI_INIT_F) Top ----------------
| One train of HHSI (HHSI_INIT_F_1P) is available if loose one DG or one DC
| train; otherwise, both trains are available (HHSI_INIT_F).

if DG_A + DG_B + /RED + WHITE + /ORANGE + PURPLE then
   /HHSI_INIT_F = HHSI_INIT_F_1P;
    HHSI_INIT_F = HHSI_INIT_F_1P;
endif

| ---------------------------------------------------------------------

| --- Rule for HHSI recovery (HHSI_REC_F) Top --------------------------------
| No rule required for failure to recover HHSIs.  It is a binary question
| establishing the status of HHSI recovery with no variations due to
| prior failures.
| ---------------------------------------------------------------------

| --- Rule for Recirc pump trip (RCP_TRIP) Top -----------------------------

if /PORV_ISO_F then
   /RCP_TRIP = RCP_TRIP_PORV;
```

Table 4.1. Event tree linkage rules for Beaver Valley power or HZP event trees.

```
   RCP_TRIP = RCP_TRIP_PORV;
else
  /RCP_TRIP = RCP_INADV_TRIP;
   RCP_TRIP = RCP_INADV_TRIP;
endif

| ---------------------------------------------------------------------

| --- Rule for secondary cooling recovery (SEC_COOL_REC_F) Top -------------
| No rule required for failure to recover secondary cooling using either
| MFW or AFW.  It is a binary question establishing the status of
| secondary cooling recovery with no variations due to prior failures.
| ---------------------------------------------------------------------

| --- Rule for secondary cooling recovery (A_SEC_COOL_REC_F) Top -----------
| No rule required for failure to recover secondary cooling using AFW.
| It is a binary question establishing the status of secondary cooling
| recovery with no variations due to prior failures.
| ---------------------------------------------------------------------

| --- Rule for leakage of PCCW valve (PCCW_VALVE_F) Top --------------------
| No rule required for leakage of PCCW valve.  It is a binary question
| establishing the status of the PCCW valve with no variations due to
| prior failures.
| ---------------------------------------------------------------------

| --- Rule for termination of HHSI (HHSI_TERM_F) Top ------------------------

if (SRV_ISO_F_0-FT + SSRV_ISO_F_1-FT) * (/HHSI_INIT_F * /AFW-FT +
    /HHSI_INIT_F_1P * /AFW-MDP-FT) then
   /HHSI_TERM_F = HHSI_TERM_0SRV;
    HHSI_TERM_F = HHSI_TERM_0SRV;
else
   /HHSI_TERM_F = HHSI_SCREEN30MIN;
    HHSI_TERM_F = HHSI_SCREEN30MIN;
endif

| ---------------------------------------------------------------------

| --- Rule for Recirc pump restart (RCP_RESTART_F) Top ---------------------
| No rule required for failure to restart RCPs.  It is a binary question
| establishing the status of Recirc pump restart with no variations due to
| prior failures.
```

Table 4.2. Number of power or HZP event tree sequences by initiating event.

Initiating Event	Description	Number of Sequences
LLOCA	Large LOCA	1
LOAC	Loss of 120V AC bus	1051
LOCAIR	Loss of containment air	213
LODC	Loss of 125V DC bus	292
LOIA	Loss of instrument (station) air	363
LOMC	Loss of main condenser	213
LOMF	Loss of main feedwater	239
LOR-RW	Loss of river water and raw water	143
LOSP	Loss of offsite power	501
LPCCW	Loss of (reactor) primary component cooling water	213
LTPCCW	Loss of turbine plant component cooling water	329
MLOCA	Medium LOCA	1
RTTT	Reactor trip with turbine trip	335
SLB1	Small steam line break	103
SLB2	Large steam line break	103
SLOCA	Small LOCA	49
	Total number of sequences	4149

Table 4.3. Recovery rules for power and HZP models.

```
| Replace /RED and /ORANGE with RED and ORANGE, respectively

if /RED then
   DeleteEvent = /RED;
   AddEvent = RED;
endif

if /ORANGE then
   DeleteEvent = /ORANGE;
   AddEvent = ORANGE;
endif

| Replace HHSI_SCREEN30MIN event in selected SLB1 and SLB2 sequences

if (init(SLB1) + init(SLB2)) * AFW_ISO_FL10 * /HHSI_INIT_F *
```

Table 4.3. Recovery rules for power and HZP models.

```
   /HHSI_SCREEN30MIN then
   DeleteEvent = /HHSI_SCREEN30MIN;
   AddEvent = /HHSI_TERM_MSLB-A;
endif

if (init(SLB1) + init(SLB2)) * AFW_ISO_FL30 * /HHSI_INIT_F *
   /HHSI_SCREEN30MIN then
   DeleteEvent = /HHSI_SCREEN30MIN;
   AddEvent = /HHSI_TERM_MSLB-B;
endif

if (init(SLB1) + init(SLB2)) * /MFW_REC_F * /HHSI_SCREEN30MIN then
   DeleteEvent = /HHSI_SCREEN30MIN;
   AddEvent = /HHSI_TERM_MSLB-B;
endif

if (init(SLB1) + init(SLB2)) * AFW_ISO_FL10 * /HHSI_INIT_F *
   HHSI_SCREEN30MIN then
   DeleteEvent = HHSI_SCREEN30MIN;
   AddEvent = HHSI_TERM_MSLB-30A;
   CopyCutset;
   DeleteEvent = HHSI_TERM_MSLB-30A;
   AddEvent = HHSI_TERM_MSLB-60A;
endif

if (init(SLB1) + init(SLB2)) * AFW_ISO_FL30 * /HHSI_INIT_F *
   HHSI_SCREEN30MIN then
   DeleteEvent = HHSI_SCREEN30MIN;
   AddEvent = HHSI_TERM_MSLB-60B;
endif

if (init(SLB1) + init(SLB2)) * /MFW_REC_F * HHSI_SCREEN30MIN then
   DeleteEvent = HHSI_SCREEN30MIN;
   AddEvent = HHSI_TERM_MSLB-60B;
endif

if ((/PORV-1-FT + /PORV-2-FT) * (AFW_FAIL + AFW_MDP_FAIL) * AFW_REC_NONE) *
     (/SEC_COOL_REC_F + /A_SEC_COOL_REC_F) * /HHSI_SCREEN30MIN  then
   DeleteEvent = /HHSI_SCREEN30MIN;
   AddEvent = /HHSI_TERM_FB;
endif

if ((/PORV-1-FT + /PORV-2-FT) * (AFW_FAIL + AFW_MDP_FAIL) * AFW_REC_NONE) *
     (/SEC_COOL_REC_F + /A_SEC_COOL_REC_F) * HHSI_SCREEN30MIN  then
```

Table 4.3. Recovery rules for power and HZP models.

```
  DeleteEvent = HHSI_SCREEN30MIN;
  AddEvent = HHSI_TERM_FB-1;
  CopyCutset;
  DeleteEvent = HHSI_TERM_FB-1;
  AddEvent = HHSI_TERM_FB-10;
endif
```

of the HZP event trees was the same as generated for the power trees (see Table 4.2). Thus, just as for power, a total of 4,149 HZP sequences was generated. These sequences were solved for minimal cut sets and recovery rules were applied–the same rules as used in the power analysis (see Table 4.3). As noted in section 4.3.1, a listing of the generated logic and associated cut sets is not reproduced in this report.

4.4 Thermal-Hydraulic Bin Creation

Given the number of potential PTS sequences generated (8,298), it was necessary to group (i.e., bin) sequences with like characteristics into representative TH cases that could be analyzed in the thermal-hydraulic portions of the PTS study using the RELAP code [NUREG/CR-6858].

Initial bins were constructed by developing event tree partitioning rules in SAPHIRE and then applying these rules to produce the TH bins. Development of the partitioning rules required the analysts to examine the TH information available from preliminary analyses to identify the characteristics that defined the preliminary analyses.

Using this information, the analysts then made judgments as to whether existing TH characteristics could be used to represent new groups of sequences. If the analysts judged that existing characteristics were appropriate, either because they matched the examined sequences exactly or because the TH conditions from the new sequences were expected to be similar to but not be worse than the conditions from the existing analysis, then the uniquely-defining characteristics associated with the existing TH analyses were written in an “if-then-else” rule form for application in SAPHIRE. For those cases where the analysts were sufficiently unsure as to the appropriateness of using existing characteristics, new TH characteristics were identified. These new sets of characteristics were discussed with the TH analysts. If after discussion with the TH analysts it was concluded that the expected TH conditions could be sufficiently different from prior TH analyses and that the frequency of occurrence of the conditions was such that it could not be “added” to some existing TH bin without being unnecessarily conservative, then a new TH calculation was identified. The TH characteristics associated with this new calculation were then written in rule form for subsequent application in SAPHIRE. This iterative process continued until all accident sequence cut sets were associated with a TH bin.

At the conclusion of this initial binning phase, partitioning rules had been developed for the set of accident sequences. The rules created for the power model are presented in Table 4.4. The rules for the HZP model are provided in Table 4.5.

Table 4.4. Sequence partitioning rules for power model.

```
| Beaver Valley Family Partition Rules
| Last Updated 8/26/02 1:20Pm
|
if init(LLOCA) then
   partition = "LLOCA-01";
|
elsif init(MLOCA) then
   partition = "MLOCA-01";
|
elsif init(SLOCA) then
   partition = "SLOCA-01";
|
| One stuck open SRV that closes at 3000 seconds
|
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * system(/HHSI_TERM_0SRV) then
   partition = "SSRV-01C-3000";
elsif  /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-1 then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-10 then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * /HHSI_SCREEN30MIN then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "SSRV-02-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
   partition = "SSRV-03-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_3_OF * HHSI_REC_F then
   partition = "SSRV-03-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_3_OF * /HHSI_SCREEN30MIN then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_3_OF * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_3_OF then
   partition = "SSRV-04-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_1_OF * HHSI_REC_F then
   partition = "SSRV-03-6000";
```

Table 4.4. Sequence partitioning rules for power model.

```
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_1_OF * /HHSI_SCREEN30MIN then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_1_OF * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_1_OF then
   partition = "SSRV-05-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * DG_A * DG_B_GIVEN_A then
   partition = "SSRV-03-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * /AFW_REC_FT-T-C * /HHSI_INIT_F_1P * /HHSI_SCREEN30MIN
then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * /AFW_REC_FT-T-C * /HHSI_INIT_F_1P * HHSI_SCREEN30MIN
then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * HHSI_REC_F then
   partition = "SSRV-03-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * /HHSI_SCREEN30MIN then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC then
   partition = "SSRV-06-3000";
|
| One stuck open SRV that closes at 6000 seconds
|
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * system(/HHSI_TERM_0SRV) then
   partition = "SSRV-01A-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-1 then
   partition = "SSRV-01B-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-10 then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * /HHSI_SCREEN30MIN then
   partition = "SSRV-01B-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "SSRV-02-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
```

Table 4.4. Sequence partitioning rules for power model.

```
   partition = "SSRV-03-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_3_OF * HHSI_REC_F then
   partition = "SSRV-03-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_3_OF * /HHSI_SCREEN30MIN then
   partition = "SSRV-01A-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_3_OF * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_3_OF then
   partition = "SSRV-04-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_1_OF * HHSI_REC_F then
   partition = "SSRV-03-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_1_OF * /HHSI_SCREEN30MIN then
   partition = "SSRV-01A-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_1_OF * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_1_OF then
   partition = "SSRV-05-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * DG_A * DG_B_GIVEN_A then
   partition = "SSRV-03-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * /AFW_REC_FT-T-C * /HHSI_INIT_F_1P * /HHSI_SCREEN30MIN
then
   partition = "SSRV-01A-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * /AFW_REC_FT-T-C * /HHSI_INIT_F_1P * HHSI_SCREEN30MIN
then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * HHSI_REC_F then
   partition = "SSRV-03-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * /HHSI_SCREEN30MIN then
   partition = "SSRV-01B-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC then
   partition = "SSRV-06-6000";
|
| One stuck open SRV
|
elsif SRV_ISO_F_1 * ((/AFW-FT * /HHSI_INIT_F) + (/AFW-MDP-FT *
/HHSI_INIT_F_1P)) then
   partition = "SRV-01";
elsif SRV_ISO_F_1 * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "SRV-01";
elsif SRV_ISO_F_1 * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
   partition = "SRV-03";
elsif SRV_ISO_F_1 * AFW_3_OF * HHSI_REC_F then
   partition = "SRV-03";
```

Table 4.4. Sequence partitioning rules for power model.

```
elsif SRV_ISO_F_1 * AFW_3_OF * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN) then
   partition = "SRV-01";
elsif SRV_ISO_F_1 * AFW_3_OF then
   partition = "SRV-04";
elsif SRV_ISO_F_1 * AFW_1_OF * HHSI_REC_F then
   partition = "SRV-03";
elsif SRV_ISO_F_1 * AFW_1_OF * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN) then
   partition = "SRV-01";
elsif SRV_ISO_F_1 * AFW_1_OF then
   partition = "SRV-05";
elsif SRV_ISO_F_1 * DG_A * DG_B_GIVEN_A then
   partition = "SRV-03";
elsif SRV_ISO_F_1 * (/AFW-FT + /AFW_REC_FT-T-C) * /HHSI_INIT_F_1P then
   partition = "SRV-01";
elsif SRV_ISO_F_1 * HHSI_REC_F then
   partition = "SRV-03";
elsif SRV_ISO_F_1 * (HHSI_SCREEN30MIN + /HHSI_SCREEN30MIN) then
   partition = "SRV-01";
elsif SRV_ISO_F_1 then
   partition = "SRV-06";
|
| 2 SRVs stuck open both closes at 3000 seconds
|
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * system(/HHSI_TERM_0SRV) then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-1 then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-10 then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * /HHSI_SCREEN30MIN then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * HHSI_SCREEN30MIN then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "0SRV-02-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
   partition = "0SRV-03-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_3_OF * HHSI_REC_F then
```

Table 4.4. Sequence partitioning rules for power model.

```
   partition = "0SRV-03-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_3_OF * /HHSI_SCREEN30MIN then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_3_OF * HHSI_SCREEN30MIN then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_3_OF then
   partition = "0SRV-04-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_1_OF * HHSI_REC_F then
   partition = "0SRV-03-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_1_OF * /HHSI_SCREEN30MIN then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_1_OF * HHSI_SCREEN30MIN then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_1_OF then
   partition = "0SRV-05-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * DG_A * DG_B_GIVEN_A then
   partition = "0SRV-03-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * HHSI_REC_F then
   partition = "0SRV-03-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * /HHSI_SCREEN30MIN then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * HHSI_SCREEN30MIN then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC then
   partition = "0SRV-06-3000";
|
| 2 SRVs stuck open both closes at 6000 seconds
|
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * system(/HHSI_TERM_0SRV) then
   partition = "0SRV-01A-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-1 then
   partition = "0SRV-01B-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-10 then
   partition = "0SRV-01C-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * /HHSI_SCREEN30MIN then
   partition = "0SRV-01B-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * HHSI_SCREEN30MIN then
   partition = "0SRV-01C-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "0SRV-02-6000";
```

Table 4.4. Sequence partitioning rules for power model.

```
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
   partition = "0SRV-03-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_3_OF * HHSI_REC_F then
   partition = "0SRV-03-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_3_OF * /HHSI_SCREEN30MIN then
   partition = "0SRV-01A-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_3_OF * HHSI_SCREEN30MIN then
   partition = "0SRV-01C-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_3_OF then
   partition = "0SRV-04-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_1_OF * HHSI_REC_F then
   partition = "0SRV-03-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_1_OF * /HHSI_SCREEN30MIN then
   partition = "0SRV-01A-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_1_OF * HHSI_SCREEN30MIN then
   partition = "0SRV-01C-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_1_OF then
   partition = "0SRV-05-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * DG_A * DG_B_GIVEN_A then
   partition = "0SRV-03-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * HHSI_REC_F then
   partition = "0SRV-03-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * /HHSI_SCREEN30MIN then
   partition = "0SRV-01B-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * HHSI_SCREEN30MIN then
   partition = "0SRV-01C-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC then
   partition = "0SRV-06-6000";
|
| 2 SRVs stuck open one closes at 3000 seconds
|
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * ((/AFW-FT * /HHSI_INIT_F) + (/AFW-MDP-FT *
/HHSI_INIT_F_1P)) then
   partition = "1SRV-01-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "1SRV-01-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "1SRV-02-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
   partition = "0SRV-03-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * AFW_3_OF * HHSI_REC_F then
```

Table 4.4. Sequence partitioning rules for power model.

```
   partition = "0SRV-03-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * AFW_3_OF * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN)
then
   partition = "1SRV-01-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * AFW_3_OF then
   partition = "1SRV-04-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * AFW_1_OF * HHSI_REC_F then
   partition = "0SRV-03-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * AFW_1_OF * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN)
then
   partition = "1SRV-01-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * AFW_1_OF then
   partition = "1SRV-05-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * DG_A * DG_B_GIVEN_A then
   partition = "0SRV-03-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * HHSI_REC_F then
   partition = "0SRV-03-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN) then
   partition = "1SRV-01-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC then
   partition = "1SRV-06-3000";
|
| 2 SRVs stuck open one closes at 6000 seconds
|
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * ((/AFW-FT * /HHSI_INIT_F) + (/AFW-MDP-FT *
/HHSI_INIT_F_1P)) then
   partition = "1SRV-01-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "1SRV-01-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "1SRV-02-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
   partition = "0SRV-03-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * AFW_3_OF * HHSI_REC_F then
   partition = "0SRV-03-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * AFW_3_OF * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN)
then
   partition = "1SRV-01-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * AFW_3_OF then
   partition = "1SRV-04-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * AFW_1_OF * HHSI_REC_F then
   partition = "0SRV-03-6000";
```

Table 4.4. Sequence partitioning rules for power model.

```
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * AFW_1_OF * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN)
then
   partition = "1SRV-01-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * AFW_1_OF then
   partition = "1SRV-05-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * DG_A * DG_B_GIVEN_A then
   partition = "0SRV-03-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * HHSI_REC_F then
   partition = "0SRV-03-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN) then
   partition = "1SRV-01-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC then
   partition = "1SRV-06-6000";
|
| 2 SRVs stuck open
|
elsif SRV_ISO_F_2 * ((/AFW-FT * /HHSI_INIT_F) + (/AFW-MDP-FT *
/HHSI_INIT_F_1P)) then
   partition = "2SRV-01";
elsif SRV_ISO_F_2 * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "2SRV-01";
elsif SRV_ISO_F_2 * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "2SRV-02";
elsif SRV_ISO_F_2 * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
   partition = "2SRV-03";
elsif SRV_ISO_F_2 * AFW_3_OF then
   partition = "2SRV-01";
elsif SRV_ISO_F_2 * AFW_1_OF then
   partition = "2SRV-01";
elsif SRV_ISO_F_2 * AFW_1_OF then
   partition = "2SRV-05";
elsif SRV_ISO_F_2 * DG_A * DG_B_GIVEN_A then
   partition = "2SRV-03";
elsif SRV_ISO_F_2 * HHSI_REC_F then
   partition = "2SRV-03";
elsif SRV_ISO_F_2 * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN) then
   partition = "2SRV-01";
elsif SRV_ISO_F_2 then
   partition = "2SRV-06";
|
| Small Steam line break
|
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
```

Table 4.4. Sequence partitioning rules for power model.

```
    /RCP_INADV_TRIP then
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
    /RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
    /RCP_INADV_TRIP then
   partition = "SLB1-02C";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
    RCP_INADV_TRIP then
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
    RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
    RCP_INADV_TRIP then
   partition = "SLB1-02C";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
    /HHSI_SCREEN30MIN then
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
    HHSI_SCREEN30MIN then
   partition = "SLB1-02C";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * HHSI_INIT_F * HHSI_REC_F then
   partition = "SLB2-05";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
    /RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
    /RCP_INADV_TRIP then
   partition = "SLB1-02C";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
    RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
    RCP_INADV_TRIP then
   partition = "SLB1-02C";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
    /HHSI_SCREEN30MIN then
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
    HHSI_SCREEN30MIN then
   partition = "SLB1-02C";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL30 * HHSI_INIT_F * HHSI_REC_F then
   partition = "SLB2-05";
elsif init(SLB1) * AFW_FAIL * /MFW_REC_F * /HHSI_TERM_MSLB-B * /RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * AFW_FAIL * /MFW_REC_F * HHSI_TERM_MSLB-60B * /RCP_INADV_TRIP then
   partition = "SLB1-02C";
```

Table 4.4. Sequence partitioning rules for power model.

```
elsif init(SLB1) * AFW_FAIL * /MFW_REC_F * /HHSI_TERM_MSLB-B * RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * AFW_FAIL * /MFW_REC_F * HHSI_TERM_MSLB-60B * RCP_INADV_TRIP then
   partition = "SLB1-02C";
elsif init(SLB1) * AFW_FAIL then
   partition = "SLB1-06A";
|
elsif init(SLB1) * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
     /RCP_INADV_TRIP then
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
     /RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
     /RCP_INADV_TRIP then
   partition = "SLB1-02C";
elsif init(SLB1) * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
     RCP_INADV_TRIP then
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
     RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
     RCP_INADV_TRIP then
   partition = "SLB1-02C";
elsif init(SLB1) * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
     /HHSI_SCREEN30MIN then
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
     HHSI_SCREEN30MIN then
   partition = "SLB1-02C";
elsif init(SLB1) * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F then
   partition = "SLB1-04";
elsif init(SLB1) * AFW_ISO_FL10 * HHSI_INIT_F * HHSI_REC_F then
   partition = "SLB2-05";
elsif init(SLB1) * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
     /RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
     /RCP_INADV_TRIP then
   partition = "SLB1-02C";
elsif init(SLB1) * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
     RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
     RCP_INADV_TRIP then
   partition = "SLB1-02C";
elsif init(SLB1) * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
     /HHSI_SCREEN30MIN then
```

Table 4.4. Sequence partitioning rules for power model.

```
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
     HHSI_SCREEN30MIN then
   partition = "SLB1-02C";
elsif init(SLB1) * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F then
   partition = "SLB1-08";
elsif init(SLB1) * AFW_ISO_FL30 * HHSI_INIT_F * HHSI_REC_F then
   partition = "SLB2-05";
elsif init(SLB1) * /MFW_REC_F * /HHSI_TERM_MSLB-B * /RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * /MFW_REC_F * HHSI_TERM_MSLB-60B * /RCP_INADV_TRIP then
   partition = "SLB1-02C";
elsif init(SLB1) * /MFW_REC_F * /HHSI_TERM_MSLB-B * RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * /MFW_REC_F * HHSI_TERM_MSLB-60B * RCP_INADV_TRIP then
   partition = "SLB1-02C";
|
| Large steam line break
|
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
     /RCP_INADV_TRIP then
   partition = "SLB2-02A";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
     /RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
     /RCP_INADV_TRIP then
   partition = "SLB2-02C";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
     RCP_INADV_TRIP then
   partition = "SLB2-02A";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
     RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
     RCP_INADV_TRIP then
   partition = "SLB2-02C";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
     /HHSI_SCREEN30MIN then
   partition = "SLB2-02A";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
     HHSI_SCREEN30MIN then
   partition = "SLB2-02C";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * HHSI_INIT_F * HHSI_REC_F then
   partition = "SLB2-05";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
     /RCP_INADV_TRIP then
   partition = "SLB2-06A";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
```

Table 4.4. Sequence partitioning rules for power model.

```
    /RCP_INADV_TRIP then
   partition = "SLB2-02C";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
    RCP_INADV_TRIP then
   partition = "SLB2-06A";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
    RCP_INADV_TRIP then
   partition = "SLB2-02C";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
    /HHSI_SCREEN30MIN then
   partition = "SLB2-02A";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
    HHSI_SCREEN30MIN then
   partition = "SLB2-02C";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL30 * HHSI_INIT_F * HHSI_REC_F then
   partition = "SLB2-05";
elsif init(SLB2) * AFW_FAIL * /MFW_REC_F * /HHSI_TERM_MSLB-B * /RCP_INADV_TRIP then
   partition = "SLB2-06A";
elsif init(SLB2) * AFW_FAIL * /MFW_REC_F * HHSI_TERM_MSLB-60B * /RCP_INADV_TRIP then
   partition = "SLB2-02C";
elsif init(SLB2) * AFW_FAIL * /MFW_REC_F * /HHSI_TERM_MSLB-B * RCP_INADV_TRIP then
   partition = "SLB2-06A";
elsif init(SLB2) * AFW_FAIL * /MFW_REC_F * HHSI_TERM_MSLB-60B * RCP_INADV_TRIP then
   partition = "SLB2-02C";
elsif init(SLB2) * AFW_FAIL then
   partition = "SLB2-06A";
|
elsif init(SLB2) * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
    /RCP_INADV_TRIP then
   partition = "SLB2-02A";
elsif init(SLB2) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
    /RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
    /RCP_INADV_TRIP then
   partition = "SLB2-02C";
elsif init(SLB2) * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
    RCP_INADV_TRIP then
   partition = "SLB2-02A";
elsif init(SLB2) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
    RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
    RCP_INADV_TRIP then
   partition = "SLB2-02C";
elsif init(SLB2) * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
    /HHSI_SCREEN30MIN then
   partition = "SLB2-02A";
elsif init(SLB2) * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
```

Table 4.4. Sequence partitioning rules for power model.

```
    HHSI_SCREEN30MIN then
  partition = "SLB2-02C";
elsif init(SLB2) * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F then
  partition = "SLB2-04";
elsif init(SLB2) * AFW_ISO_FL10 * HHSI_INIT_F * HHSI_REC_F then
  partition = "SLB2-05";
elsif init(SLB2) * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
    /RCP_INADV_TRIP then
  partition = "SLB2-06A";
elsif init(SLB2) * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
    /RCP_INADV_TRIP then
  partition = "SLB2-02C";
elsif init(SLB2) * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
    RCP_INADV_TRIP then
  partition = "SLB2-06A";
elsif init(SLB2) * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
    RCP_INADV_TRIP then
  partition = "SLB2-02C";
elsif init(SLB2) * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
    /HHSI_SCREEN30MIN then
  partition = "SLB2-02A";
elsif init(SLB2) * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
    HHSI_SCREEN30MIN then
  partition = "SLB2-02C";
elsif init(SLB2) * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F then
  partition = "SLB2-08";
elsif init(SLB2) * AFW_ISO_FL30 * HHSI_INIT_F * HHSI_REC_F then
  partition = "SLB2-05";
elsif init(SLB2) * /MFW_REC_F * /HHSI_TERM_MSLB-B * /RCP_INADV_TRIP then
  partition = "SLB2-06A";
elsif init(SLB2) * /MFW_REC_F * HHSI_TERM_MSLB-60B * /RCP_INADV_TRIP then
  partition = "SLB2-02C";
elsif init(SLB2) * /MFW_REC_F * /HHSI_TERM_MSLB-B * RCP_INADV_TRIP then
  partition = "SLB2-06A";
elsif init(SLB2) * /MFW_REC_F * HHSI_TERM_MSLB-60B * RCP_INADV_TRIP then
  partition = "SLB2-02C";
|
elsif (/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * DG_A * DG_B_GIVEN_A then
  partition = "PORV1-01";
elsif (/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_FAIL + AFW_MDP_FAIL) * AFW_REC_NONE *
    CBP_GEN-OVERFD then
  partition = "PORV1-02";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_FAIL + AFW_MDP_FAIL) * AFW_REC_NONE) *
    (SEC_COOL_REC_F + A_SEC_COOL_REC_F) then
  partition = "PORV1-03";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_FAIL + AFW_MDP_FAIL) * AFW_REC_NONE) *
    (/SEC_COOL_REC_F + /A_SEC_COOL_REC_F) * /HHSI_TERM_FB then
  partition = "PORV1-03";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_FAIL + AFW_MDP_FAIL) * AFW_REC_NONE) *
```

Table 4.4. Sequence partitioning rules for power model.

```
    (/SEC_COOL_REC_F + /A_SEC_COOL_REC_F) * HHSI_TERM_FB-1 then
   partition = "PORV1-03";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_FAIL + AFW_MDP_FAIL) * AFW_REC_NONE) *
    (/SEC_COOL_REC_F + /A_SEC_COOL_REC_F) * HHSI_TERM_FB-10 then
   partition = "PORV1-03";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-20AB + AFW_REC_FL-20C +
FW_REC_FL-20AB +
    FW_REC_FL-20C) * /HHSI_INIT_F) +
    ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-20C + FW_REC_FL-20C) * /HHSI_INIT_F_1P)
then
   partition = "PORV1-05";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-20AB + AFW_REC_FL-20C +
FW_REC_FL-20AB +
    FW_REC_FL-20C) * HHSI_INIT_F * /HHSI_REC_F) +
    ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-20C + FW_REC_FL-20C) * /HHSI_REC_F) then
   partition = "PORV1-05";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-20AB + AFW_REC_FL-20C +
FW_REC_FL-20AB +
    FW_REC_FL-20C) * HHSI_INIT_F * HHSI_REC_F) +
    ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-20C + FW_REC_FL-20C) * HHSI_REC_F) then
   partition = "PORV1-01";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-45C + FW_REC_FL-45C) * /HHSI_INIT_F) +
    ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-45C + FW_REC_FL-45C) * /HHSI_INIT_F_1P) +
    ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * MFW_TRIP_F * /MFW_REC_F * /HHSI_INIT_F) then
   partition = "PORV1-05";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-45C + FW_REC_FL-45C) * HHSI_INIT_F *
    /HHSI_REC_F) + ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * AFW_REC_FL-45C * /HHSI_REC_F) +
    ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * MFW_TRIP_F * /MFW_REC_F * HHSI_INIT_F * /HHSI_REC_F)
    then
   partition = "PORV1-05";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-45C + FW_REC_FL-45C) * HHSI_INIT_F *
    HHSI_REC_F) + ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * AFW_REC_FL-45C * HHSI_REC_F) +
    ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * MFW_TRIP_F * /MFW_REC_F * HHSI_INIT_F * HHSI_REC_F)
    then
   partition = "PORV1-01";
|
else
   partition = "SRV-03";
endif
```

Table 4.5. Sequence partitioning rules for HZP model.

```
| Beaver Valley Family Partition Rules
| Last Updated 8/24/02 10:25am
|
if init(LLOCA) then
   partition = "LLOCA-01";
|
elsif init(MLOCA) then
   partition = "MLOCA-01";
|
elsif init(SLOCA) then
   partition = "SLOCA-01";
|
| One stuck open SRV that closes at 3000 seconds
|
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * system(/HHSI_TERM_0SRV) then
   partition = "SSRV-01A-3000";
elsif  /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-1 then
   partition = "SSRV-01B-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-10 then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * /HHSI_SCREEN30MIN then
   partition = "SSRV-01B-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "SSRV-02-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_3_OF * HHSI_REC_F then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_3_OF * /HHSI_SCREEN30MIN then
   partition = "SSRV-01A-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_3_OF * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_3_OF then
   partition = "SSRV-04-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_1_OF * HHSI_REC_F then
   partition = "SSRV-01C-3000";
```

Table 4.5. Sequence partitioning rules for HZP model.

```
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_1_OF * /HHSI_SCREEN30MIN then
   partition = "SSRV-01A-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_1_OF * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * AFW_1_OF then
   partition = "SSRV-05-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * DG_A * DG_B_GIVEN_A then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * /AFW_REC_FT-T-C * /HHSI_INIT_F_1P * /HHSI_SCREEN30MIN then
   partition = "SSRV-01A-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * /AFW_REC_FT-T-C * /HHSI_INIT_F_1P * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * HHSI_REC_F then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * /HHSI_SCREEN30MIN then
   partition = "SSRV-01B-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-3000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-3000-SEC then
   partition = "SSRV-06-3000";
|
| One stuck open SRV that closes at 6000 seconds
|
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * system(/HHSI_TERM_0SRV) then
   partition = "SSRV-01A-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-1 then
   partition = "SSRV-01B-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-10 then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * /HHSI_SCREEN30MIN then
   partition = "SSRV-01B-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "SSRV-02-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_3_OF * HHSI_REC_F then
```

Table 4.5. Sequence partitioning rules for HZP model.

```
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_3_OF * /HHSI_SCREEN30MIN then
   partition = "SSRV-01A-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_3_OF * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_3_OF then
   partition = "SSRV-04-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_1_OF * HHSI_REC_F then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_1_OF * /HHSI_SCREEN30MIN then
   partition = "SSRV-01A-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_1_OF * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * AFW_1_OF then
   partition = "SSRV-05-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * DG_A * DG_B_GIVEN_A then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * /AFW_REC_FT-T-C * /HHSI_INIT_F_1P * /HHSI_SCREEN30MIN then
   partition = "SSRV-01A-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * /AFW_REC_FT-T-C * /HHSI_INIT_F_1P * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * HHSI_REC_F then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * /HHSI_SCREEN30MIN then
   partition = "SSRV-01B-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC * HHSI_SCREEN30MIN then
   partition = "SSRV-01C-6000";
elsif /SRV_ISO_F_1 * SRV-CLOSES-6000-SEC then
   partition = "SSRV-06-6000";
|
| One stuck open SRV
|
elsif SRV_ISO_F_1 * ((/AFW-FT * /HHSI_INIT_F) + (/AFW-MDP-FT *
/HHSI_INIT_F_1P)) then
   partition = "SRV-01";
elsif SRV_ISO_F_1 * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "SRV-01";
elsif SRV_ISO_F_1 * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
   partition = "SRV-03";
elsif SRV_ISO_F_1 * AFW_3_OF * HHSI_REC_F then
   partition = "SRV-03";
elsif SRV_ISO_F_1 * AFW_3_OF * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN) then
   partition = "SRV-01";
elsif SRV_ISO_F_1 * AFW_3_OF then
   partition = "SRV-04";
```

Table 4.5. Sequence partitioning rules for HZP model.

```
elsif SRV_ISO_F_1 * AFW_1_OF * HHSI_REC_F then
   partition = "SRV-03";
elsif SRV_ISO_F_1 * AFW_1_OF * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN) then
   partition = "SRV-01";
elsif SRV_ISO_F_1 * AFW_1_OF then
   partition = "SRV-05";
elsif SRV_ISO_F_1 * DG_A * DG_B_GIVEN_A then
   partition = "SRV-03";
elsif SRV_ISO_F_1 * (/AFW-FT + /AFW_REC_FT-T-C) * /HHSI_INIT_F_1P then
   partition = "SRV-01";
elsif SRV_ISO_F_1 * HHSI_REC_F then
   partition = "SRV-03";
elsif SRV_ISO_F_1 * (HHSI_SCREEN30MIN + /HHSI_SCREEN30MIN) then
   partition = "SRV-01";
elsif SRV_ISO_F_1 then
   partition = "SRV-06";
|
| 2 SRVs stuck open both closes at 3000 seconds
|
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * system(/HHSI_TERM_0SRV) then
   partition = "0SRV-01A-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-1 then
   partition = "0SRV-01B-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-10 then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * /HHSI_SCREEN30MIN then
   partition = "0SRV-01B-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * HHSI_SCREEN30MIN then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "0SRV-02-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_3_OF * HHSI_REC_F then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_3_OF * /HHSI_SCREEN30MIN then
   partition = "0SRV-01A-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_3_OF * HHSI_SCREEN30MIN then
```

Table 4.5. Sequence partitioning rules for HZP model.

```
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_3_OF then
   partition = "0SRV-04-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_1_OF * HHSI_REC_F then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_1_OF * /HHSI_SCREEN30MIN then
   partition = "0SRV-01A-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_1_OF * HHSI_SCREEN30MIN then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * AFW_1_OF then
   partition = "0SRV-05-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * DG_A * DG_B_GIVEN_A then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * HHSI_REC_F then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * /HHSI_SCREEN30MIN then
   partition = "0SRV-01B-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC * HHSI_SCREEN30MIN then
   partition = "0SRV-01C-3000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-3000-SEC then
   partition = "0SRV-06-3000";
|
| 2 SRVs stuck open both closes at 6000 seconds
|
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * system(/HHSI_TERM_0SRV) then
   partition = "0SRV-01A-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-1 then
   partition = "0SRV-01B-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * (/AFW-FT + /AFW-MDP-FT) *
    (/HHSI_INIT_F + /HHSI_INIT_F_1P) * HHSI_TERM_0SRV-10 then
   partition = "0SRV-01C-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * /HHSI_SCREEN30MIN then
   partition = "0SRV-01B-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) * HHSI_SCREEN30MIN then
   partition = "0SRV-01C-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "0SRV-02-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
   partition = "0SRV-01C-6000";
```

Table 4.5. Sequence partitioning rules for HZP model.

```
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_3_OF * HHSI_REC_F then
   partition = "0SRV-01C-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_3_OF * /HHSI_SCREEN30MIN then
   partition = "0SRV-01A-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_3_OF * HHSI_SCREEN30MIN then
   partition = "0SRV-01C-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_3_OF then
   partition = "0SRV-04-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_1_OF * HHSI_REC_F then
   partition = "0SRV-01C-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_1_OF * /HHSI_SCREEN30MIN then
   partition = "0SRV-01A-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_1_OF * HHSI_SCREEN30MIN then
   partition = "0SRV-01C-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * AFW_1_OF then
   partition = "0SRV-05-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * DG_A * DG_B_GIVEN_A then
   partition = "0SRV-01C-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * HHSI_REC_F then
   partition = "0SRV-01C-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * /HHSI_SCREEN30MIN then
   partition = "0SRV-01B-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC * HHSI_SCREEN30MIN then
   partition = "0SRV-01C-6000";
elsif /SRV_ISO_F_0 * SRV-CLOSES-6000-SEC then
   partition = "0SRV-06-6000";
|
| 2 SRVs stuck open one closes at 3000 seconds
|
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * ((/AFW-FT * /HHSI_INIT_F) + (/AFW-MDP-FT *
/HHSI_INIT_F_1P)) then
   partition = "1SRV-01-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "1SRV-01-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "1SRV-02-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
   partition = "1SRV-01-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * AFW_3_OF * HHSI_REC_F then
   partition = "1SRV-01-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * AFW_3_OF * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN)
then
   partition = "1SRV-01-3000";
```

Table 4.5. Sequence partitioning rules for HZP model.

```
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * AFW_3_OF then
   partition = "1SRV-04-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * AFW_1_OF * HHSI_REC_F then
   partition = "1SRV-01-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * AFW_1_OF * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN)
then
   partition = "1SRV-01-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * AFW_1_OF then
   partition = "1SRV-05-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * DG_A * DG_B_GIVEN_A then
   partition = "1SRV-01-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * HHSI_REC_F then
   partition = "1SRV-01-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN) then
   partition = "1SRV-01-3000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-3000-SEC then
   partition = "1SRV-06-3000";
|
| 2 SRVs stuck open one closes at 6000 seconds
|
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * ((/AFW-FT * /HHSI_INIT_F) + (/AFW-MDP-FT *
/HHSI_INIT_F_1P)) then
   partition = "1SRV-01-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "1SRV-01-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "1SRV-02-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
   partition = "1SRV-01-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * AFW_3_OF * HHSI_REC_F then
   partition = "1SRV-01-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * AFW_3_OF * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN)
then
   partition = "1SRV-01-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * AFW_3_OF then
   partition = "1SRV-04-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * AFW_1_OF * HHSI_REC_F then
   partition = "1SRV-01-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * AFW_1_OF * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN)
then
   partition = "1SRV-01-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * AFW_1_OF then
   partition = "1SRV-05-6000";
```

Table 4.5. Sequence partitioning rules for HZP model.

```
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * DG_A * DG_B_GIVEN_A then
   partition = "1SRV-01-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * HHSI_REC_F then
   partition = "1SRV-01-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN) then
   partition = "1SRV-01-6000";
elsif SRV_ISO_F_1OF2 * SRV-CLOSES-6000-SEC then
   partition = "1SRV-06-6000";
|
| 2 SRVs stuck open
|
elsif SRV_ISO_F_2 * ((/AFW-FT * /HHSI_INIT_F) + (/AFW-MDP-FT *
/HHSI_INIT_F_1P)) then
   partition = "2SRV-01";
elsif SRV_ISO_F_2 * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "2SRV-01";
elsif SRV_ISO_F_2 * ((/AFW-FT * HHSI_INIT_F * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * /HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * /HHSI_REC_F)) then
   partition = "2SRV-02";
elsif SRV_ISO_F_2 * ((/AFW-FT * HHSI_INIT_F * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_FTS * HHSI_REC_F) +
     (/AFW-MDP-FT * HHSI_PUMP_OOS * HHSI_REC_F)) then
   partition = "2SRV-01";
elsif SRV_ISO_F_2 * AFW_3_OF then
   partition = "2SRV-01";
elsif SRV_ISO_F_2 * AFW_1_OF then
   partition = "2SRV-01";
elsif SRV_ISO_F_2 * AFW_1_OF then
   partition = "2SRV-05";
elsif SRV_ISO_F_2 * DG_A * DG_B_GIVEN_A then
   partition = "2SRV-01";
elsif SRV_ISO_F_2 * HHSI_REC_F then
   partition = "2SRV-01";
elsif SRV_ISO_F_2 * (/HHSI_SCREEN30MIN + HHSI_SCREEN30MIN) then
   partition = "2SRV-01";
elsif SRV_ISO_F_2 then
   partition = "2SRV-06";
|
| Small Steam line break
|
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
     /RCP_INADV_TRIP then
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
     /RCP_INADV_TRIP then
   partition = "SLB1-02B";
```

Table 4.5. Sequence partitioning rules for HZP model.

```
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
    /RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
    RCP_INADV_TRIP then
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
    RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
    RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
    /HHSI_SCREEN30MIN then
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
    HHSI_SCREEN30MIN then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL10 * HHSI_INIT_F * HHSI_REC_F then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
    /RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
    /RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
    RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
    RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
    /HHSI_SCREEN30MIN then
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
    HHSI_SCREEN30MIN then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_FAIL * AFW_ISO_FL30 * HHSI_INIT_F * HHSI_REC_F then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_FAIL * /MFW_REC_F * /HHSI_TERM_MSLB-B * /RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * AFW_FAIL * /MFW_REC_F * HHSI_TERM_MSLB-60B * /RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_FAIL * /MFW_REC_F * /HHSI_TERM_MSLB-B * RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * AFW_FAIL * /MFW_REC_F * HHSI_TERM_MSLB-60B * RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_FAIL then
```

Table 4.5. Sequence partitioning rules for HZP model.

```
   partition = "SLB1-06A";
|
elsif init(SLB1) * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
     /RCP_INADV_TRIP then
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
     /RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
     /RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
     RCP_INADV_TRIP then
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
     RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
     RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
     /HHSI_SCREEN30MIN then
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
     HHSI_SCREEN30MIN then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F then
   partition = "SLB1-04";
elsif init(SLB1) * AFW_ISO_FL10 * HHSI_INIT_F * HHSI_REC_F then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
     /RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
     /RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
     RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
     RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
     /HHSI_SCREEN30MIN then
   partition = "SLB1-02A";
elsif init(SLB1) * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
     HHSI_SCREEN30MIN then
   partition = "SLB1-02B";
elsif init(SLB1) * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F then
```

Table 4.5. Sequence partitioning rules for HZP model.

```
   partition = "SLB1-08";
elsif init(SLB1) * AFW_ISO_FL30 * HHSI_INIT_F * HHSI_REC_F then
   partition = "SLB1-02B";
elsif init(SLB1) * /MFW_REC_F * /HHSI_TERM_MSLB-B * /RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * /MFW_REC_F * HHSI_TERM_MSLB-60B * /RCP_INADV_TRIP then
   partition = "SLB1-02B";
elsif init(SLB1) * /MFW_REC_F * /HHSI_TERM_MSLB-B * RCP_INADV_TRIP then
   partition = "SLB1-06A";
elsif init(SLB1) * /MFW_REC_F * HHSI_TERM_MSLB-60B * RCP_INADV_TRIP then
   partition = "SLB1-02B";
|
| Large steam line break
|
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
     /RCP_INADV_TRIP then
   partition = "SLB2-02A";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
     /RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
     /RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
     RCP_INADV_TRIP then
   partition = "SLB2-02A";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
     RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
     RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
     /HHSI_SCREEN30MIN then
   partition = "SLB2-02A";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
     HHSI_SCREEN30MIN then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL10 * HHSI_INIT_F * HHSI_REC_F then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
     /RCP_INADV_TRIP then
   partition = "SLB2-06A";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
     /RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
     RCP_INADV_TRIP then
   partition = "SLB2-06A";
```

Table 4.5. Sequence partitioning rules for HZP model.

```
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
     RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
     /HHSI_SCREEN30MIN then
   partition = "SLB2-02A";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
     HHSI_SCREEN30MIN then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_FAIL * AFW_ISO_FL30 * HHSI_INIT_F * HHSI_REC_F then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_FAIL * /MFW_REC_F * /HHSI_TERM_MSLB-B * /RCP_INADV_TRIP then
   partition = "SLB2-06A";
elsif init(SLB2) * AFW_FAIL * /MFW_REC_F * HHSI_TERM_MSLB-60B * /RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_FAIL * /MFW_REC_F * /HHSI_TERM_MSLB-B * RCP_INADV_TRIP then
   partition = "SLB2-06A";
elsif init(SLB2) * AFW_FAIL * /MFW_REC_F * HHSI_TERM_MSLB-60B * RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_FAIL then
   partition = "SLB2-06A";
|
elsif init(SLB2) * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
     /RCP_INADV_TRIP then
   partition = "SLB2-02A";
elsif init(SLB2) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
     /RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
     /RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_ISO_FL10 * /HHSI_INIT_F * /HHSI_TERM_MSLB-A *
     RCP_INADV_TRIP then
   partition = "SLB2-02A";
elsif init(SLB2) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-30A *
     RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_ISO_FL10 * /HHSI_INIT_F * HHSI_TERM_MSLB-60A *
     RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
     /HHSI_SCREEN30MIN then
   partition = "SLB2-02A";
elsif init(SLB2) * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F *
     HHSI_SCREEN30MIN then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_ISO_FL10 * HHSI_INIT_F * /HHSI_REC_F then
   partition = "SLB2-04";
elsif init(SLB2) * AFW_ISO_FL10 * HHSI_INIT_F * HHSI_REC_F then
```

Table 4.5. Sequence partitioning rules for HZP model.

```
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
     /RCP_INADV_TRIP then
   partition = "SLB2-06A";
elsif init(SLB2) * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
     /RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_ISO_FL30 * /HHSI_INIT_F * /HHSI_TERM_MSLB-B *
     RCP_INADV_TRIP then
   partition = "SLB2-06A";
elsif init(SLB2) * AFW_ISO_FL30 * /HHSI_INIT_F * HHSI_TERM_MSLB-60B *
     RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
     /HHSI_SCREEN30MIN then
   partition = "SLB2-02A";
elsif init(SLB2) * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F *
     HHSI_SCREEN30MIN then
   partition = "SLB2-02B";
elsif init(SLB2) * AFW_ISO_FL30 * HHSI_INIT_F * /HHSI_REC_F then
   partition = "SLB2-08";
elsif init(SLB2) * AFW_ISO_FL30 * HHSI_INIT_F * HHSI_REC_F then
   partition = "SLB2-02B";
elsif init(SLB2) * /MFW_REC_F * /HHSI_TERM_MSLB-B * /RCP_INADV_TRIP then
   partition = "SLB2-06A";
elsif init(SLB2) * /MFW_REC_F * HHSI_TERM_MSLB-60B * /RCP_INADV_TRIP then
   partition = "SLB2-02B";
elsif init(SLB2) * /MFW_REC_F * /HHSI_TERM_MSLB-B * RCP_INADV_TRIP then
   partition = "SLB2-06A";
elsif init(SLB2) * /MFW_REC_F * HHSI_TERM_MSLB-60B * RCP_INADV_TRIP then
   partition = "SLB2-02B";
|
elsif (/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * DG_A * DG_B_GIVEN_A then
   partition = "PORV1-05";
elsif (/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_FAIL + AFW_MDP_FAIL) * AFW_REC_NONE *
     CBP_GEN-OVERFD then
   partition = "PORV1-05";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_FAIL + AFW_MDP_FAIL) * AFW_REC_NONE) *
     (SEC_COOL_REC_F + A_SEC_COOL_REC_F) then
   partition = "PORV1-05";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_FAIL + AFW_MDP_FAIL) * AFW_REC_NONE) *
     (/SEC_COOL_REC_F + /A_SEC_COOL_REC_F) * /HHSI_TERM_FB then
   partition = "PORV1-05";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_FAIL + AFW_MDP_FAIL) * AFW_REC_NONE) *
     (/SEC_COOL_REC_F + /A_SEC_COOL_REC_F) * HHSI_TERM_FB-1 then
   partition = "PORV1-05";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_FAIL + AFW_MDP_FAIL) * AFW_REC_NONE) *
     (/SEC_COOL_REC_F + /A_SEC_COOL_REC_F) * HHSI_TERM_FB-10 then
   partition = "PORV1-05";
```

Table 4.5. Sequence partitioning rules for HZP model.

```
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-20AB + AFW_REC_FL-20C + FW_REC_FL-20AB
+
    FW_REC_FL-20C) * /HHSI_INIT_F) +
    ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-20C + FW_REC_FL-20C) * /HHSI_INIT_F_1P) then
   partition = "PORV1-05";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-20AB + AFW_REC_FL-20C + FW_REC_FL-20AB
+
    FW_REC_FL-20C) * HHSI_INIT_F * /HHSI_REC_F) +
    ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-20C + FW_REC_FL-20C) * /HHSI_REC_F) then
   partition = "PORV1-05";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-20AB + AFW_REC_FL-20C + FW_REC_FL-20AB
+
    FW_REC_FL-20C) * HHSI_INIT_F * HHSI_REC_F) +
    ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-20C + FW_REC_FL-20C) * HHSI_REC_F) then
   partition = "PORV1-05";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-45C + FW_REC_FL-45C) * /HHSI_INIT_F) +
    ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-45C + FW_REC_FL-45C) * /HHSI_INIT_F_1P) +
    ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * MFW_TRIP_F * /MFW_REC_F * /HHSI_INIT_F) then
   partition = "PORV1-05";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-45C + FW_REC_FL-45C) * HHSI_INIT_F *
    /HHSI_REC_F) + ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * AFW_REC_FL-45C * /HHSI_REC_F) +
    ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * MFW_TRIP_F * /MFW_REC_F * HHSI_INIT_F * /HHSI_REC_F)
    then
   partition = "PORV1-05";
elsif ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * (AFW_REC_FL-45C + FW_REC_FL-45C) * HHSI_INIT_F *
    HHSI_REC_F) + ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * AFW_REC_FL-45C * HHSI_REC_F) +
    ((/PORV-1-FT + /PORV-2-FT + /PORV_ISO_F) * MFW_TRIP_F * /MFW_REC_F * HHSI_INIT_F * HHSI_REC_F)
    then
   partition = "PORV1-05";
|
else
   partition = "SRV-03";
endif
```

After development of the binning rules, each set of rules was applied to their respective set of accident sequence cut sets. Once the rules were applied, the cut sets were gathered into the defined bins. This initial gathering created 32 power bins and 27 HZP bins, containing all[5] of the original power or HZP accident sequence cut sets as modified by the recovery rules contained in Table 4.3. Table 4.6 lists these initial bins for the Power and HZP models.

At this point in the TH bin creation process, the Power and HZP models assumed binary logic (e.g., valve fully re-closes or sticks wide open; no in-between states) for all events except for the explicit modeling of the time at which operator actions occur (i.e., failure to take an action is modeled as failure to take that

[5] During the automated binning process some cut sets were lost when SAPHIRE automatically subsumed cut sets. This subsuming involved some cut sets from the SLB1, SLB2, and LOSP sequences. The frequencies of the subsumed cut sets are negligible compared to the frequency of the bin the cut sets belong in.

Table 4.6. Initial set of TH bins created by application of binning rules.

Power	HZP
Bin Identifier (Endstate Name)	**Bin Identifier (Endstate Name)**
0SRV-01A-6000	0SRV-01A-3000
0SRV-01B-6000	0SRV-01A-6000
0SRV-01C-3000	0SRV-01B-3000
0SRV-01C-6000	0SRV-01B-6000
0SRV-03-6000	0SRV-01C-3000
1SRV-01-3000	0SRV-01C-6000
1SRV-01-6000	1SRV-01-3000
2SRV-01	1SRV-01-6000
2SRV-03	2SRV-01
LLOCA-01	LLOCA-01
MLOCA-01	MLOCA-01
PORV1-01	PORV1-05
PORV1-02	SLB1-02A
PORV1-03	SLB1-02B
PORV1-05	SLB1-06A
SLB1-02A	SLB2-02A
SLB1-02B	SLB2-02B
SLB1-02C	SLB2-06A
SLB1-06A	SLOCA-01
SLB2-02A	SRV-01
SLB2-02B	SRV-03
SLB2-02C	SSRV-01A-3000
SLB2-05	SSRV-01A-6000
SLB2-06A	SSRV-01B-3000
SLOCA-01	SSRV-01B-6000
SRV-01	SSRV-01C-3000
SRV-03	SSRV-01C-6000
SSRV-01A-6000	
SSRV-01B-6000	
SSRV-01C-3000	
SSRV-01C-6000	
SSRV-03-6000	

action in multiple discrete times–for example, by 10 min, by 20 min–each with a probability), and the time at which a stuck open SRV recloses[6].

As part of the overall PTS project, the University of Maryland (UMD) performed a series of uncertainty analyses on many of the inputs and parameters potentially affecting the PTS results to see which uncertainties would most affect those results [Chang]. That work concluded that a few modeling uncertainties were sufficiently important that they needed to be explicitly treated in the PRA model. The uncertainties identified as important included:

- size of the LOCA within a LOCA category plus other factors (e.g., initial injection water temperature),
- size of the opening associated with a single or multiple stuck open SRV(s) that remain open or multiple stuck open PORVs that remain open,
- size of the opening associated with a single or multiple stuck open SRV(s) that reclose, and
- the time at which a stuck open SRV recloses (incorporated directly in the fault tree models as previously described in footnote 6).

The first three uncertainties and how they affected the TH bin creation process are discussed in the following paragraphs.

The actual break size of a LOCA for a specific LOCA class (i.e., small, medium, or large) can be any point on the spectrum of sizes defined by the two end points for that class. In addition, other factors (e.g., initial injection water temperature, break location, and injection flow rate) can contribute to the overall PTS model uncertainty since these factors along with the specific break size affect the rate of cooling and subsequent plant response. Results from the UMD uncertainty analysis [Chang] indicated that for the small LOCA category five distinct small LOCA cases (i.e., break size and other factors) were needed to adequately represent the uncertainty associated with the factors considered during the UMD analysis.

To incorporate this finding into the PRA, SAPHIRE was used to reproduce the small LOCA cut sets from the Power model (i.e., SLOCA-01), creating five sets of identical cut sets. Each of the five sets of cut

[6] The time at which a stuck open SRV recloses is unknown and can occur at any point after the valve sticks open. To approximate this, a fault tree consisting of two specific SRV reclosure times (i.e., either 3000 sec and 6000 sec) was constructed and used in the analysis of sequences involving stuck open SRVs that reclosed. These two time points were chosen after reviewing stuck open SRV thermal-hydraulic conditions. The 6000 sec point was chosen to coincide with the point where the change in downcomer wall temperature had "flattened out." The 3000 sec point was chosen to coincide with the point where sufficient cooling has occurred to the downcomer wall such that PTS could become an issue. Each case (i.e., 6000 sec and 3000 sec) was assigned a 50% chance of occurring.

Subsequent sensitivity analyses showed that delaying the reclosure until 7000 sec or beyond could result in higher conditional probabilities of vessel failure about 2x that predicted for 6000 seconds but (a) this is a small difference and within the uncertainties of the analysis and (b) beyond 1-2 hours, the operators are likely to transition the plant toward cold shutdown changing the TH response of the plant to a safer state (from a PTS perspective). Hence the 6000 sec case was kept as representative of a worst condition.

sets was then edited in SAPHIRE to insert a new event that represented a probability assigned by UMD of how much of the total spectrum of uncertainty the five distinct small LOCA cases represented. Each of these new sets of small LOCA cut sets was then assigned to a new TH bin. Table 4.7 provides the five probabilities assigned by UMD, a short description of each of the new TH bins, and the new TH bin designators. For the medium LOCA a similar process was used; however, only three new bins were needed. Thus, the medium LOCA cut set from the Power model (i.e., MLOCA-01) was reproduced to produce three sets, and edited to insert a new event representing the portion of the uncertainty spectrum associated with each of the three medium LOCA cases. Each new medium LOCA case was assigned to a new TH bin. Table 4.8 provides the medium LOCA information similar to that provided for the small LOCA in Table 4.7. For the large LOCA it was decided that a single TH bin was sufficient. Thus, the large LOCA cut set from the Power model (i.e., LLOCA-01) was assigned to a new TH bin (i.e., bin 009).

Just as with the LOCAs, the size of the opening associated with one or two stuck open SRVs or two stuck open PORVs that remain open can vary from a size that is not PTS significant all the way to the valve or valves being stuck fully open. To deal with this issue and other relevant issues examined in the UMD analysis, cut sets from the initial binning process (summarized in Table 4.6) involving stuck open SRVs or PORVs that remain open and cut sets involving two stuck open SRVs where only one SRV recloses were combined and/or edited in SAPHIRE. Table 4.9 provides a description of how the initial binned cut sets were processed and indicates the final TH bin identifier chosen from the set of TH calculations to best represent the PTS-relevant TH conditions.

In a similar manner, the initial TH bins from Table 4.6 that involved stuck open SRVs that reclosed were combined and/or edited in SAPHIRE. Table 4.10 provides the same type of information as Table 4.9.

Table 4.11 provides a short description of the final TH bins identified in Tables 4.9 and 4.10.

The final step in the TH bin creation process was to assign final TH characteristics (and a new TH descriptor) to the remainder of the TH bins contained in Table 4.6. This was accomplished by reviewing available PTS-relevant information and determining whether existing TH calculations were still appropriate or whether new TH calculations should be performed. Table 4.12 provides a cross-reference between the remaining bins and the final bins used in the PTS analysis. Table 4.13 provides a complete listing of the final set of TH bins used in the PTS analysis[7, 8].

[7] (NOTE: In Table 4.13 there is a "High K" column. This refers to the fact that generally the LOCA analyses were performed using large reverse flow loss coefficients in the pump suction cold leg region of the RELAP5 model. These coefficients are used to preclude setting up non-physical flow recirculation between the two common cold legs on each coolant loop.)

[8] As a result of sensitivity calculations dealing with how operators would implement the HHSI throttling criteria, new TH results were obtained for TH bins where throttling occurred. Table 4.13 provides both the original TH bin identifier (i.e., TH bin number) and the revised (or new) TH bin number.

Table 4.7. Information on small LOCA bins.

Probability	TH Description	TH Bin Designator
0.23	4.0” surge line break at hot zero power (HZP)	056
0.18	2.828" surge line break, summer conditions (HPI, LPI temp = 55°F, Accumulator Temp = 105°F), heat transfer coefficient increased 30% (modeled by increasing heat transfer surface area by 30% in passive heat structures).	114
0.18	2.0" surge line break	003
0.18	2.828" cold leg break	115
0.23	1.414" surge line break	002

Table 4.8. Information on medium LOCA bins.

Probability	TH Description	TH Bin Designator
0.35	8.0" surge line break	007
0.30	5.657" cold leg break with break area increased 30%	116
0.35	5.657" cold leg break, summer conditions (HPI, LPI temp = 55°F, Accumulator Temp = 105°F)	117

Table 4.9. Rules for slicing original Power or HZP cut sets into new TH bins representing stuck open SRVs or PORVs.

Original TH Bin	Action	New TH Bin Designator
Power Model		
SRV-01	Slice cut sets into U10-(SRV-01-TH-014)-P1. Edit cut sets to add event AREA-FRAC-1. Assign a value of 0.564 to AREA-FRAC-1.	
2SRV-01	Slice cut sets into U10-(2SRV-01-TH-014)-P2. Edit cut sets to add event AREA-FRAC-2. Assign a value of 0.4 to AREA-FRAC-2.	
	Slice cut sets from U10-(SRV-01-TH-014)-P1 and U10-(2SRV-01-TH-014)-P2 into U10-(TH-014)	014
SRV-03	Slice cut sets into U10-(SRV-03-TH-072)-P1. Edit cut sets to add event AREA-FRAC-1.	

Table 4.9. Rules for slicing original Power or HZP cut sets into new TH bins representing stuck open SRVs or PORVs.

Original TH Bin	Action	New TH Bin Designator
2SRV-03	Slice cut sets into U10-(2SRV-03-TH-072)-P2. Edit cut sets to add event AREA-FRAC-2.	
	Slice cut sets from U10-(SRV-03-TH-072)-P1 and U10-(2SRV-03-TH-072)-P2 into U10-(TH-072)	072
2SRV-01	Slice cut sets into U11-(TH-034). Edit cut sets to add event AREA-FRAC-3. Assign a value of 0.5 to AREA-FRAC-3.	034
2SRV-03	Slice cut sets into U11-(TH-065). Edit cut sets to add event AREA-FRAC-3. Assign a value of 0.5 to AREA-FRAC-3.	065
1SRV-01-3000	Slice cut sets into U12-(TH-066). Edit cut sets to add event AREA-FRAC-2.	066
1SRV-01-6000	Slice cut sets into U12-(TH-067). Edit cut sets to add event AREA-FRAC-2	067
PORV-01	Slice cut sets into U13-(TH-083). No area adjustment necessary.	083
PORV-02	Slice cut sets into U13-(TH-078). No area adjustment necessary.	078
PORV-03	Slice cut sets into U13-(TH-031). No area adjustment necessary.	031
PORV-05	Slice cut sets into U13-(TH-075). No area adjustment necessary.	075
HZP Model		
SRV-01	Slice cut sets into U14-(SRV-01-TH-094)-P1. Edit cut sets to add event AREA-FRAC-1.	
2SRV-01	Slice cut sets into U14-(2SRV-01-TH-094)-P2. Edit cut sets to add event AREA-FRAC-2.	
	Slice cut sets from U14-(SRV-01-TH-094)-P1 and U14-(2SRV-01-TH-094)-P2 into U14-(TH-094)	094
SRV-03	Slice cut sets into U14-(TH-073). Edit cut sets to add event AREA-FRAC-1.	073
2SRV-01	Slice cut sets into U15-(TH-064). Edit cut sets to add event AREA-FRAC-3.	064

Table 4.9. Rules for slicing original Power or HZP cut sets into new TH bins representing stuck open SRVs or PORVs.

Original TH Bin	Action	New TH Bin Designator
1SRV-01-3000	Slice cut sets into U16-(TH-092). Edit cut sets to add event AREA-FRAC-2.	092
1SRV-01-6000	Slice cut sets into U16-(TH-093). Edit cut sets to add event AREA-FRAC-2	093
PORV-05	Slice cut sets into U17-(TH-076). No area adjustment necessary.	076

Table 4.10. Rules for slicing original Power or HZP cut sets into new TH bins representing stuck open SRVs that reclose.

Original TH Bin	Action	New TH Bin Designator
Power Model		
SSRV-01C-3000	Slice cut sets into U20-(SSRV-01C-3-TH059)1. Edit cut sets to add event AREA-FRAC-1. Assign a value of 0.564 to AREA-FRAC-1.	
0SRV-01C-3000	Slice cut sets into U20-(0SRV-01C-3-TH059)2. Edit cut sets to add event AREA-FRAC-2. Assign a value of 0.4 to AREA-FRAC-2.	
	Slice cut sets from and U20-(SSRV-01C-3-TH059)1 and U20-(0SRV-01C-3-TH059)2 into U20-(TH-059)	059
SSRV-01A-6000	Slice cut sets into U21-(SSRV-01A-6-TH095)1. Edit cut sets to add event AREA-FRAC-1.	
0SRV-01A-6000	Slice cut sets into U21-(0SRV-01A-6-TH095)2. Edit cut sets to add event AREA-FRAC-2.	
	Slice cut sets from and U21-(SSRV-01A-6-TH095)1 and U21-(0SRV-01A-6-TH095)2 into U21-(TH-095)	095
SSRV-01B-6000	Slice cut sets into U22-(SSRV-01B-6-TH096)1. Edit cut sets to add event AREA-FRAC-1.	
0SRV-01B-6000	Slice cut sets into U22-(0SRV-01B-6-TH096)2. Edit cut sets to add event AREA-FRAC-2.	
	Slice cut sets from and U22-(SSRV-01B-6-TH096)1 and U22-(0SRV-01B-6-TH096)2 into U22-(TH-096)	096

Table 4.10. Rules for slicing original Power or HZP cut sets into new TH bins representing stuck open SRVs that reclose.

Original TH Bin	Action	New TH Bin Designator
SSRV-01C-6000	Slice cut sets into U23-(SSRV-01C-6-TH060)1. Edit cut sets to add event AREA-FRAC-1.	
0SRV-01C-6000	Slice cut sets into U23-(0SRV-01C-6-TH060)2. Edit cut sets to add event AREA-FRAC-2.	
	Slice cut sets from and U23-(SSRV-01C-6-TH060)1 and U23-(0SRV-01C-6-TH060)2 into U23-(TH-060)	060
SSRV-03-6000	Slice cut sets into U23-(SSRV-03-6-TH082)1. Edit cut sets to add event AREA-FRAC-1.	
0SRV-03-6000	Slice cut sets into U23-(0SRV-03-6-TH082)2. Edit cut sets to add event AREA-FRAC-2.	
	Slice cut sets from and U23-(SSRV-03-6-TH082)1 and U23-(0SRV-03-6-TH082)2 into U23-(TH-082)	082
0SRV-01C-3000	Slice cut sets into U32-(TH-061). Edit cut sets to add event AREA-FRAC-3. Assign a value of 0.5 to AREA-FRAC-3.	061
0SRV-01A-6000	Slice cut sets into U33-(TH-086). Edit cut sets to add event AREA-FRAC-3.	086
0SRV-01B-6000	Slice cut sets into U34-(TH-087). Edit cut sets to add event AREA-FRAC-3.	087
0SRV-01C-6000	Slice cut sets into U35-(TH-062). Edit cut sets to add event AREA-FRAC-3.	062
0SRV-03-6000	Slice cut sets into U35-(TH-068). Edit cut sets to add event AREA-FRAC-3.	068
HZP Model		
SSRV-01A-3000	Slice cut sets into U24-(SSRV-01A-3-TH099)1. Edit cut sets to add event AREA-FRAC-1. Assign a value of 0.564 to AREA-FRAC-1.	
0SRV-01A-3000	Slice cut sets into U24-(0SRV-01A-3-TH099)2. Edit cut sets to add event AREA-FRAC-2. Assign a value of 0.4 to AREA-FRAC-2.	
	Slice cut sets from and U24-(SSRV-01A-3-TH099)1 and U24-(0SRV-01A-3-TH099)2 into U24-(TH-099)	099

Table 4.10. Rules for slicing original Power or HZP cut sets into new TH bins representing stuck open SRVs that reclose.

Original TH Bin	Action	New TH Bin Designator
SSRV-01B-3000	Slice cut sets into U25-(SSRV-01B-3-TH101)1. Edit cut sets to add event AREA-FRAC-1.	
0SRV-01B-3000	Slice cut sets into U25-(0SRV-01B-3-TH101)2. Edit cut sets to add event AREA-FRAC-2.	
	Slice cut sets from and U25-(SSRV-01B-3-TH101)1 and U25-(0SRV-01B-3-TH101)2 into U25-(TH-101)	101
SSRV-01C-3000	Slice cut sets into U26-(SSRV-01C-3-TH097)1. Edit cut sets to add event AREA-FRAC-1.	
0SRV-01C-3000	Slice cut sets into U26-(0SRV-01C-3-TH097)2. Edit cut sets to add event AREA-FRAC-2.	
	Slice cut sets from and U26-(SSRV-01C-3-TH097)1 and U26-(0SRV-01C-3-TH097)2 into U26-(TH-097)	097
SSRV-01A-6000	Slice cut sets into U27-(SSRV-01A-6-TH098)1. Edit cut sets to add event AREA-FRAC-1.	
0SRV-01A-6000	Slice cut sets into U27-(0SRV-01A-6-TH098)2. Edit cut sets to add event AREA-FRAC-2.	
	Slice cut sets from and U27-(SSRV-01A-6-TH098)1 and U27-(0SRV-01A-6-TH098)2 into U27-(TH-098)	098
SSRV-01B-6000	Slice cut sets into U28-(SSRV-01B-6-TH100)1. Edit cut sets to add event AREA-FRAC-1.	
0SRV-01B-6000	Slice cut sets into U28-(0SRV-01B-6-TH100)2. Edit cut sets to add event AREA-FRAC-2.	
	Slice cut sets from and U28-(SSRV-01B-6-TH100)1 and U28-(0SRV-01B-6-TH100)2 into U28-(TH-100)	100
SSRV-01C-6000	Slice cut sets into U29-(SSRV-01C-6-TH071)1. Edit cut sets to add event AREA-FRAC-1.	
0SRV-01C-6000	Slice cut sets into U29-(0SRV-01C-6-TH071)2. Edit cut sets to add event AREA-FRAC-2.	
	Slice cut sets from and U29-(SSRV-01C-6-TH071)1 and U29-(0SRV-01C-6-TH071)2 into U29-(TH-071)	071
0SRV-01A-3000	Slice cut sets into U36-(TH-088). Edit cut sets to add event AREA-FRAC-3.	088

Table 4.10. Rules for slicing original Power or HZP cut sets into new TH bins representing stuck open SRVs that reclose.

Original TH Bin	Action	New TH Bin Designator
0SRV-01B-3000	Slice cut sets into U37-(TH-090). Edit cut sets to add event AREA-FRAC-3.	090
0SRV-01C-3000	Slice cut sets into U38-(TH-069). Edit cut sets to add event AREA-FRAC-3.	069
0SRV-01A-6000	Slice cut sets into U39-(TH-089). Edit cut sets to add event AREA-FRAC-3.	089
0SRV-01B-6000	Slice cut sets into U40-(TH-091). Edit cut sets to add event AREA-FRAC-3.	091
0SRV-01C-6000	Slice cut sets into U41-(TH-070). Edit cut sets to add event AREA-FRAC-3.	070

Table 4.11. Description of TH bins identified in Tables 4.9 and 4.10.

Model	TH Description		TH Bin Designator
	Initiator	Description	
Power	Turbine Trip/ Reactor Trip (TT/RT)	One stuck open pressurizer SRV	014
	TT/RT	feed and bleed (operators open all pressurizer PORVs and use all charging/HPI pumps)	031
	TT/RT	Two stuck open pressurizer SRV's	034
	TT/RT	One stuck open pressurizer SRV which recloses at 3,000 s.	059
	TT/RT	One stuck open pressurizer SRV which recloses at 6,000 s.	060
	TT/RT	Two stuck open pressurizer SRV which recloses at 3,000 s.	061
	TT/RT	Two stuck open pressurizer SRV which recloses at 6,000 s.	062
	TT/RT	Two stuck open pressurizer SRV's, no HPI, and open all ASDVs 5 minutes after HPI would have come on	065
	TT/RT	Two stuck open pressurizer SRV's, one recloses at 3000 seconds	066
	TT/RT	Two stuck open pressurizer SRV's, one recloses at 6000 seconds	067

Table 4.11. Description of TH bins identified in Tables 4.9 and 4.10.

Model	TH Description		TH Bin Designator
	Initiator	Description	
	TT/RT	Two stuck open pressurizer SRV's (reclose at 6000 s), no HPI, and open all ASDVs 5 minutes after HPI would have come on.	068
	TT/RT	One stuck open pressurizer SRV, no HPI and open all ASDVs 5 minutes after HPI would have come on	072
	TT/RT	Full MFW to all 3 SGs (MFW maintains SG level near top) and RCPs tripped	075
	TT/RT	No MFW, no AFW, open all ASDV's and let condensate fill SGs.	078
	TT/RT	One stuck open pressurizer SRV (recloses at 6000 s), no HPI and open all ASDVs 5 minutes after HPI would have come on	082
	LOCA	1.0" surge line break, no HPI, no motor AFW, RCPs tripped, trip MFW, overfeed all SGs with turbine AFW and maintain level at top of SGs, open all ASDVs 5 minutes after HPI would have come on.	083
	TT/RT	Two stuck open pressurizer SRV which recloses at 6,000 s and operator controls HHSI 1 minute after allowed.	086
	TT/RT	Two stuck open pressurizer SRV which recloses at 6,000 s and operator controls HHSI 10 minutes after allowed.	087
	TT/RT	One stuck open pressurizer SRV which recloses at 6,000 s and operator controls HHSI 1 minute after allowed.	095
	TT/RT	One stuck open pressurizer SRV which recloses at 6,000 s and operator controls HHSI 10 minutes after allowed.	096
HZP	TT/RT	Two stuck open pressurizer SRV's	064
	TT/RT	Two stuck open pressurizer SRVs which reclose at 3,000 s	069
	TT/RT	Two stuck open pressurizer SRVs which reclose at 6,000 s	070
	TT/RT	One stuck open pressurizer SRV which recloses at 6,000 s	071
	TT/RT	One stuck open pressurizer SRV, no HPI and open all ASDVs 5 minutes after HPI would have come on	073
	TT/RT	Full MFW to all 3 SGs (MFW maintains SG level near top) and RCPs tripped	076
	TT/RT	Two stuck open pressurizer SRV which recloses at 3,000 s and operator controls HHSI 1 minute after allowed	088
	TT/RT	Two stuck open pressurizer SRVs which reclose at 6,000 s and operator controls HHSI 1 minute after allowed.	089
	TT/RT	Two stuck open pressurizer SRVs which reclose at 3,000 s and operator controls HHSI 10 minutes after allowed.	090
	TT/RT	Two stuck open pressurizer SRVs which reclose at 6,000 s and operator controls HHSI 10 minutes after allowed.	091

Table 4.11. Description of TH bins identified in Tables 4.9 and 4.10.

Model	TH Description		TH Bin Designator
	Initiator	Description	
	TT/RT	Two stuck open pressurizer SRV's, one recloses at 3000 seconds	092
	TT/RT	Two stuck open pressurizer SRV's, one recloses at 6000 seconds	093
	TT/RT	One stuck open pressurizer SRV	094
	TT/RT	One stuck open pressurizer SRV which recloses at 3,000 s	097
	TT/RT	One stuck open pressurizer SRV which recloses at 6,000 s and operator controls HHSI 1 minute after allowed.	098
	TT/RT	One stuck open pressurizer SRV which recloses at 3,000 s and operator controls HHSI 1 minute after allowed.	099
	TT/RT	One stuck open pressurizer SRV which recloses at 6,000 s and operator controls HHSI 10 minutes after allowed.	100
	TT/RT	One stuck open pressurizer SRV which recloses at 3,000 s and operator controls HHSI 10 minutes after allowed.	101

Table 4.12. Cross-reference of remaining initial power and HZP bins to final TH bins.

Model	Collapsed Bin	Final TH Bin
Power	SLB1-02A	108
	SLB1-02B	110
	SLB1-02C	118
	SLB1-06A	112
	SLB2-02A	102
	SLB2-02B	104
	SLB2-02C	074
	SLB2-05	081
	SLB2-06A	106
HZP	SLB1-02A	109
	SLB1-02B	111
	SLB1-06A	113
	SLB2-02A	103
	SLB2-02B	105
	SLB2-06A	107

Table 4.13. Final set of TH bins used in Beaver Valley PTS

TH Bin No.[1]	IE	Primary Side Failure	Secondary Side Failure	Operator Action	HZP
002	LOCA	3.59 cm (1.414 in) surge line break	None	None	
003	LOCA	5.08 cm (2.0 in) surge line break	None	None	
007	LOCA	20.32 cm (8.0 in) surge line break	None	None	
009	LOCA	40.64 cm (16.0 in) hot leg break	None	None	
014	RT/TT	One stuck open pressurizer SRV	None	None	
031	RT/TT	None	Loss of all feedwater	Opens all pressurizer PORVs and uses all HPI pumps	
034	RT/TT	Two stuck open pressurizer SRVs	None	None	
056	LOCA	10.16 cm (4.0 in) surge line break	None	None	Yes
059	RT/TT	One stuck open pressurizer SRV, recloses at 3000 sec	None	None	
060	RT/TT	One stuck open pressurizer SRV, recloses at 6000 sec	None	None	
061	RT/TT	Two stuck open pressurizer SRVs, recloses at 3000 sec	None	None	
062	RT/TT	Two stuck open pressurizer SRVs, recloses at 6000 sec	None	None	
064	RT/TT	Two stuck open pressurizer SRVs	None	None	Yes
065	RT/TT	Two stuck open pressurizer SRVs, no HPI	None	Open all ASDVs 5 minutes after HPI would have come on	
066	RT/TT	Two stuck open pressurizer SRVs, one recloses at 3000 sec	None	None	
067	RT/TT	Two stuck open pressurizer SRVs, one recloses at 3000 sec	None	None	
068	RT/TT	Two stuck open pressurizer SRVs, recloses at 6000 sec, no HPI	None	Open all ASDVs 5 minutes after HPI would have come on	
069	RT/TT	Two stuck open pressurizer SRVs, recloses at 3000 sec	None	None	Yes
070	RT/TT	Two stuck open pressurizer SRVs, recloses at 6000 sec	None	None	Yes
071	RT/TT	One stuck open pressurizer SRV, recloses at 6000 sec	None	None	Yes
072	RT/TT	One stuck open pressurizer SRV, no HPI	None	Open all ASDVs 5 minutes after HPI would have come on	
073	RT/TT	One stuck open pressurizer SRV, no HPI	None	Open all ASDVs 5 minutes after HPI would have come on	Yes
074	MSLB	None	Double ended guillotine break of steam line A	None	

Table 4.13. Final set of TH bins used in Beaver Valley PTS

TH Bin No.[1]	IE	Primary Side Failure	Secondary Side Failure	Operator Action	HZP
075	RT/TT	None	MFW overfeed of all SGs	RCP's are tripped	
076	RT/TT	None	MFW overfeed of all SGs	RCP's are tripped	Yes
078	RT/TT	None	Loss of MFW and AFW	Open all ASDVs	
081	MSLB	Initial HPI failure	Double ended guillotine break of steam line A	Open ASDVs on SG A	
082	RT/TT	One stuck open pressurizer SRV, recloses at 6000 sec, no HPI	None	Open all ASDVs 5 minutes after HPI would have come on	
083	LOCA	2.54 cm (1.0 in) surge line break, no HPI	no motor AFW, overfeed of SGs with turbine AFW	RCP's are tripped, MFW tripped, open all ASDVs 5 minutes after HPI would have come on	
119 (086)	RT/TT	Two stuck open pressurizer SRVs, recloses at 6000 sec	None	Controls HPI 1 minute after allowed	
120 (087)	RT/TT	Two stuck open pressurizer SRVs, recloses at 6000 sec	None	Controls HPI 10 minutes after allowed	
121 (088)	RT/TT	Two stuck open pressurizer SRVs, recloses at 3000 sec	None	Controls HPI 1 minutes after allowed	Yes
122 (089)	RT/TT	Two stuck open pressurizer SRVs, recloses at 6000 sec	None	Controls HPI 1 minutes after allowed	Yes
123 (090)	RT/TT	Two stuck open pressurizer SRVs, recloses at 3000 sec	None	Controls HPI 10 minutes after allowed	Yes
124 (091)	RT/TT	Two stuck open pressurizer SRVs, recloses at 6000 sec	None	Controls HPI 10 minutes after allowed	Yes
092	RT/TT	Two stuck open pressurizer SRVs, one recloses at 3000 sec	None	None	Yes
093	RT/TT	Two stuck open pressurizer SRVs, one recloses at 6000 sec	None	None	Yes
094	RT/TT	One stuck open pressurizer SRV	None	None	Yes
125 (095)	RT/TT	One stuck open pressurizer SRV, recloses at 6000 sec	None	Controls HPI 1 minutes after allowed	
126 (096)	RT/TT	One stuck open pressurizer SRV, recloses at 6000 sec	None	Controls HPI 10 minutes after allowed	
097	RT/TT	One stuck open pressurizer SRV, recloses at 3000 sec	None	None	Yes
127 (098)	RT/TT	One stuck open pressurizer SRV, recloses at 6000 sec	None	Controls HPI 1 minutes after allowed	Yes
128 (099)	RT/TT	One stuck open pressurizer SRV, recloses at 3000 sec	None	Controls HPI 1 minutes after allowed	Yes
129 (100)	RT/TT	One stuck open pressurizer SRV, recloses at 6000 sec	None	Controls HPI 10 minutes after allowed	Yes

Table 4.13. Final set of TH bins used in Beaver Valley PTS

TH Bin No.[1]	IE	Primary Side Failure	Secondary Side Failure	Operator Action	HZP
130 (101)	RT/TT	One stuck open pressurizer SRV, recloses at 3000 sec	None	Controls HPI 10 minutes after allowed	Yes
102	MSLB	None	Double ended guillotine break of steam line A	RCP's are tripped. Controls HPI 30 minutes after allowed	
103	MSLB	None	Double ended guillotine break of steam line A	RCP's are tripped. Controls HPI 30 minutes after allowed	Yes
104	MSLB	None	Double ended guillotine break of steam line A	RCP's are tripped. Controls HPI 60 minutes after allowed	
105	MSLB	None	Double ended guillotine break of steam line A	RCP's are tripped. Controls HPI 60 minutes after allowed	Yes
106	MSLB	None	Double ended guillotine break of steam line A	RCP's are tripped. Controls HPI 30 minutes after allowed	
107	MSLB	None	Double ended guillotine break of steam line A	RCP's are tripped. Controls HPI 30 minutes after allowed	Yes
108	MSLB	None	All MS-SRVs on SG A stuck open	Controls HPI 30 minutes after allowed	
109	MSLB	None	All MS-SRVs on SG A stuck open	RCP's are tripped. Controls HPI 30 minutes after allowed	Yes
110	MSLB	None	All MS-SRVs on SG A stuck open	Controls HPI 60 minutes after allowed	
111	MSLB	None	All MS-SRVs on SG A stuck open	RCP's are tripped. Controls HPI 60 minutes after allowed	Yes
112	MSLB	None	All MS-SRVs on SG A stuck open	RCP's are tripped. Controls HPI 30 minutes after allowed	
113	MSLB	None	All MS-SRVs on SG A stuck open	RCP's are tripped. Controls HPI 30 minutes after allowed	Yes
114	LOCA	7.18 cm (2.828 in) surge line break	None	None	
115	LOCA	7.18 cm (2.828 in) cold leg break	None	None	
116	LOCA	16.38 cm (6.45 in) cold leg break	None	None	
117	LOCA	14.37 cm (5.657 in) cold leg break	None	None	
118	MSLB	None	All MS-SRVs on SG A stuck open	None	

[1] TH bin numbers that appear in parentheses, for example (086), have been replaced by new TH bin numbers, reflecting the updated implementation of HHSI throttling criteria discussed in Footnote 8.

5. SUCCESS CRITERIA

In a typical full-power probabilistic risk assessment (PRA), success criteria are defined for systems, structures, components (SSCs), and human actions such that operation of the SSCs and performance of the human actions will *prevent* an undesired condition (e.g., core damage). However, in this pressurized thermal shock (PTS) PRA, the objective is different. Here the objective is to determine the combinations of SSCs and human actions that if the SSCs work and the human actions are performed (or not performed) will *cause or exacerbate* an undesired condition (i.e., PTS). To this end, the basic assumption made in this analysis was that if an SSC was demanded it either worked or failed, i.e., there were no partial operations. Obviously, an exception was made for those cases where the initiating event prevented certain SSCs or portions of systems from operating (e.g., for the loss of main condenser initiating event, main feed water is lost initially). Similarly, for human actions, if the action was required to be performed within a certain time period (error of omission) or postulated (error of commission), the action was either performed or not. Table 5.1 identifies in general terms the "success criteria" examined in this analysis where "success criteria" are the combinations of SSCs and human actions that alter the reactor coolant system pressure and amount of overcooling and hence the PTS challenge.

Table 5.1. General "success criteria" versus function.

Primary Integrity	Secondary Pressure [1]	Secondary Feed	Primary Flow/Pressure
Reactor coolant system (RCS) piping [different size breaks] • small • medium • large	Steam lines [different size breaks] • small • large	Status of main feedwater (MFW) • tripped • overfeeding one steam generator (SG) • overfeeding three SGs Status of MFW trip on high SG level • tripped • not tripped Status of recovery from MFW overfeed • overfeed controlled • overfeed not controlled	Status of reactor coolant pumps (RCPs) • tripped • not tripped • if tripped, restarted • if tripped, not restarted

Table 5.1. General "success criteria" versus function.

Primary Integrity	Secondary Pressure [1]	Secondary Feed	Primary Flow/Pressure
Power-operated relief valves (PORVs) status • opens but recloses • opens and sticks open Status of PORV block valves • closed • not closed		Status of auxiliary feedwater (AFW) system • successfully operating • overfeeding one steam generator (SG) • overfeeding three SGs • fails to provide flow Status of AFW recovery <u>Case 1: AFW overfeed to three steam generators</u> • overfeed controlled • overfeed not controlled <u>Case 2: AFW fails to provide flow</u> • recovered and successfully operating • recovered but flow to SG not controlled • not recovered Status of dedicated AFW pump • successfully operating • fails to operate	Status of high pressure injection (HPI) pumps [2] and the core flood tanks (CFTs) [3] • system operates • system fails Status of HPI recovery • recovered • not recovered HPI injection throttled • throttled • not throttled
Pressurizer safety relief valves (SRVs) status • opens but recloses • opens and remains open		Status of condensate (i.e., condensate booster pump [CBP]) • successful use of CBP (operator depressurize, CBP works, operator controls CBP injection) • operators fail to control CBP injection • CBP fails	low pressure injection (LPI) pumps • assumed to function if required (i.e., not explicitly incorporated into the model)

[1] Status of secondary side valves (e.g., main steam safety relief valves and atmospheric dump valves) not modeled based on simplifying model assumptions discussed in section 4.1.2

[2] Note that Beaver Valley's pumps are intermediate-head pumps. Normal makeup is provided by the charging pumps and can pressurize the primary system to the pressurizer safety valve setpoints. The charging pumps are not explicitly incorporated into the model. They are assumed to continue to function unless failed by the initiating event or controlled/turned off by the operators.

[3] Failure of CFTs not explicitly incorporated into the model. If required, they are assumed to function as designed.

6. SYSTEMS ANALYSIS

This section provides a description of the systems analysis effort performed to support the pressurized thermal shock (PTS) probabilistic risk assessment (PRA) of Unit 1 at Beaver Valley. Given that the purpose of this analysis was to identify and quantify potential PTS scenarios, the development of detailed system models (consisting of the various component-related failure mechanisms) was deemed unnecessary. The major justification for this decision is that for many systems detailed knowledge of which set of component failure mechanisms occurred to cause system failure ultimately has minimal impact on PTS since for many systems *continued* operation (sometimes beyond the point where the system should have stopped) contributes to PTS conditions. In addition, the use of simple models allowed the analysts to concentrate on development of the expanded set of thermal-hydraulic bins used to characterize the plant's susceptibility to PTS (see section 4), one of the major enhancements of this PTS analysis.

6.1 Modeling Approach and Scope

Two different types of system models were used in the systems analysis:

1. Black box models, and
2. Simplified fault tree models.

The black box models use a single event to represent a system's unavailability, where the unavailability is determined from existing data sources or is derived from the quantification of more detailed system models (e.g., a system model from an Individual Plant Examination). The simplified fault tree models, as the description implies, consist of simple representations of system failure, including major equipment unavailabilities and/or human actions. Table 6.1 lists the events used to represent the systems included in this analysis. The system event names are grouped by major function, and the type of model constructed for each event is identified. In addition, Table 6.1 identifies the figure (Figures 6.1 through 6.31) that depicts the system logic for each model.

6.2 System Description

The following sections provide a brief description of the main function of the systems included in this analysis. In addition, a brief description of the PTS-related consequences of the system's successful operation or failure to operate is provided.

6.2.1 Power-Operated Relief Valve and Its Block Valve

The three power-operated relief valves (PORVs) provide both automatic and manual control of reactor coolant system (RCS) pressure by releaving pressure from the pressurizer. The block valve can be used to terminate flow from the PORV in the event it becomes stuck open.

If a PORV opens and then sticks open, the loss of inventory will require injection by some system (e.g., high pressure injection). This injection of relatively cold water enhances the potential for PTS. If a stuck open PORV subsequently recloses, the relatively sudden increase in reactor pressure enhances the potential for PTS. Early closure of the PORV block valve can minimize the PTS consequences associated with a stuck open PORV.

Table 6.1. Events model types by system/function.

Function	System	Event Name	Model Type	Fault Tree Figure
Primary integrity	Stuck open PORV/SRV	PORV-1-FT	Simplified fault tree	6.1
		PORV-2-FT	Simplified fault tree	6.2
		PORV_SO_2	Black box	
		SRV_SO	Black box	
		SRV_SO_2	Black box	
	PORV/SRV isolation	PORV_ISO_F	Black box	
		PORV_CLOSE_1	Black box	
		PORV_CLOSE_2	Black box	
		PORV_SELF_CLOSE_1	Black box	
		PORV_SELF_CLOSE_2	Black box	
		SSRV_ISO_F_1-FT	Simplified fault tree	6.3
		SRV_ISO_F_1-FT	Simplified fault tree	6.4
		SRV_ISO_F_0-FT	Simplified fault tree	6.5
		SRV_ISO_F_1OF2-FT	Simplified fault tree	6.6
		SRV_ISO_F_2-FT	Simplified fault tree	6.7
Secondary feed	Main feed	MFW-FT	Simplified fault tree	6.8
		MFW_3_OF	Black box	
		MFW-FT-SLB	Simplified fault tree	6.9
	Recovery of main feed	MFW_TRIP_F	Black box	
		MFW_REC_F	Black box	
		FW_REC_FT-T-AB	Simplified fault tree	6.10
		FW_REC_FT-T-C	Simplified fault tree	6.11
		FW_REC_C-FT	Simplified fault tree	6.12
	Auxiliary feed	AFW-FT	Simplified fault tree	6.13
		AFW_1_OF	Black box	
		AFW_3_OF	Black box	
		AFW_FAIL	Black box	
		AFW-MDP-FT	Simplified fault tree	6.14
		AFW_MDP_1_OF	Black box	
		AFW_MDP_3_OF	Black box	
		AFW_MDP_FAIL	Black box	
		AFW-TDP-FT	Simplified fault tree	6.15
		AFW_F_SLB-FT	Simplified fault tree	6.16
		AFW_TDP_1_OF	Black box	
		AFW_TDP_3_OF	Black box	
		AFW_DED	Black box	
	Recovery of auxiliary feed	AFW_REC_FT-T-AB	Simplified fault tree	6.17
		AFW_REC_FT-T-C	Simplified fault tree	6.18
		AFW_REC_AB-FT	Simplified fault tree	6.19
		AFW_REC_C-FT	Simplified fault tree	6.20
		AFW_REC_NONE	Black box	
		AFW_REC_SLB-FT	Simplified fault tree	6.21
		TAFW_REC_FT-T-C	Simplified fault tree	6.22

Table 6.1. Events model types by system/function.

Function	System	Event Name	Model Type	Fault Tree Figure
	Condensate	CBP_GEN-FT	Simplified fault tree	6.23
		CBP_SLB-FT	Simplified fault tree	6.24
		CBP_GEN-OVERFD	Black box	
		CBP_SLB-OVERFD	Black box	
		COND_FAIL	Black box	
	Secondary cooling recovery late	SEC_COOL_REC_F	Black box	
		A_SEC_COOL_REC_F	Black box	
Primary flow/ pressure	High pressure injection	HHSI_INIT_F	Black box	
		HHSI_INIT_F_1P	Simplified fault tree	6.25
	Recovery of high pressure injection	HHSI_REC_F	Black box	
	Throttling high pressure injection	HHSI_TERM-0SRV	Simplified fault tree	6.26
		HHSI_SCREEN30MIN	Black box	
		HHSI_TERM_FB	Simplified fault tree	6.27
		HHSI_TERM_MSLB-A	Simplified fault tree	6.28
		HHSI_TERM_MSLB-B	Simplified fault tree	6.29
	Reactor coolant pump trip	RCP_TRIP_PORV	Black box	
		RCP_INADV_TRIP	Black box	
	Reactor coolant pump restart	RCP_RESTART_F	Black box	
Miscellaneous		PCCW_VALVE_F	Black box	
		DG_A	Black box	
		DG_B	Black box	
		DG_B_GIVEN_A	Black box	
		SRV_CLOSURE-TIME	Simplifed transfer tree	6.30
		AFW_ISO_FAIL-FT	Simplified transfer tree	6.31

6.2.2 Pressurizer Safety Relief Valves

The three pressurizer safety relief valves (SRVs) provide code safety relief of pressure if the PORV fails or if pressure continues to increase with an open PORV.

If a SRV sticks open, the effect on PTS is similar to that described for the PORV.

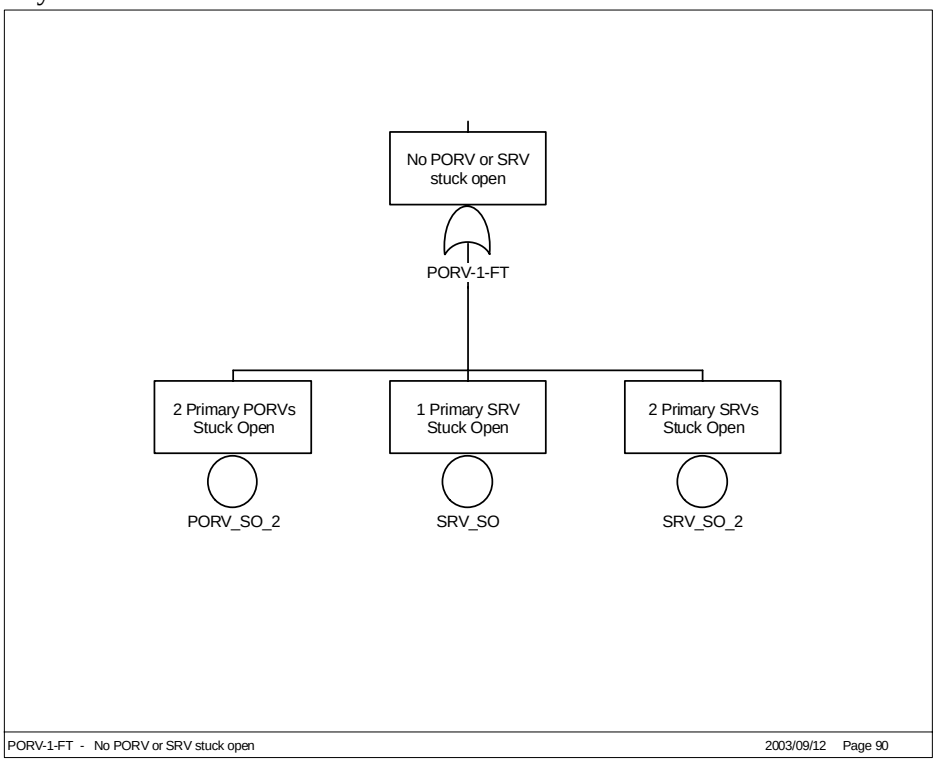

Figure 6.1. Fault tree for PORV-1-FT.

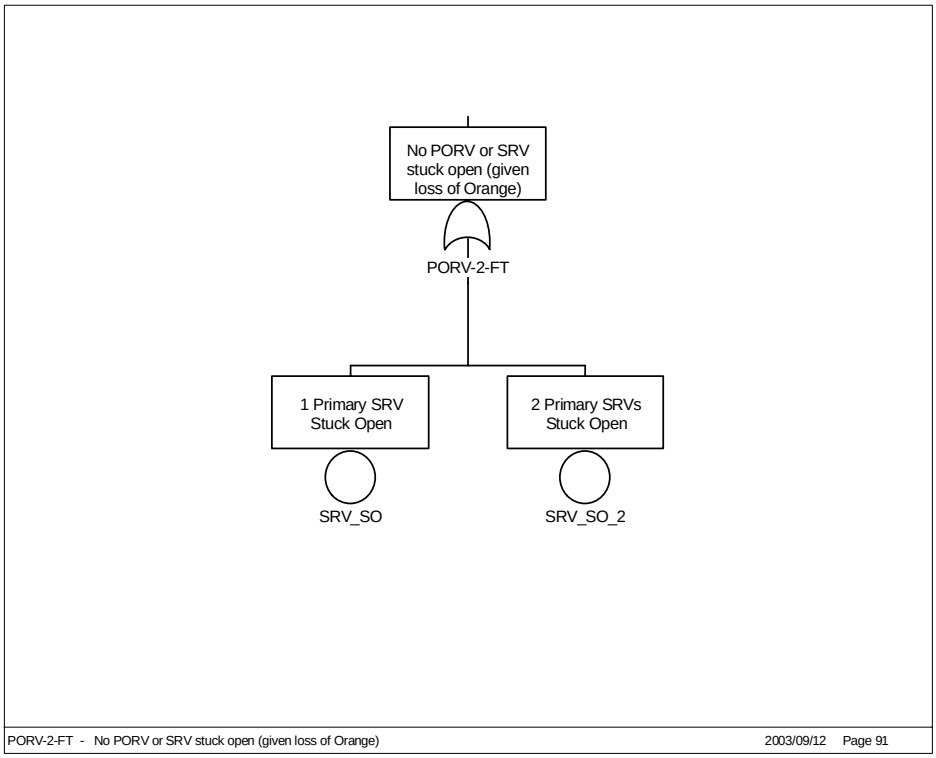

Figure 6.2. Fault tree for PORV-2-FT.

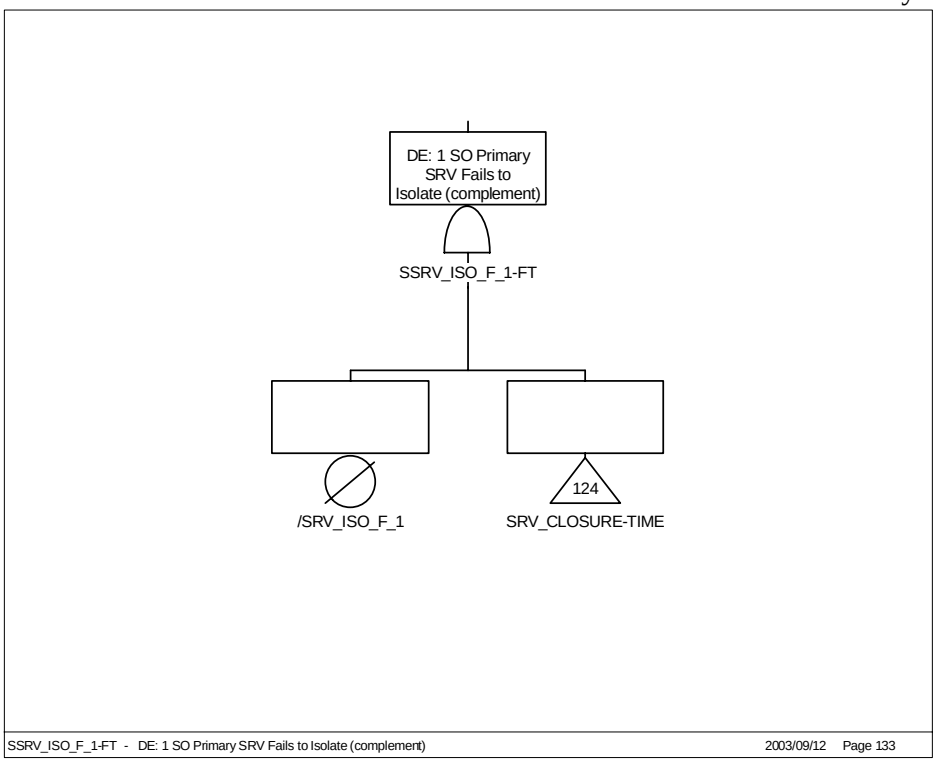

Figure 6.3. Fault tree for SSRV_ISO_F_1-FT.

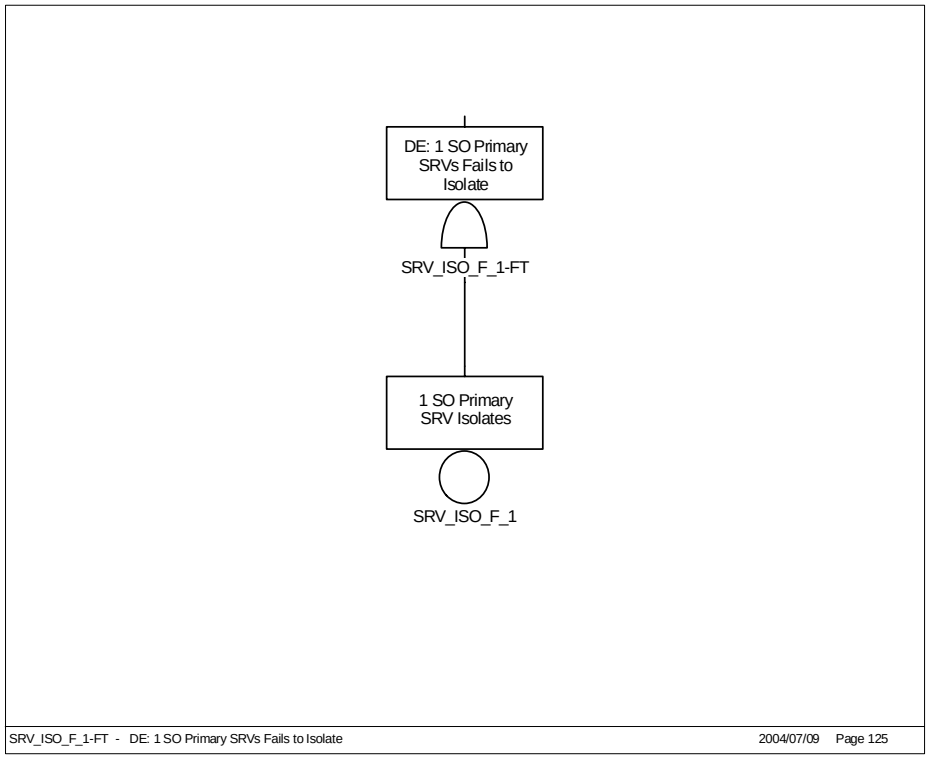

Figure 6.4. Fault tree for SRV_ISO_F_1-FT.

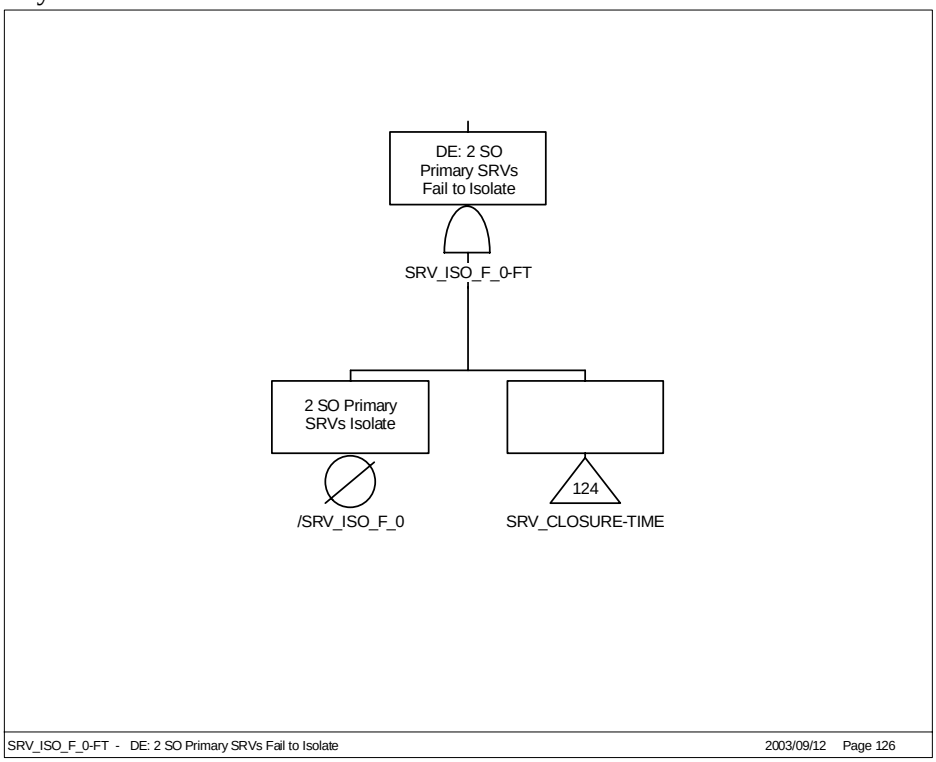

Figure 6.5. Fault tree for SRV_ISO_F_0-FT.

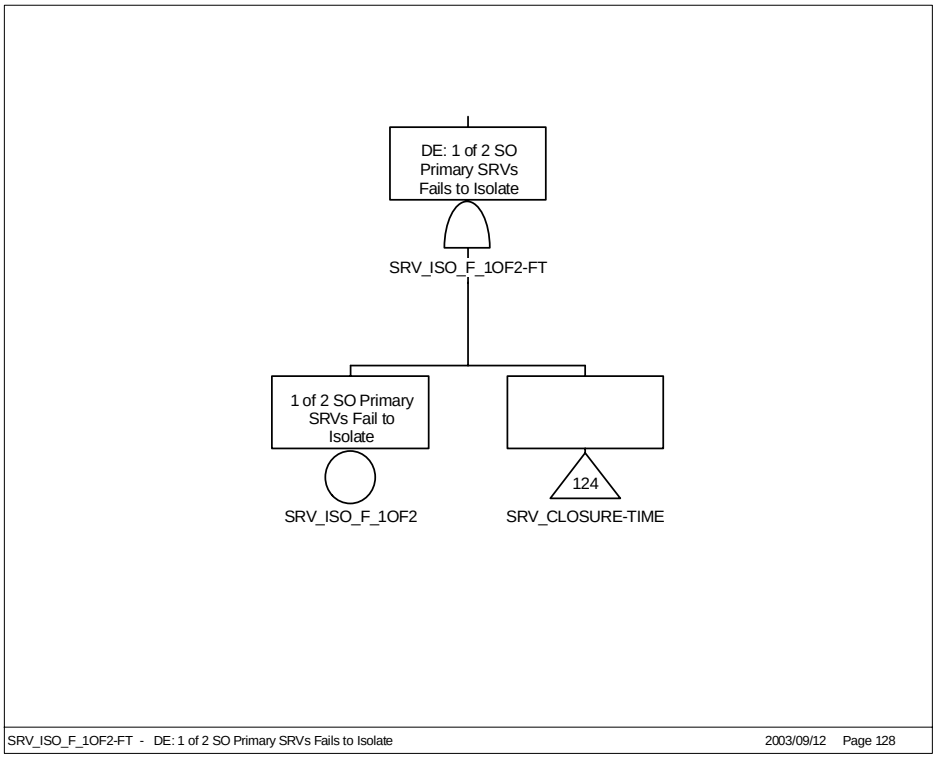

Figure 6.6. Fault tree for SRV_ISO_F_1OF2-FT.

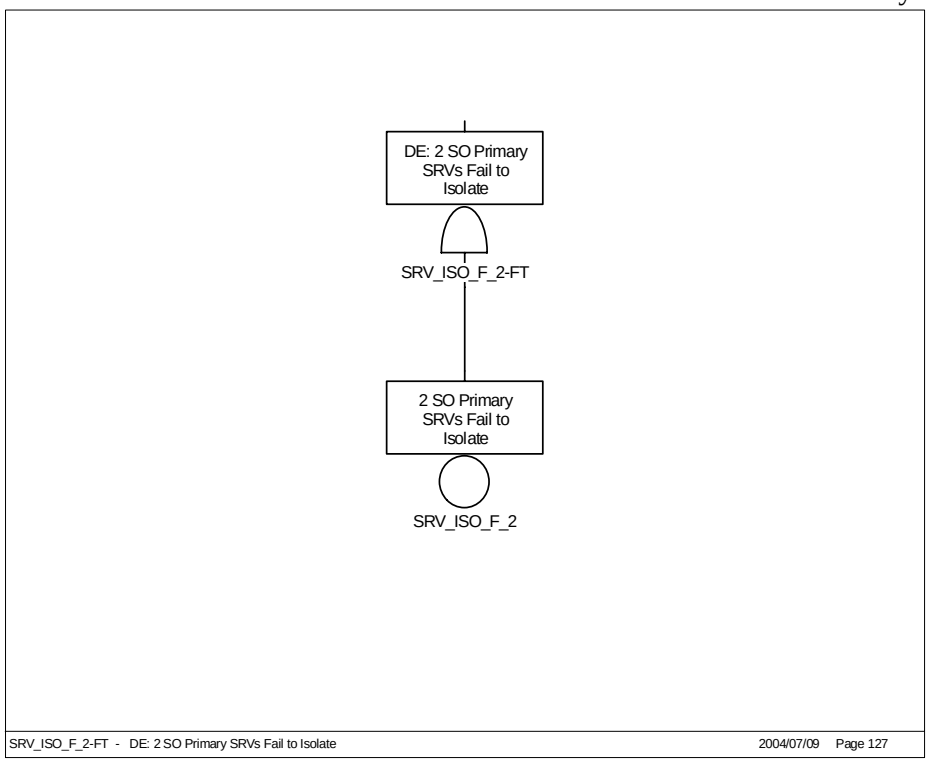

Figure 6.7. Fault tree for SRV_ISO_F_2-FT.

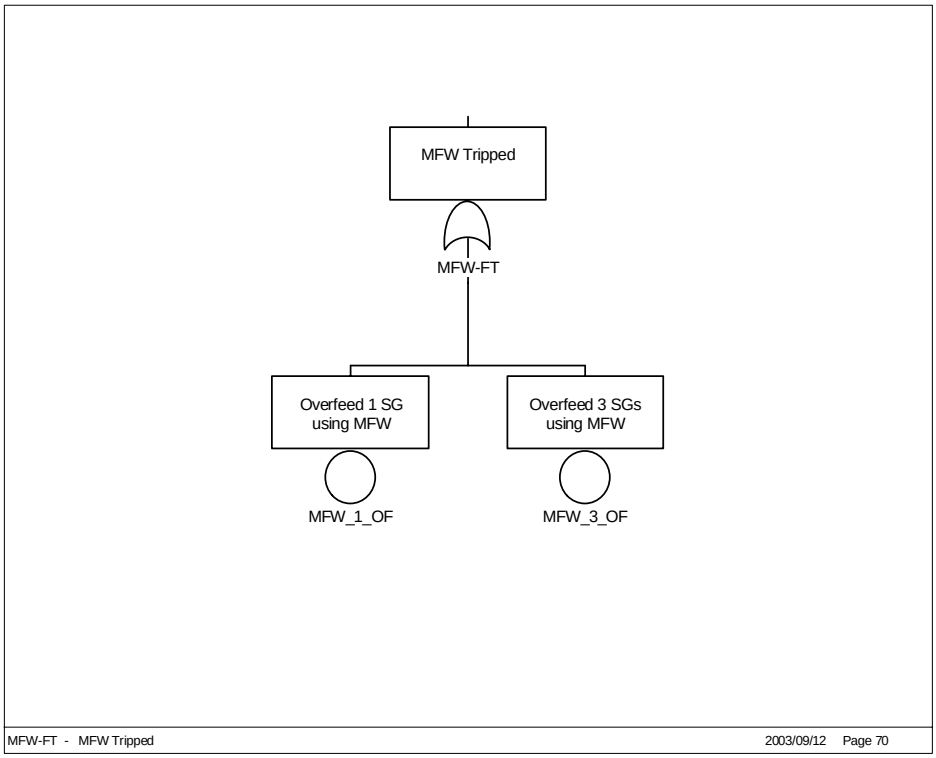

Figure 6.8. Fault tree for MFW-FT.

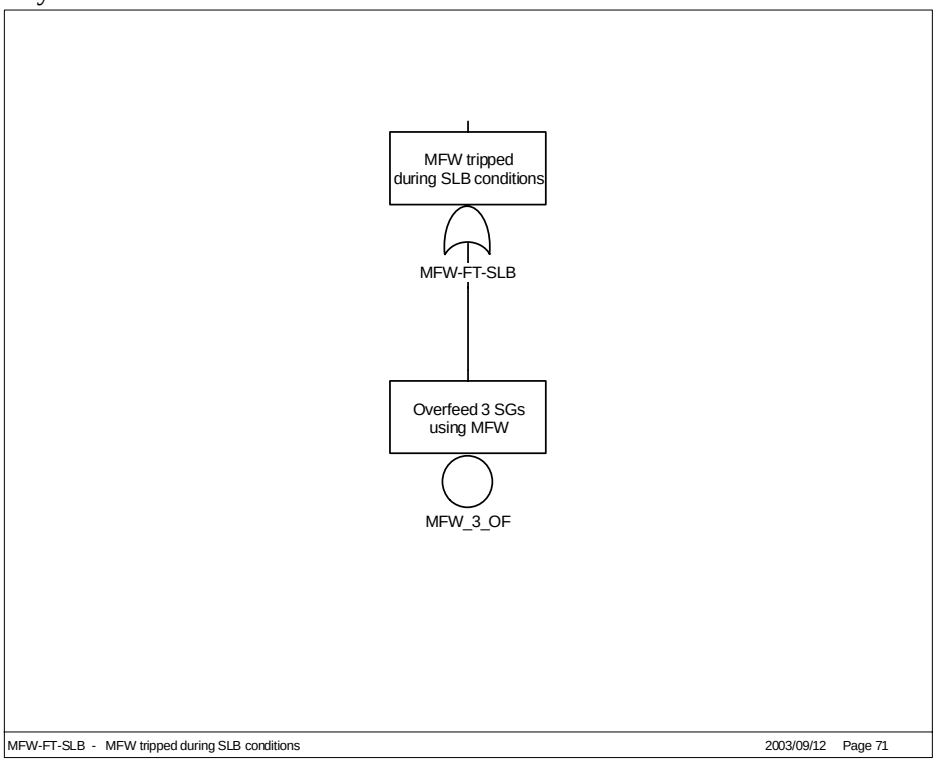

Figure 6.9. Fault tree for MFW-FT-SLB.

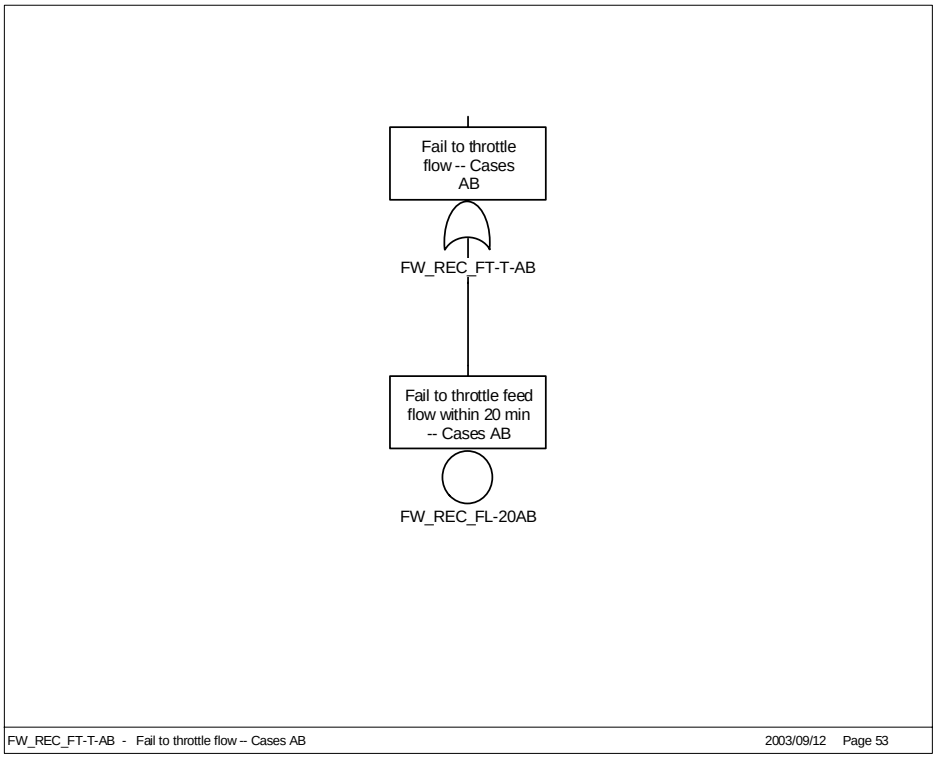

Figure 6.10. Fault tree for FW_REC_FT-T-AB.

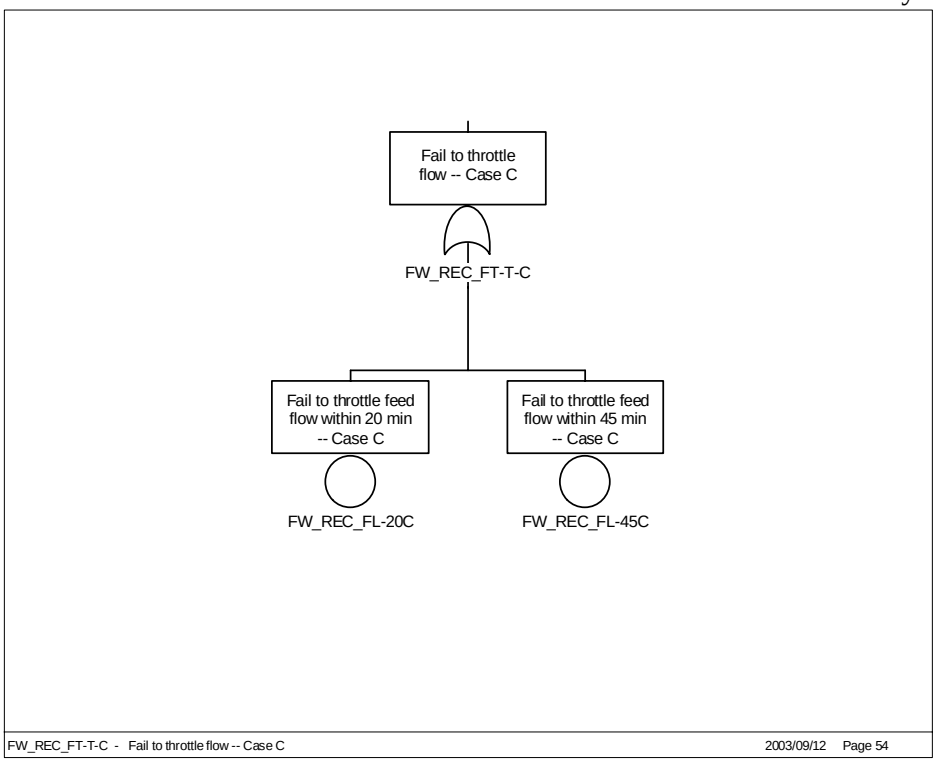

Figure 6.11. Fault tree for FW_REC_FT-T-C.

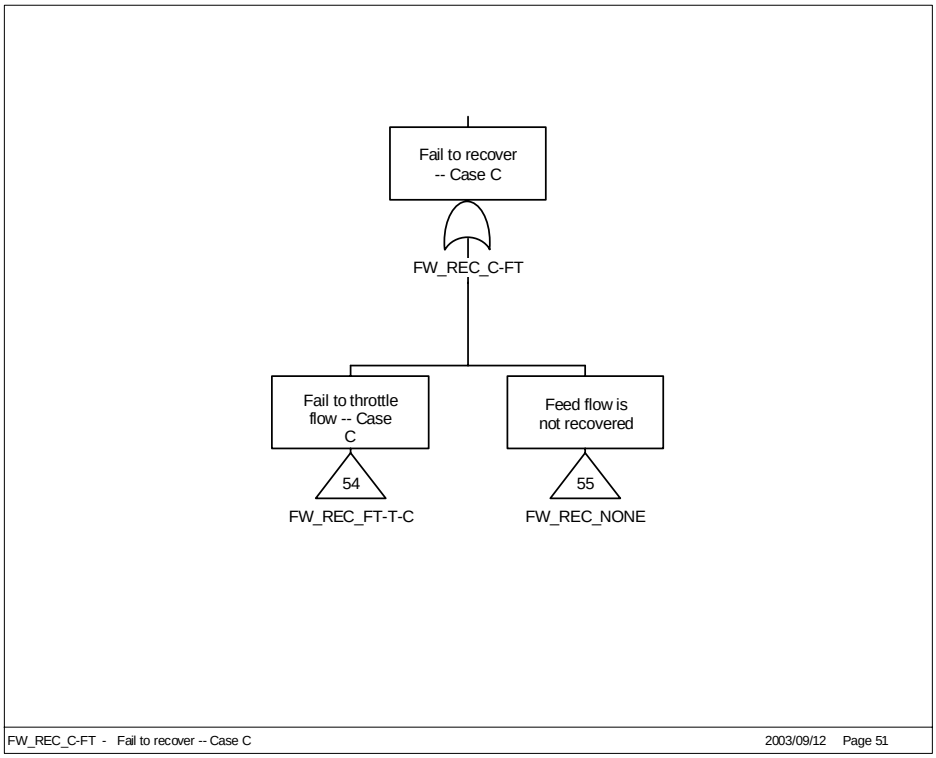

Figure 6.12. Fault tree for FW_REC_C-FT.

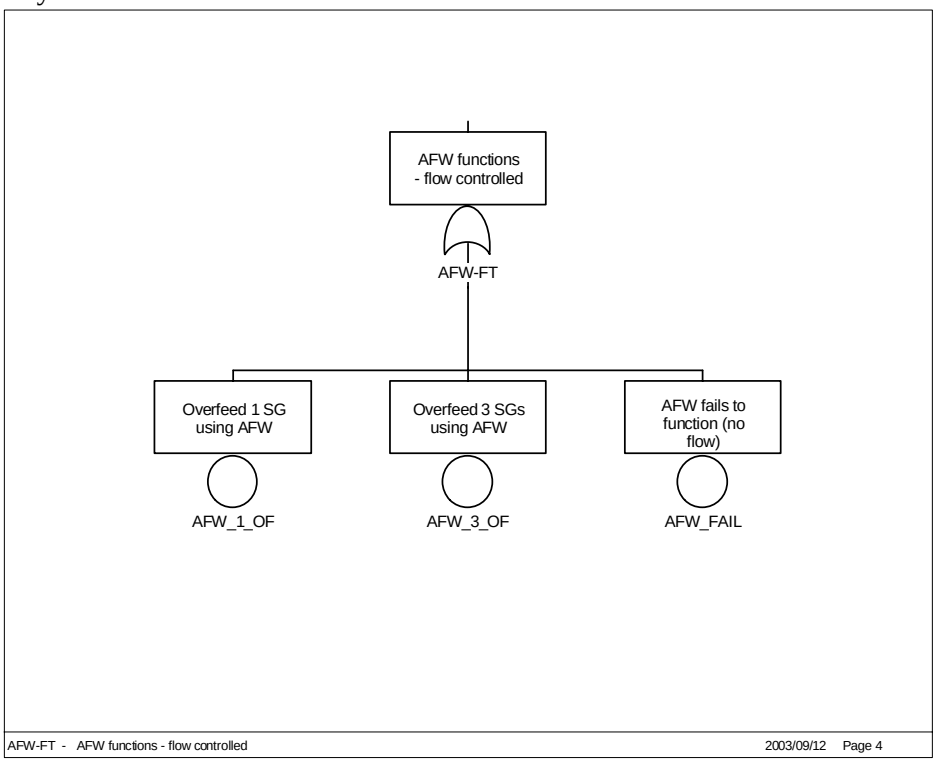

Figure 6.13. Fault tree for AFW-FT.

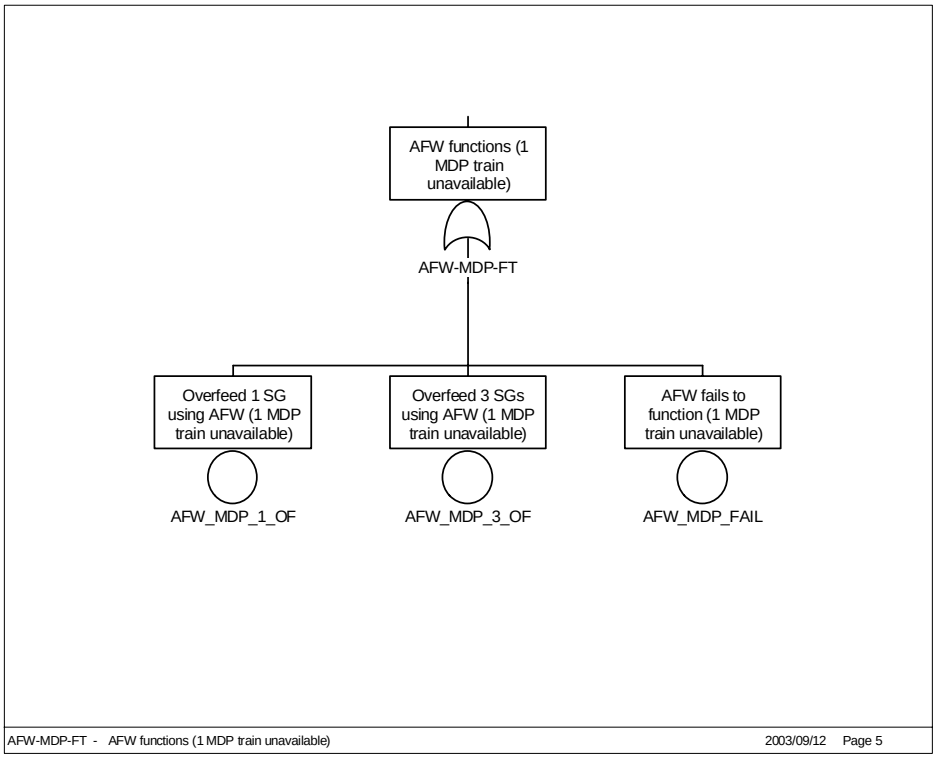

Figure 6.14. Fault tree for AFW-MDP-FT.

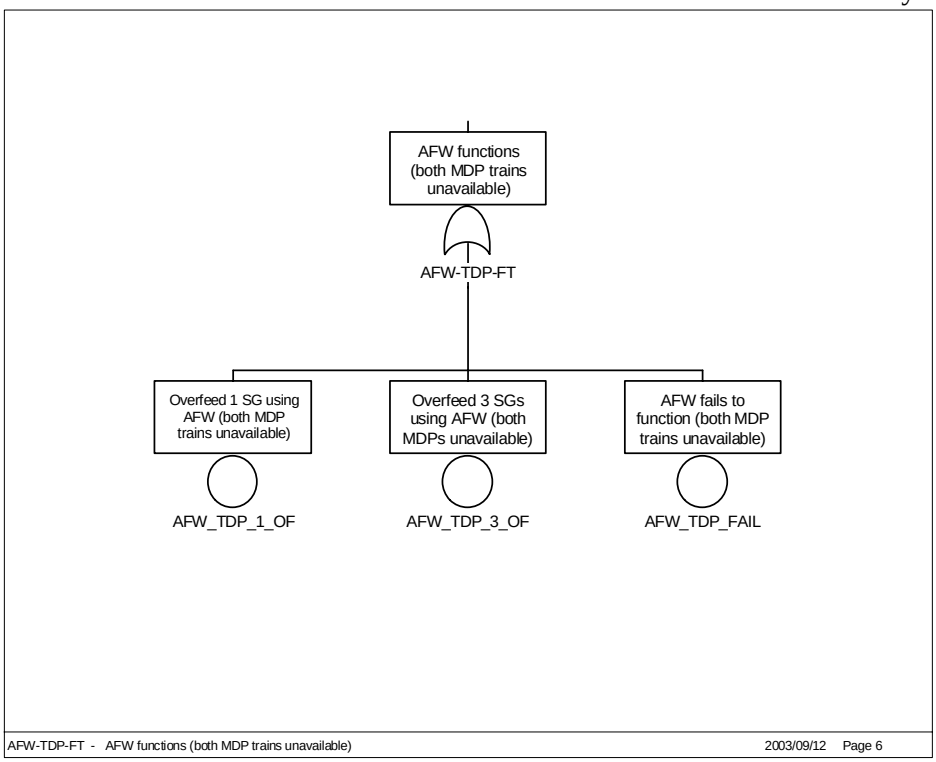

Figure 6.15. Fault tree for AFW-TDP-FT.

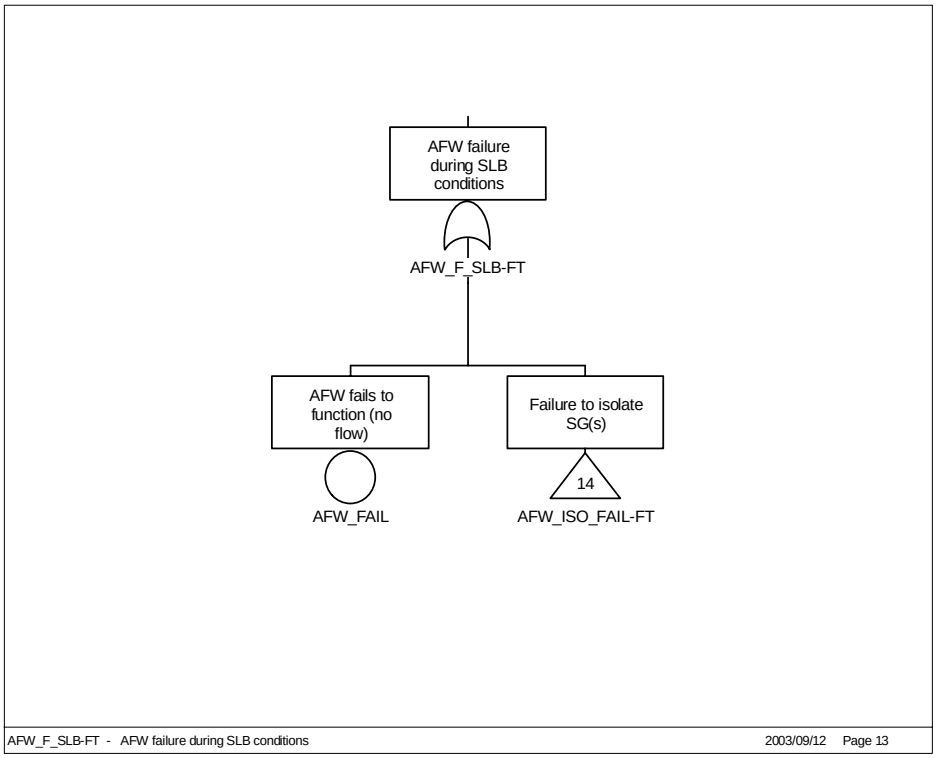

Figure 6.16. Fault tree for AFW_F_SLB-FT.

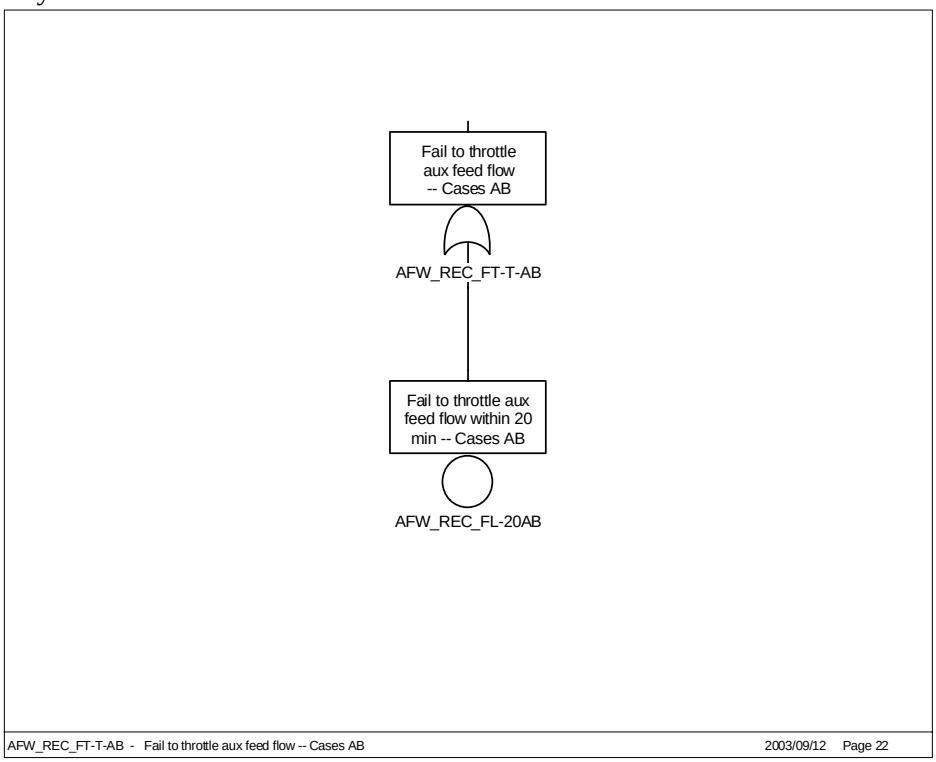

Figure 6.17. Fault tree for AFW_REC_FT-T-AB.

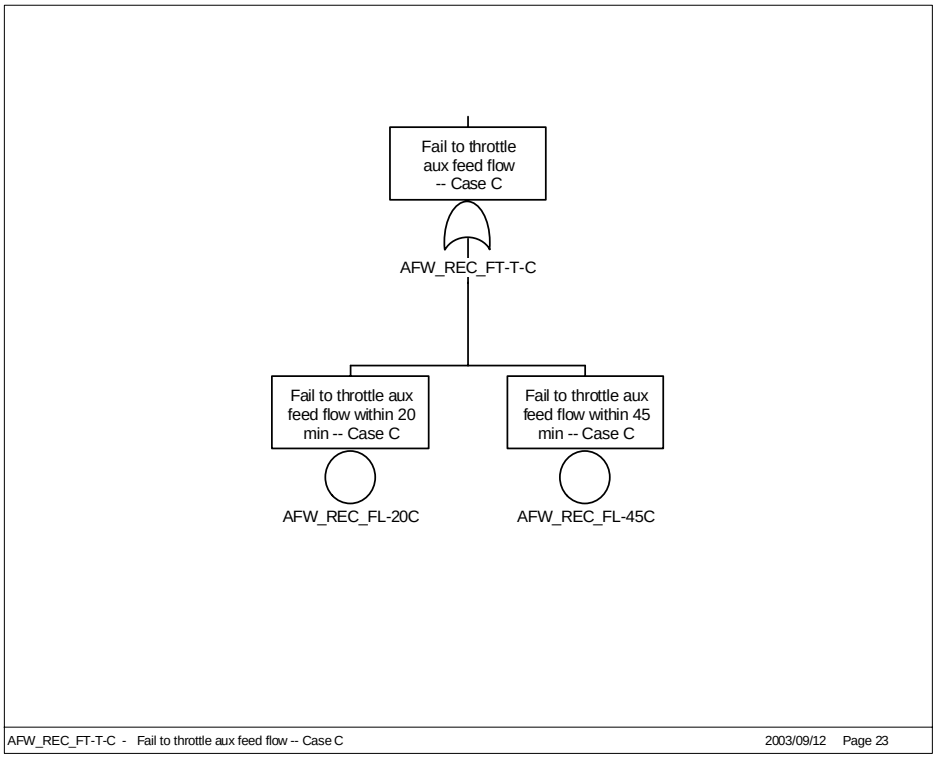

Figure 6.18. Fault tree for AFW_REC_FT-T-C.

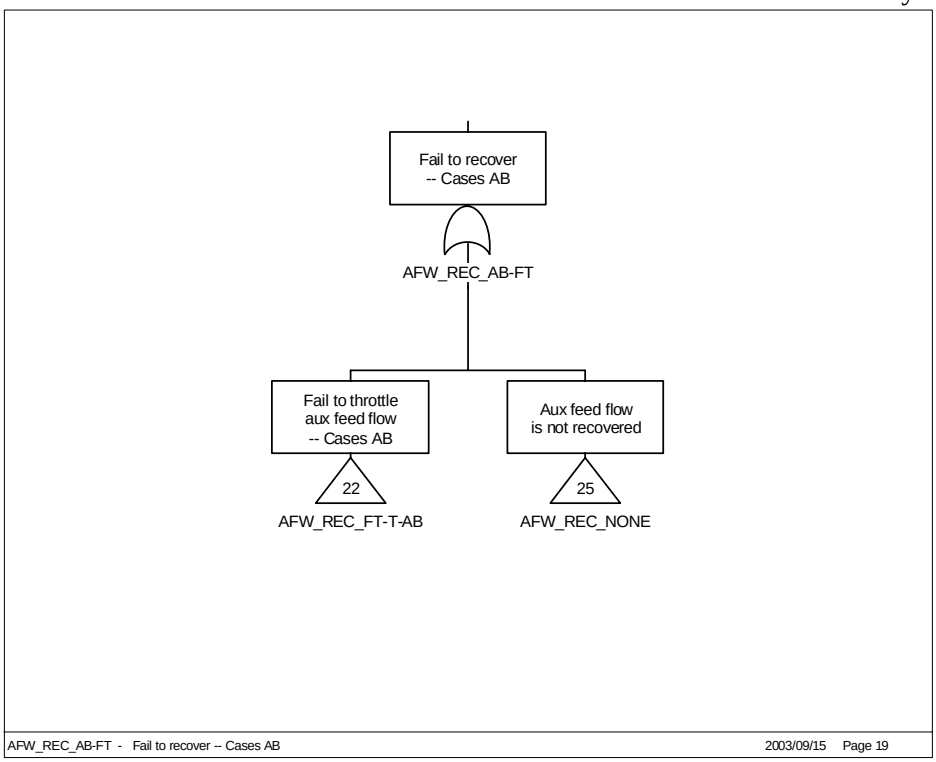

Figure 6.19. Fault tree for AFW_REC_AB-FT.

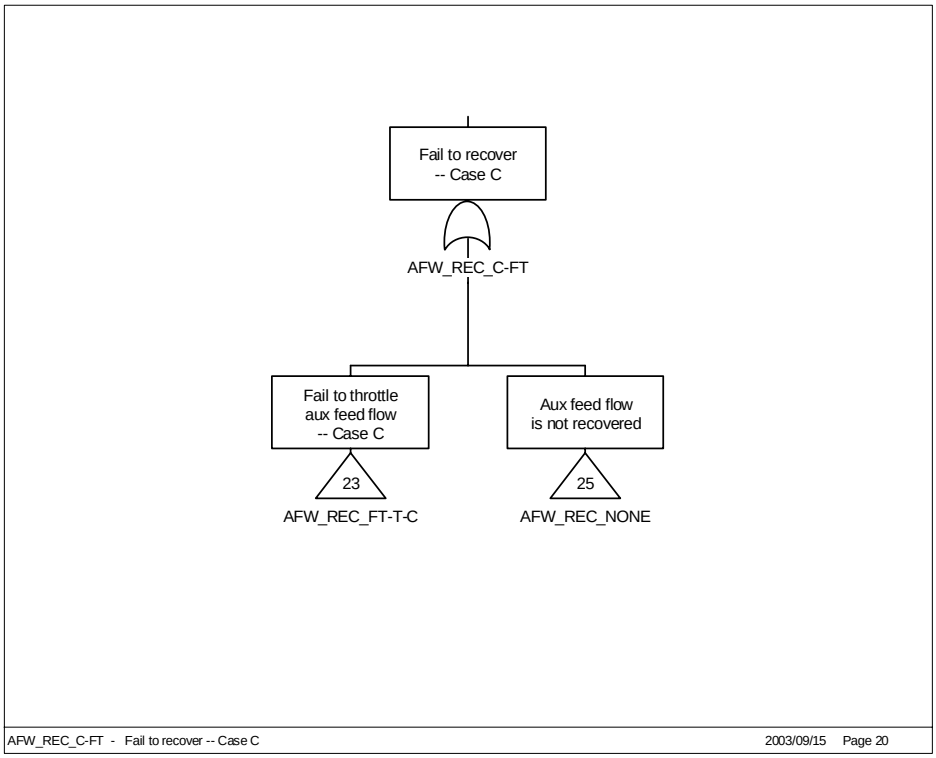

Figure 6.20. Fault tree for FW_REC_C-FT.

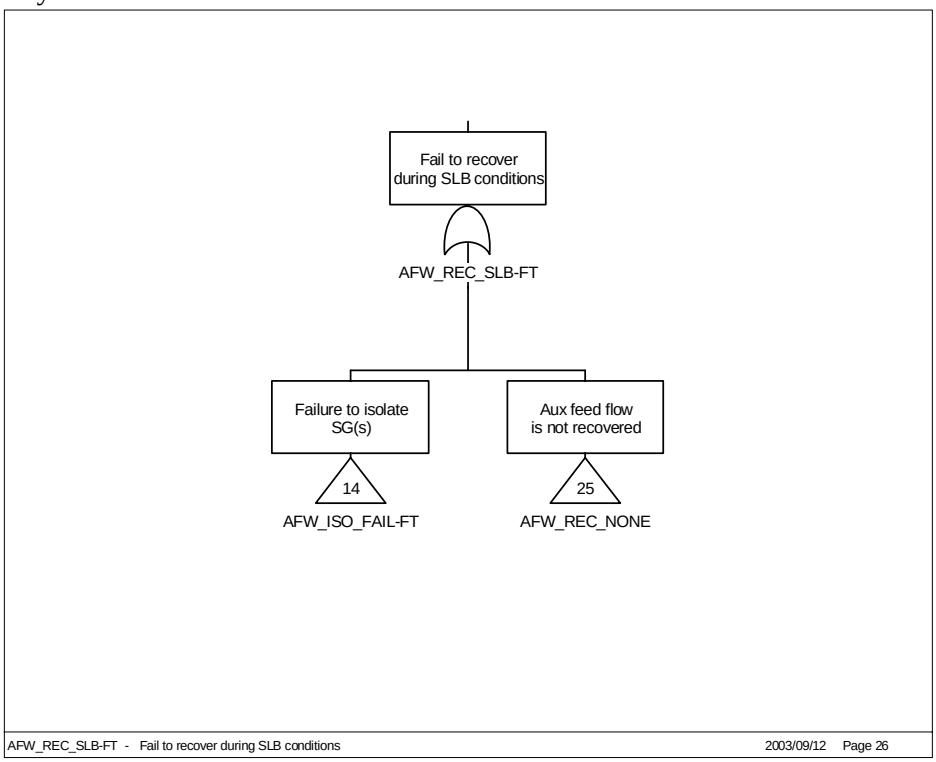

Figure 6.21. Fault tree for AFW_REC_SLB-FT.

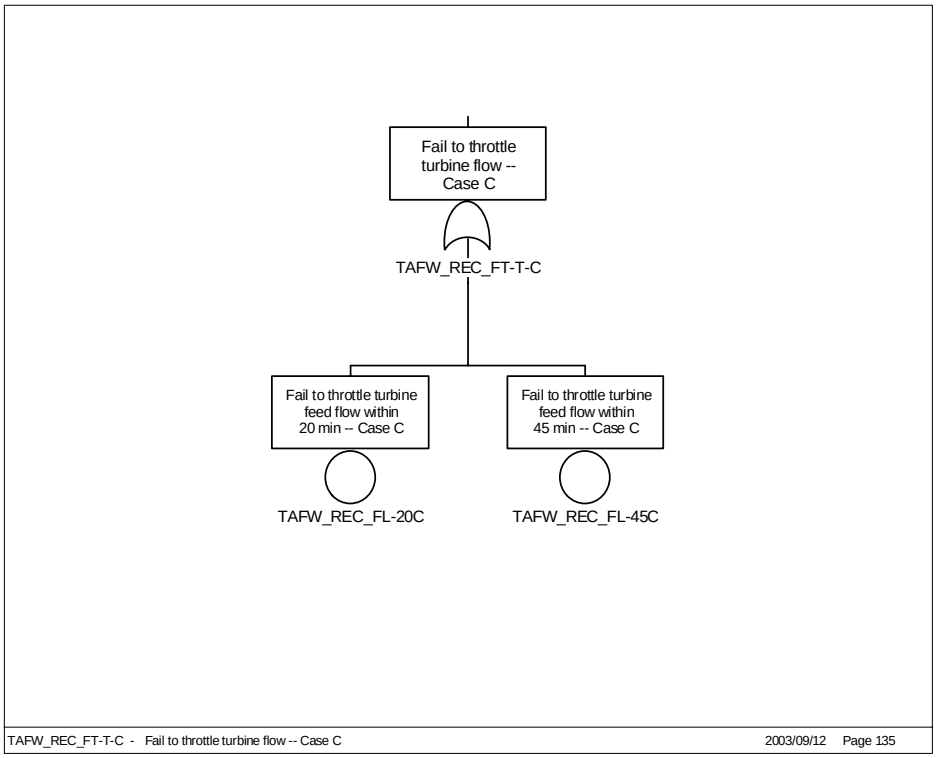

Figure 6.22. Fault tree for TAFW_REC_FT-T-C.

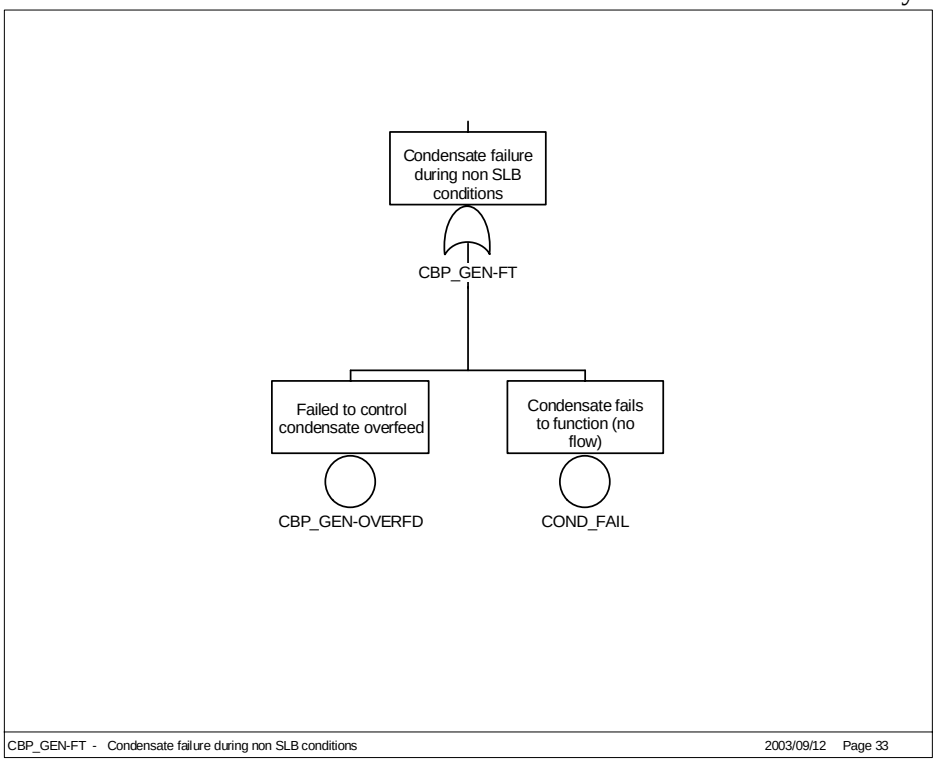

Figure 6.23. Fault tree for CBP_GEN-FT.

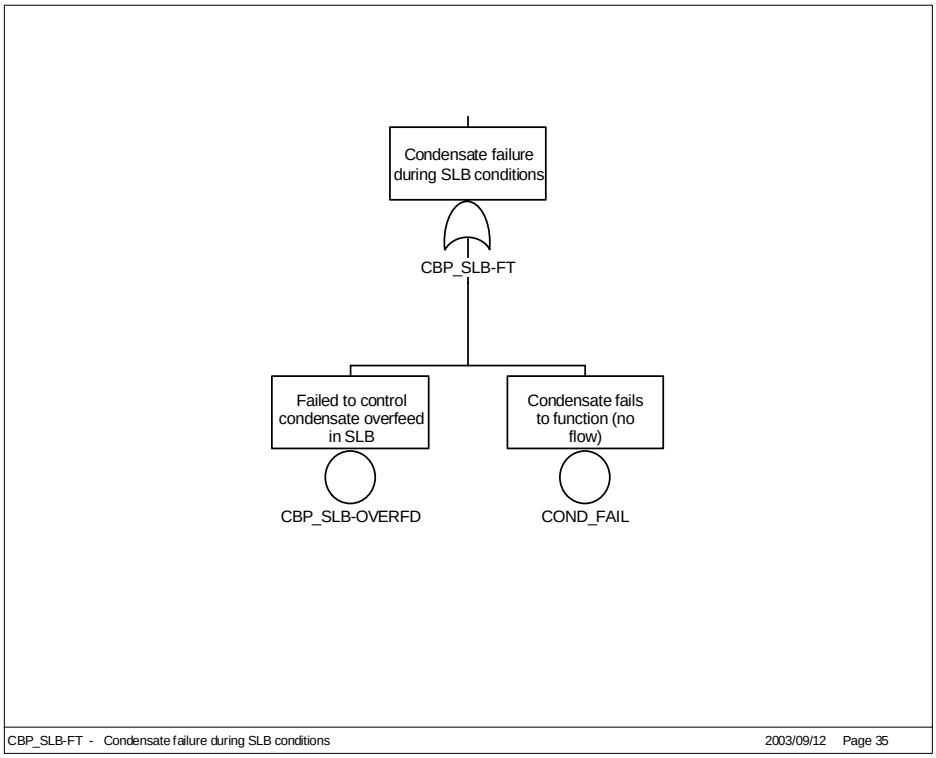

Figure 6.24. Fault tree for CBP_SLB-FT.

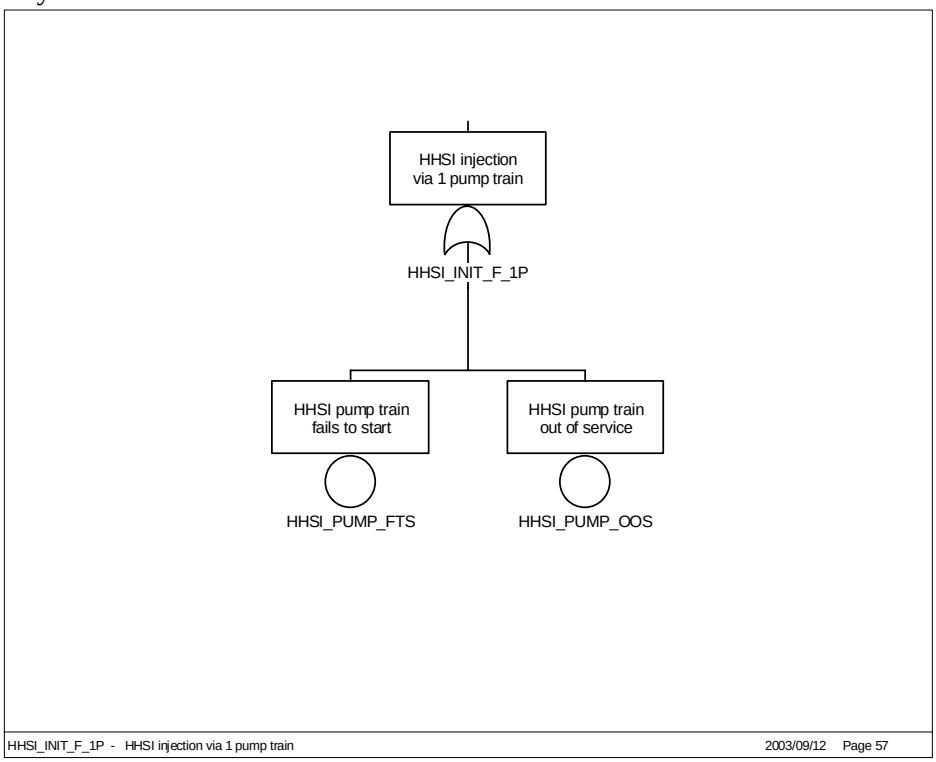

Figure 6.25. Fault tree for HHSI_INIT_F_1P.

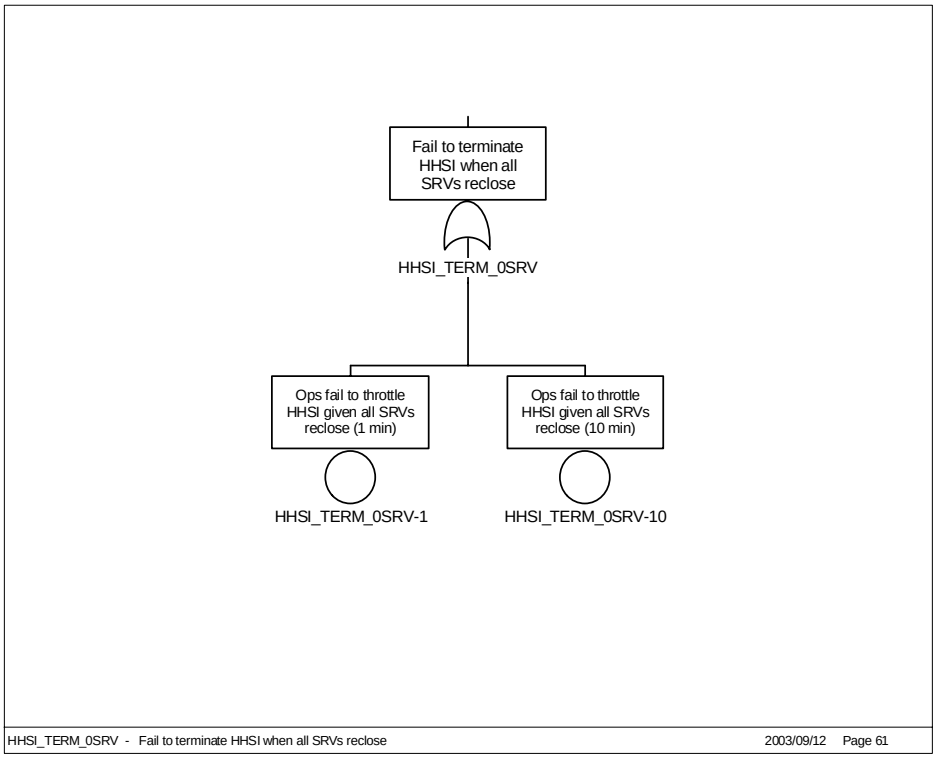

Figure 6.26. Fault tree for HHSI_TERM_0SRV.

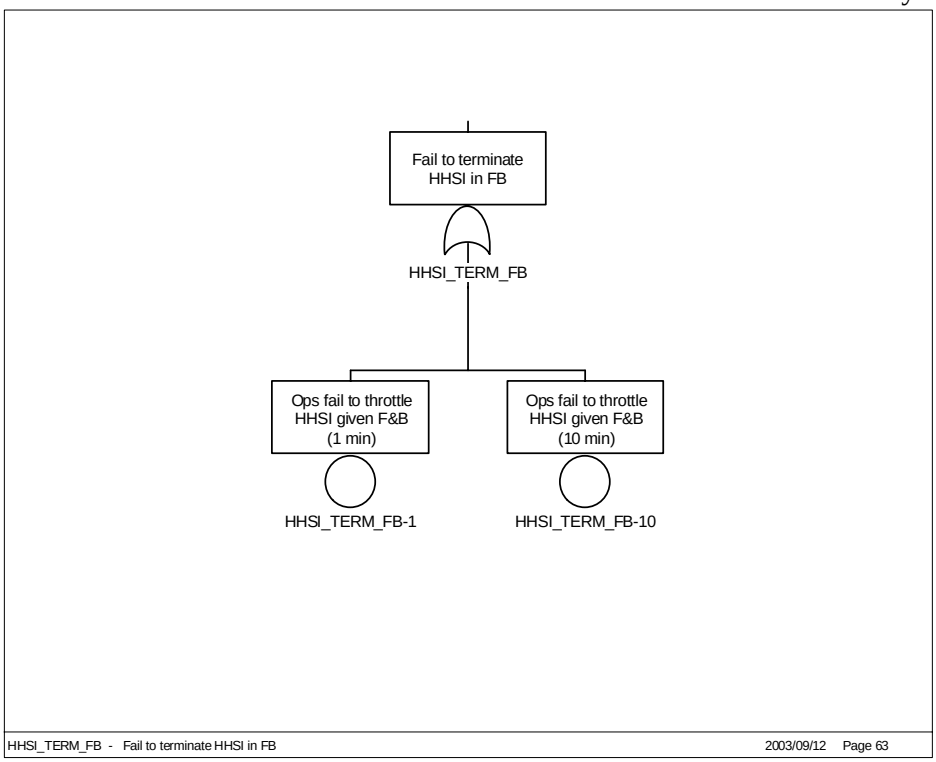

Figure 6.27. Fault tree for HHSI_TERM_FB.

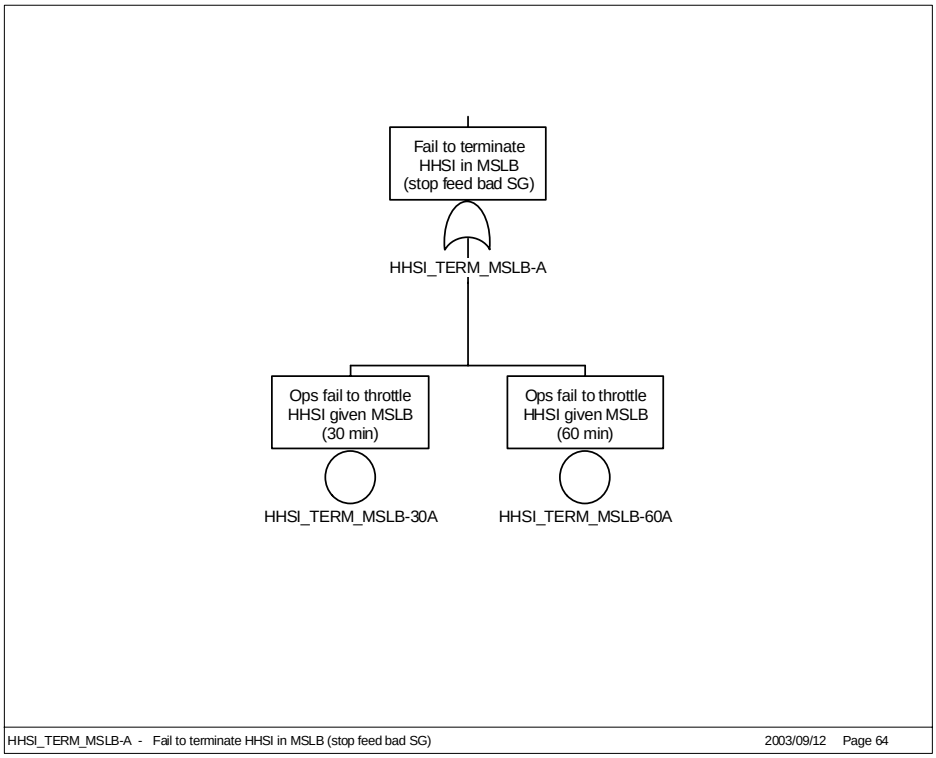

Figure 6.28. Fault tree for HHSI_TERM_MSLB-A.

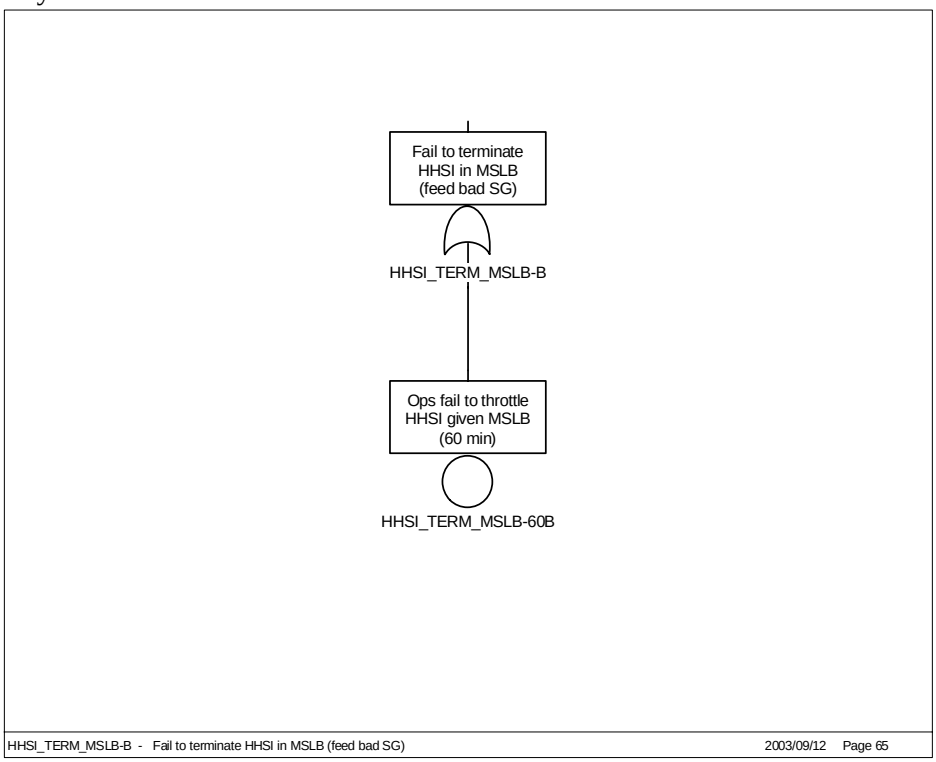

Figure 6.29. Fault tree for HHSI_TERM_MSLB-B.

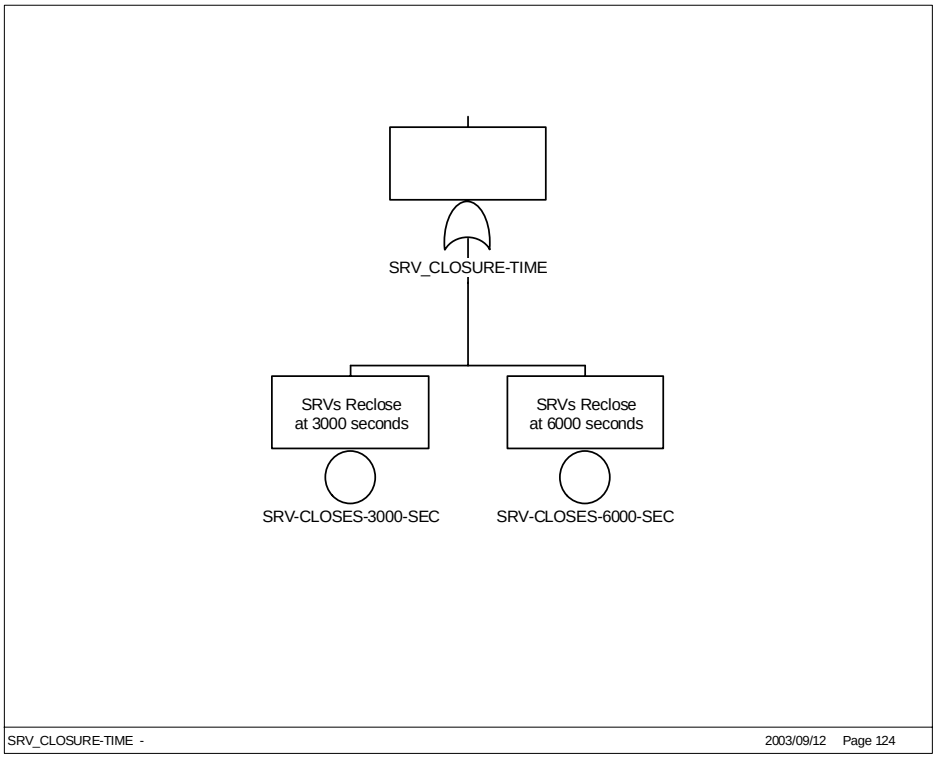

Figure 6.30. Fault tree for SRV_CLOSURE-TIME.

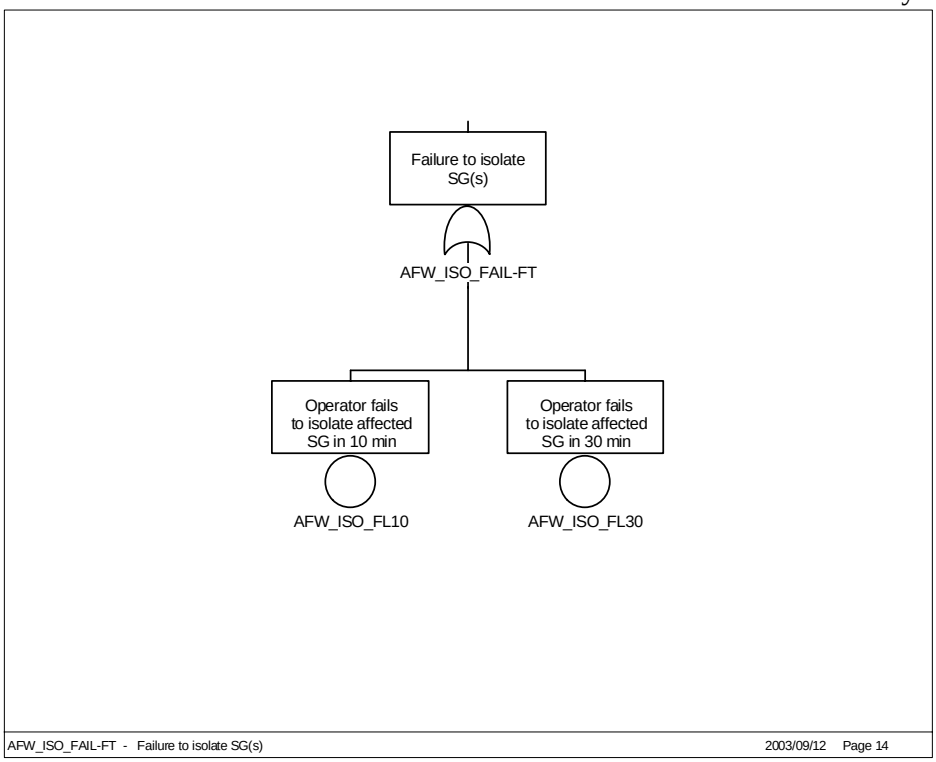

Figure 6.31. Fault tree for AFW_ISO_FAIL-FT.

6.2.3 Main Feedwater

The main feedwater (MFW) system provides feedwater to the three u-tube steam generators by means of two motor-driven MFW pumps. Feedwater flow to the steam generators typically trips given an initiating event.

If MFW flow does not trip or is not terminated by the operators, then excessive heat can be removed from the primary system as long as the primary and secondary systems remain thermally “connected.” Removal of sufficient heat will cause the primary system pressure to decrease and the inventory to shrink, necessitating injection of relatively cold water. This injection of relatively cold water enhances the potential for PTS.

6.2.4 Auxiliary Feedwater

The auxiliary feedwater (AFW) system provides feedwater to the three u-tube steam generators by means of two motor-driven pumps and one steam-driven pump after loss of MFW. Once started, AFW flow to the steam generators is automatically controlled.

If AFW flow is not controlled to intact steam generators or flow is not terminated to a faulted steam generator, the effect on PTS is similar to that described for MFW.

6.2.5 Dedicated Auxiliary Feedwater Pump

The dedicated auxiliary feedwater (DAFW) pump can be used to supply feedwater to the steam generators if both MFW and AFW are unavailable. The pump is started manually.

If DAFW flow is not controlled, the effect on PTS is similar to that described for AFW.

6.2.6 Condensate Booster Pumps

Any one of the condensate booster pumps (CBPs) can be used to provide alternate feedwater to the steam generators if AFW and DAFW fail to provide feedwater flow. Use of a CBP requires the depressurization of the secondary side of the steam generators.

The process required to establish alternate feedwater flow by a CBP to the steam generators enhances the potential for PTS by removing heat from the primary system. This removal of heat causes the primary system pressure to decrease and the inventory to shrink, necessitating injection of relatively cold water. Failure to control alternate feedwater flow by a CBP to the steam generators increases the potential for PTS.

6.2.7 High Head Safety Injection

The high head safety injection (HHSI) system is a three-pump[9], two-injection-train system that normally provides makeup to the RCS and RCP seal injection flow. It also supplies high-pressure emergency cooling and can be used to provide an alternate means of core heat removal if cooling via the steam generators is lost. Discharge pressure for the HPI system is sufficient to lift the pressurizer SRVs.

The injection of relatively cold water by the HPI system enhances the potential for PTS. Continued, uncontrolled injection by the HPI system that results in an increase in reactor pressure enhances the potential for PTS both by injection of relatively cold water and the increase in reactor pressure. The control or throttling of HPI minimizes the potential for PTS.

6.2.8 Accumulators

The accumulators inject borated water from three tanks into the reactor vessel whenever reactor coolant system pressure falls below 605 psig.

The injection of relatively cold water by the accumulators enhances the potential for PTS.

6.2.9 Low Pressure Injection

The low pressure injection (LPI) system is a two-train, high-capacity, low pressure system designed to protect the reactor core from overheating due to loss of coolant resulting from RCS breaks up to and including a double-ended break of a 36-inch pipe. (NOTE: This system was not explicitly modeled in

[9] The third pump does not receive a safety injection signal. Only a single HHSI pump can be powered by a 4 kV bus at any given time.

the PTS probabilistic risk assessment (PRA). Its description is provided here because the thermal-hydraulic [TH] calculations that were performed as part of the overall PTS project did include operation of the LPI system if RCS conditions were such that the LPI system would be demanded. The non-inclusion of LPI in the PRA is slightly conservative given that failure of the LPI system would tend to minimize PTS by preventing the injection of relatively cold water into the reactor vessel.)

6.2.10 Reactor Coolant Pumps

The reactor coolant pumps (RCPs) provide mixing of the water within the RCS to prevent thermal stratification. In addition, operation of an RCP minimizes the cooling effect on the reactor vessel internal wall during injection of water to the reactor vessel.

The loss of the RCPs would tend to enhance the potential for PTS.

6.2.11 Diesel Generators (Emergency AC Power)

The diesel generators (i.e., emergency AC power) provide AC power to 1E equipment. Loss of the diesel generators result in the loss of 1E equipment dependent upon AC power.

Typically, loss of emergency AC power dependent equipment will tend to reduce the potential for PTS because the equipment cannot inject relatively cold water into the reactor vessel. However, one exception does exist–loss of power to the PORV block valve. This loss of power results in the inability to close the block valve thereby preventing the termination of a stuck open PORV scenario. As described previously, a stuck open PORV increases the potential for PTS.

7. HUMAN RELIABILITY ANALYSIS

This section summarizes the human reliability analysis (HRA) performed to support the Beaver Valley PTS PRA. As for the overall PRA study, both nominal/full power and low power cases were analyzed. The HRA performed for this study addressed post-initiator human failure events (HFEs) only. Pre-initiator HFEs were not modeled explicitly in the Beaver Valley PTS PRA. Rather, such human events were assumed to be included in the industry-wide data used to model system unavailabilities as this was sufficient to meet the needs of the PTS study.

Plant records of overcooling events that have actually occurred [INEEL LER Review] as well as the earlier and other PTS analyses [NUREG/CR-3770, NUREG/CR-4183, NUREG/CR-4022, WCAP-15156] demonstrate that operator actions and inactions can significantly influence the degree of overcooling and the reactor coolant system (RCS) pressure for many types of overcooling events. Consequently, operator action directly influences, in both beneficial and detrimental ways, the potential for many types of sequences of events to become a serious PTS challenge. For example, early operator action to isolate the feed to a faulted (depressurizing or already depressurized) steam generator, directly affects the amount of overcooling that occurs and how long such cooling is sustained. Hence, any "realistic" PTS analysis needs to consider operator actions and inactions that influence overcooling sequences. Therefore, consistent with the guiding principals of this project to adopt best-estimate models and treat uncertainties explicitly whenever practicable, we have included a rigorous treatment of human actions in the Beaver Valley PTS PRA model.

Improvements in the current work as compared to that performed in the earlier PTS analyses include:

- a more realistic treatment of operator actions based on detailed consideration of sequence specific contextual factors, multiple simulator observations, latest procedures and training, and numerous discussions with licensee operating and training staffs, as compared to a lack of significant credit in earlier PTS analyses

- a greater number of discrete operator action times (where important to the degree of PTS challenge) is considered as compared to fewer and more conservative time periods treated in the early work (for instance, the current Beaver Valley analysis may examine operator action/inaction in 1 and 10 minutes for a specific human event compared with (in some cases) a corresponding early analysis of only the 10 minute time period thereby leading to conservative results since overcooling is allowed to continue for 10 minutes before human action is potentially credited in the model)

- modeling of detrimental acts of commission, especially where procedural steps call for actions that could exacerbate overcooling conditions.

The HRA for this study was performed by NRC contractors. However, significant plant support was provided by Beaver Valley staff supported by Westinghouse staff. In particular the plant staff supported the HRA by:

- supplying relevant, up-to-date plant information such as procedures, training materials, drawings, systems design information, and other related documentation

- hosting a plant site visit, including discussions with operator trainers, thermal hydraulic engineers, PRA specialists, and observations of operator simulator training on relevant scenarios

- answering questions, formally and informally, throughout the analysis

- hosting a second plant visit for reviewing preliminary results, including providing feedback and clarifying information associated with all elements of the PTS analysis including the HRA.

The ATHEANA process [NUREG-1624] was the basic approach used to perform this HRA analysis. The ATHEANA quantification approach evolved over the course of the Beaver Valley PTS HRA and this evolution is reflected in the results. A recent paper [OECD/NEA] describes the up-to-date, detailed ATHEANA quantification approach, called "quantification-including-uncertainty." Only those human failure events found to be most important to the analysis such that they required detailed HRA quantification (after an initial PRA/HRA quantification) were analyzed with the "quantification-including-uncertainty" approach.

Also, because the HRA was begun before other PTS program tasks (e.g., PRA, thermal-hydraulic calculations, fracture mechanics results) could provide all required HRA inputs, the Beaver Valley PTS HRA analysis was performed, by necessity, in an iterative fashion. The positive effects of the HRA analysis "leading" other aspects of the study were:

- greater integration between the HRA and the overall PRA tasks than is oftentimes achieved
- greater input from the HRA into the development of the PRA models
- greater input from the HRA into the selection of thermal-hydraulic calculations to perform.

For the HRA, the principal negative effect of "leading" other aspects of the study was the need to, at first, make more assumptions or rely on previous, rather than current, study inputs. To the extent possible, the early PTS analyses and especially the recent pilot plant application of the Electric Power Research Institute (EPRI) alternative method for analyzing for PTS that used Beaver Valley as the pilot plant [WCAP-15156] were used, including the HRA portions of those studies. The information from these studies was augmented by additional, up-to-date information provided by Beaver Valley staff through written questions and answers and the HRA team's analysis of current plant aspects (e.g., relevant procedures, training practices, observations of Beaver Valley simulator exercises for PTS-relevant scenarios).

7.1 Summary of the HRA Process

As noted above, the ATHEANA HRA process [NUREG-1624] was used to perform the Beaver Valley PTS HRA. This section summarizes the major tasks and milestones achieved in the HRA process as it was applied to the Beaver Valley PTS study more or less sequentially.[10]

The following is the general sequence of milestones in the Beaver Valley PTS HRA:

- information collection (continuous throughout the process)

- HRA qualitative analysis (continuous throughout the process)

[10] As noted above, some aspects of the Beaver Valley PTS HRA process steps were performed iteratively or even continuously.

- first site visit to Beaver Valley
- initial HRA quantification
- initial PRA quantification
- second site visit to Beaver Valley and receipt of comments and feedback from Beaver Valley and Westinghouse staffs on the initial results
- response to comments and concerns
- based on the initial PRA results, detailed HRA quantification (using the "quantification-including-uncertainty" approach) for a few particularly important HFEs that appeared in the most dominant PTS challenging scenarios.

While all steps in the ATHEANA process were performed, the specific tasks that supported the achievement of these milestones were:

- information collection
- review of previous PTS studies
- identification of potential HFEs (at first generally, and later on a sequence and action-specific basis)
- identification of potential vulnerabilities
- deviation analysis
- Beaver Valley plant visits
- quantification (preliminary and final)

Each of these tasks are summarized in the sections below.

7.1.1 Information Collection

Information collection was performed throughout the Beaver Valley PTS HRA as dictated by the information needs of the analysis. The following information comprised the initial information request to the Beaver Valley staff:

- The Emergency Operating Procedures and their accompanying "Bases" documentation
- Listing of the Abnormal Procedures[11]

[11] This list was reviewed to determine whether any of these procedures would be useful to determine likely human actions for some PTS-relevant initiators. Procedures were later requested and received as needed.

7. Human Reliability Analysis

- Thermal hydraulic (and if any, fracture mechanic) calculations/summaries relevant to PTS (in order to determine timing of key events and actions, assumed equipment automatic and manual operation, etc.)

- System P&IDs and related FSAR sections and other system/plant descriptive information[12]

- PTS Training information, including:
  - a description of the frequency of training
  - how such training is provided (e.g., does specific PTS training exist? Are PTS concerns discussed/simulated as part of other operator training?)
  - a copy of any relevant classroom training material
  - a description of typical scenarios trained
  - key results of any recent simulator debriefings
  - plant drill information related to the PTS issue
  - control room layout information and crew characteristics (size, key responsibilities, communication protocols, etc.)

This initial information was augmented by the Beaver Valley plant staff who provided answers to HRA-related questions throughout the analysis (e.g., hot zero power vs. full power operations).

7.1.2 Review of Previous PTS Studies

Information in the recent pilot plant PTS study [WCAP-15156] in particular, and from other PTS studies [NUREG/CR-4183, NUREG/CR-4022, NUREG/CR-3770] was reviewed in parallel with the collection and review of current Beaver Valley plant information. This review allowed the HRA team to quickly define general scenarios of interest and important related thermal-hydraulic plant responses (which dictate many of the cues for action) and relevant human actions for the Beaver Valley PTS study.

It should be noted that the information in WCAP-15156 was vitally important to the performance of this updated PTS HRA for Beaver Valley because, at the time of initial HRA quantification, updated thermal-hydraulic (TH) and fracture mechanics results were just becoming available for Beaver Valley. Fortunately, the updated TH and fracture mechanics calculations resulted in minor changes to the initial HRA (e.g., fewer PTS-relevant scenarios and some minor adjustments to the important times for human action). Consequently, the principal impact on the HRA was some loss in efficiency (i.e., some scenarios and associated actions were initially analyzed that, ultimately, were not part of the final PRA/HRA).

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[12] Beaver Valley's IPE [Beaver Valley IPE] was also reviewed to get as much of this information as possible. So, the focus of this information was on those systems/equipment particularly expected to influence PTS scenarios (e.g., auxiliary feedwater, main steam trip and non-return valves, pressurizer SRVs and PORVs/block valves arrangement and supporting electric power, high pressure injection system, and MSSRV-ADV-steam dump valves and any associated isolation valves arrangement).

7.1.2.1 General Scenarios of Interest

In addition to providing basic background information and knowledge on PTS potentially important for Beaver Valley, review of the early PTS analyses and particularly the pilot plant PTS study [WCAP-15156] allowed the HRA team to specifically perform Step 3 (i.e., define the base case scenarios) and part of Step 6 (i.e., identify deviation scenarios) of the ATHEANA process [NUREG-1624]. WCAP-15156 and the other earlier studies examined primarily what the ATHEANA process would call "base case *and* deviations from the base case" scenarios. Base case scenarios are defined as scenarios in which everything functions as planned, including operator actions. An example would be a main steam line break where all equipment and operator actions are performed successfully yielding a relatively minor overcooling event. Most of the scenarios analyzed in WCAP-15156, for instance, also included many equipment and operator failures (what ATHEANA would consider as "deviations" from the base case scenarios) that lead to many "deviation scenarios."

The current HRA took advantage of this prior work which included organization of possible scenarios and associated operator actions as they relate to four types of functional failures of interest to PTS (i.e., primary integrity, secondary pressure, secondary feed, and primary flow/pressure) as has already been discussed in prior sections of this document. Using this knowledge and particularly the same broad classification of scenarios by the functions affected, the possible human actions of interest were identified considering both (a) broad definitions of possible ways operators could affect or influence the four functions of interest as well as (b) the specific actions already analyzed in the earlier PTS studies. This is discussed more in section 7.1.3.

7.1.2.2 Thermal-Hydraulic Considerations

In performing a detailed and realistic HRA, it is important to understand the plant's expected thermal-hydraulic (TH) behavior in both base case and deviation scenarios. This is because the plant response, and associated equipment and instrument indications, form the basis and the timing for many of the cues that the crew will use in implementing their symptom-based procedures to know when and what actions to take in response to plant conditions. While updated TH calculations for Beaver Valley were in progress, few results were available at the time of initial HRA quantification. Consequently, initial HRA quantification relied considerably upon the TH calculations done in support of the pilot plant PTS PRA [WCAP-15156]. As updated Beaver Valley TH calculation results became available, the HRA was modified, as necessary, to reflect such results. Fortunately, as noted above, the updated TH and fracture mechanics calculations resulted in only minor changes to the initial HRA.

Based on this knowledge of plant thermal-hydraulic response in potential PTS-challenge scenarios, the following was observed to be particularly relevant to the HRA and the inclusion of these types of human actions in the Beaver Valley PTS study (keeping in mind the simplification process used to create the Beaver Valley PTS PRA as described earlier):

- timely action by the operators to control secondary feed and primary system injection could be important to the effects of overcooling events including overfeed events

- timely recognition and isolation of a depressurizing steam generator(s) (SG)(s) and control of primary system injection are very important to secondary depressurization events

- timely isolation (if possible) of primary integrity breaches (in which rather low downcomer temperatures may be unavoidable, depending on the break size) and control of primary pressure (if it is possible to subsequently increase the pressure via primary injection) are key operator actions.

The HRA focused on these actions in subsequent steps, although other actions such as appropriate or improper reactor coolant pump (RCP) tripping were also addressed. More complete definition of the human failure events (HFEs) of concern is presented in the next section.

It should be noted that the potential downcomer temperatures (>400F for the first ~10,000 seconds) and rates of change during any cooldown (<100F/hr) from the thermal-hydraulic information were used to screen out certain types of functional scenarios and related human actions that would be expected to be unimportant to the PTS risk. These limits were provided by the fracture mechanics specialists and/or current uniformly accepted steps under existing procedures as being safe to use to eliminate unimportant cooling scenarios (subsequent checking of these assumptions verified these were appropriate).

7.1.3 Identification of Human Actions to be Modeled

In particular, the earlier H. B. Robinson PTS analysis, NUREG/CR-4183, and the recent pilot plant PTS study with Beaver Valley as the pilot plant, WCAP-15156, were used to initiate the identification of human actions to be included in this PTS study since these are Westinghouse plants. Those studies examined the human failure events shown in Table 7.1, including consideration of responses to some equipment failures.

Besides examining the associated contexts and resulting probabilities for these HFEs for various initiating events, the current Beaver Valley HRA made use of the current Oconee PTS study that had been ongoing and was sufficiently complete to suggest other possible HFEs including any contexts in which errors of commission (EOCs) may be possible. The EOCs of interest are any operator actions that are detrimental to PTS and might be performed when they should not be, although the operators believe the action(s) to be the correct thing to do. Consideration of the four functions of interest to PTS and how the operator could affect these functions, as was done in the current Oconee analysis, proved a valuable way to define the HFEs, at a general level, that were of interest to the Beaver Valley PTS study.

Using this earlier information about modeled HFEs, following the ATHEANA guidance to explore other possible HFEs, and considering the general types of scenarios of interest and the corresponding TH impacts, possible human interventions were identified. Table 7.2 presents a summary of the HFEs of potential concern (defined at a general level) in the Beaver Valley HRA. Note that these potential HFEs cover operator interaction with all the functions of concern, and represent both errors of omission (EOOs) and possible errors of commission (EOCs). The remainder of the HRA process focused on gathering and analyzing information (e.g., procedures) potentially relevant to the HFEs of concern as well as identifying possible contexts (i.e., plant conditions, training biases, etc.) that might make such HFEs more likely.

For specific modeled sequences in the PRA, these “general” HFEs were defined at a greater level of detail (i.e., specific act in a specific time period as appropriate) and quantified accordingly. More on the detailed HFEs is found in section 7.2.

Table 7.1. Human Failure Events (HFEs) considered in two PTS studies

Initiator or Function/System Status	H.B. Robinson PTS	WCAP-15156 PTS
Steamline break (or similar)	• Failure to isolate AFW flow to affected SG[1] • Failure to control AFW to maintain SG level in unaffected SG[1] • Failure to terminate SI within 10 min after subcooling is >40F, operable heat sink avail., PZR level >6%[1] • Failure to close MSIVs[2,3]	• Failure to identify and isolate faulted SG[4]
SLOCA	• Failure to control AFW to maintain SG level in unaffected SG[5] • Failure to isolate PZR PORV[6]	• Failure to isolate single PZR PORV • Failure to isolate multiple PZR PORVs
SGTR	• Failure to terminate SI within 25 minutes[7]	• Failure to terminate SI[8]
Loss of heat sink (LOHS)	- - -	• Failure to re-establish feed[9]

[1] For breaks upstream of MSIVs. Four different cases considered, involving large or small breaks, and for initial conditions at either full-power or hot 0% power.

[2] For a small break downstream of MSIVs.

[3] Three steam dump valve failures considered: failure of 1, 2, or more than 2 to close on demand.

[4] Three time windows considered: 10, 20, 30 minutes.

[5] Two cases considered: full power or hot 0% power.

[6] For two cases: failure of PZR PORV to close as an initiator and PZR PORV failure during repressurization following a separate event.

[7] Two cases: full power and hot 0% power.

[8] Two time windows considered: 3 min and 3-60 minutes.

[9] For LMFW events, restoration of MFW was assumed to be unlikely so only AFW was considered. For non-LMFW, no SI events, restoration of MFW within one hour of losing AFW was estimated.

Table 7.2. General classes of human failures considered in the PTS analysis.

Primary Integrity Control	Secondary Pressure Control	Secondary Feed Control	Primary Pressure/Flow Control
• Operator fails to isolate an isolable LOCA in a timely manner (e.g., close a block valve to a stuck-open PORV) • Operator induces a LOCA (e.g., opens a PORV) that induces or enhances a cooldown	• Operator fails to isolate a depressurization condition in a timely manner • Operator isolates when not needed (this may create a new depressurization challenge, lose heat sink, etc.) • Operator isolates wrong path/SG (depressurization continues) • Operator creates an excess steam demand such as opening steam dump or atmospheric dump valves	• Operator fails to stop/throttle or properly align feed in a timely manner (overcooling enhanced or continues) • Operator feeds wrong (affected) SG (overcooling continues) • Operator stops/throttles feed when inappropriate (causes underfeed, may have to go to feed and bleed & possible overcooling)	• Operator does not properly control cooling and throttle or terminate injection to control RCS pressure • Operator trips reactor coolant pumps when not suppose to and/or fails to restore them when desirable • Operator does not provide sufficient injection or fails to trip RCPs appropriately (modeled as leading to core damage rather than a PTS concern)

7.1.4 Identification of Potential Vulnerabilities

For the Beaver Valley PTS HRA, potential vulnerabilities were identified through the following:

- evaluation of formal rules as primarily dictated by the emergency operating procedures and other procedures expected to be used in response to various overcooling scenarios
- development of a crew characterization
- the investigation of potential vulnerabilities in operator expectations for various overcooling scenarios
- understanding of possible plant response timelines and any inherent difficulties associated with the required response
- identification of operator action tendencies and informal rules

The key findings for each search for potential vulnerabilities are summarized in the subsections below.

7.1.4.1 Evaluation of Emergency Operating Procedures and Other Procedures

With the help of Beaver Valley staff, the numerous emergency operating procedures (EOPs) and abnormal operating procedures (AOPs) of potential relevance to PTS were identified. In turn, the PTS relevant portions of these procedures and associated training were studied and summarized. For example, procedure maps, such as that shown in Figure 7.1 were developed for important procedures.

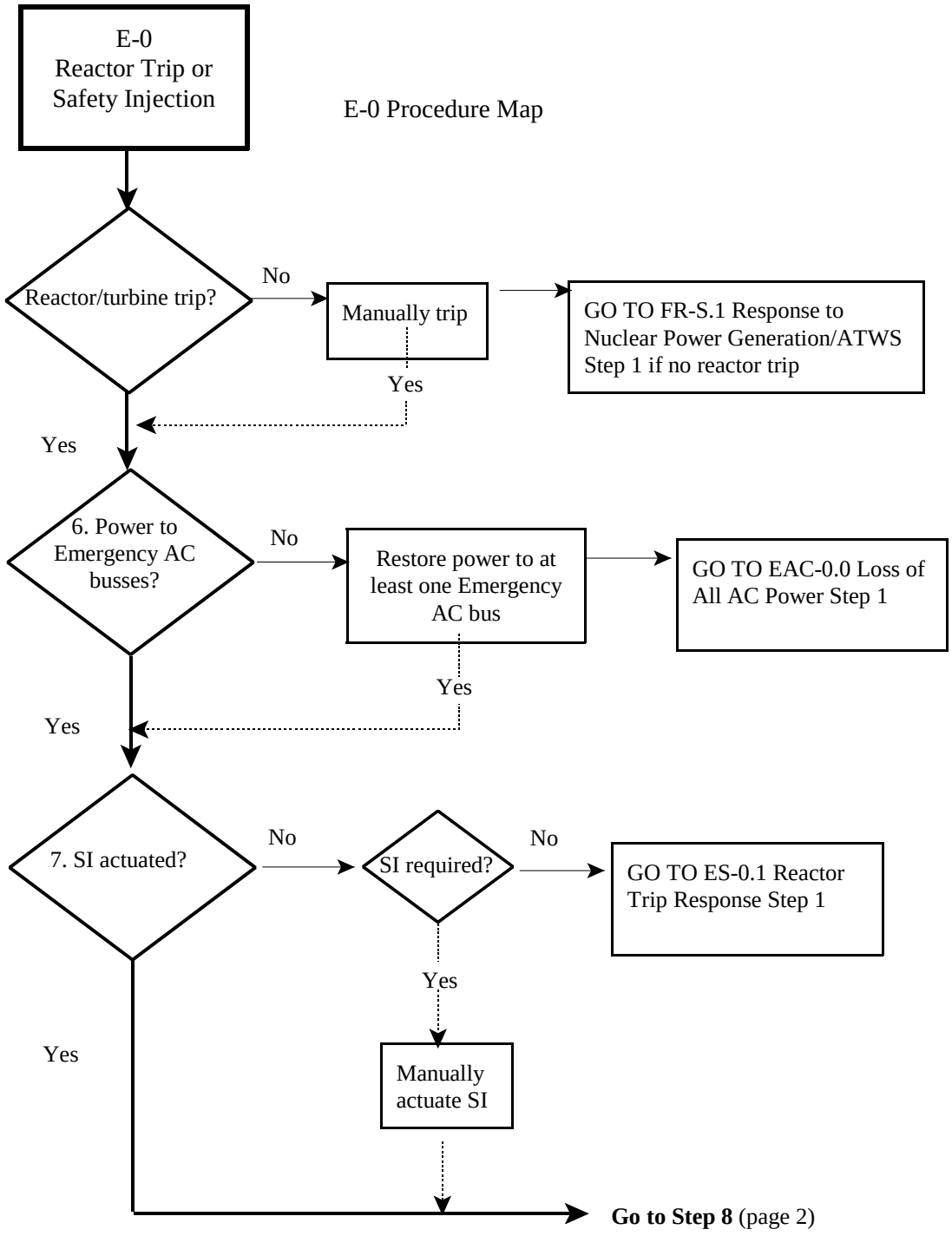

Figure 7.1. Example procedure flowchart.

7. Human Reliability Analysis

Based upon the evaluation of Beaver Valley procedures and training, and observations of simulated events, insights with regard to PTS were developed. For example, it was observed that, on the positive side, the Beaver Valley procedure set allows certain operator actions relevant to mitigating overcooling to be taken in a pre-emptive manner, even before the same specific steps would be reached in the procedures. In addition, once the critical functions are being responded to, if a higher action is called for (e.g., crew is responding to an orange condition and a red condition develops or crew is responding to a red and a higher (more important) red condition occurs), then a jump is made to the higher critical function response.

On the other hand, the Beaver Valley operations staff are trained to methodically use the procedures and though this is generally a good practice, it could delay certain overcooling responses since the mitigating action steps may take awhile to be reached in the procedures (as was observed in a simulator cooling event). Hence, deviation scenarios (i.e., scenarios with other complications from the nominal or "expected" scenarios) that create additional complexities and diversions (e.g., concurrent failures in the support systems), or that otherwise create high work loads or induce different and unexpected timing of events, would seem more apt to test the operators' ability to be successful at quickly mitigating some overcooling events. Delays or inaction could then result in higher primary or secondary flows than ideal for the conditions at the time (though still likely to be dealt with before any serious PTS challenge), therefore potentially prolonging or exacerbating an overcooling event.

Several other observations regarding the procedures and training were recognized as key issues to remember in ascertaining what operators might do under various plant conditions and the hierarchal practices carried out by the operators in responding to events. Namely,

1. The hierarchy of critical safety functions to be addressed by the operators is:

    - <u>Subcriticality</u> Such symptoms are associated with anticipated transient without scram (ATWS) types of events.

    - <u>Core cooling</u> and <u>heat sink</u> Tend to be more of a potential core damage concern although mitigating actions (e.g., open a PORV) or improper control of the secondary could lead to a subsequent overcooling event.

    - <u>RCS vessel integrity</u> Has the most relevancy to the PTS issue as this function is associated with precluding or otherwise mitigating conditions involving severe cooldown and a possible PTS challenge.

    - <u>Containment integrity</u> Involves symptoms and mitigating actions to ensure containment integrity.

    - <u>RCS inventory</u> Involves symptoms and mitigating actions to ensure sufficient coolant inventory to remove heat from the core. Improper control can have PTS relevancy.

2. Operators are to address these critical safety functions in order. Note that the most directly relevant procedure for PTS concerns is not at the top of the list, although all the procedures can have some PTS-relevancy.

3. Several Beaver Valley lesson plans for operator training address PTS. For example, the EOP lesson plan [LP-SQS-53.3] addresses:

    - examples of PTS events
    - technical definition of PTS and plant conditions characteristic of PTS
    - discussion of event types (e.g., SLOCA, steam break) that have a high potential for PTS
    - the vessel integrity status tree (F-0.4)
    - purpose, overview, and summary of FR-P.1, Response to Imminent PTS Condition
    - purpose, overview, and summary of FR-P.2, Response to Anticipated PTS Condition.

4. The EOP Generic Issues lesson plan [LP-SQS-53.2] also addresses PTS. PTS is also addressed by the lesson plans related to the critical safety functions [LP-NOMCD-1.4, LP-NOMCD-2.4]. It is noted that while many of the EOPs and related guidance contain steps to deal with such conditions as faulted SGs and when to terminate safety injection (SI), procedures specific to the concern of PTS reveal that RCS temperatures must be in the 300F-330F range before PTS concerns are deemed as imminent and specific PTS-related steps are followed.

5. E-0, the first EOP to be entered, is written and followed such that numerous equipment status checks are made before steps are reached that would begin to address overcooling and/or respond to critical safety function status indicative of overcooling. For example, E-0 first makes sure full SI and auxiliary feedwater system (AFWS) flows are occurring (among other equipment status) and doesn't address main feedwater (MFW) isolation and need for main steam isolation until steps 13 and 14, possible throttling of AFWS until step 19, possible stoppage of dumping steam until step 21, closing any open power-operated relief valves (PORVs) or similar pathways along with possible entry into E-1 to deal with loss of reactor coolant system (RCS)/secondary coolant until step 23, possibly stopping reactor coolant pumps (RCPs) until step 24, dealing with a faulted SG or possible steam generator tube rupture (SGTR) until steps 25 and 26, termination of SI until step 28, and monitoring/responding to critical safety function status trees until step 29. Even without malfunctions or other diversions, it would seemingly take at least 5-10 min to get to most of these steps with relevance to mitigating any overcooling; so, any overcooling would continue to occur at least until this time unless certain pre-emptive actions are taken. With nuisance alarms/conditions or workarounds or other malfunctions related to the equipment status covered in E-0 (e.g., MFW doesn't isolate), the time to get to these relevant steps (especially SI termination) can be significantly longer as evidenced by the observed simulations (i.e., the operators may need more time addressing a problem), further delaying response to an ongoing overcooling. In such cases, this means some time will pass before entry into the other procedures (e.g., E-2 or E-3) occurs and the subsequent actions are taken.

6. There are 6 pre-emptive actions that can be taken before they are called for in the E-0 step sequencing, some having to do with identifying and mitigating sources of overcooling. The pre-emptive actions include:

    - stop RCP feeding a failed open spray valve,
    - put steam dumps in steam pressure mode with no RCPs,
    - open instrument air cooling water supply valve,
    - throttle feed as long as heat sink requirements are met,

- isolate feed to a ruptured SG when narrow range back on scale, and
- isolate AFW to a faulted SG.

It is not clear that there is a strong bias to take these pre-emptive actions but instead it seems that there is a tendency to follow E-0 methodically and deal with the necessary actions when they are called out.

7. Response to failure of turbine trip is among the first few immediate actions and so should be responded to very quickly.

8. RCP shutdown requires a check of RCS status. All 3 SG pressure indications are located some distance from each other. In addition, operators must then make a mental or written calculation of any differences to determine if the 200 psid criteria is met. This process is apparently different from some other Westinghouse plants and, at least, provides the potential for miscalculation and, hence, inappropriate action.

9. While all the procedures are fairly clear about when throttling of AFWS and restarting of RCPs are directed, there may be some reluctance to restart RCPs if they have been shutdown for awhile. If, in addition, there is some concern about the status of heat sink, there appears to be a tendency to continue to allow more feed rather than throttle feed even though the necessary SG levels and feed capability conditions are already met.

10. Though the procedures call for local/manual use of atmospheric dump valves (ADVs) in situations where all other secondary pressure relief is lost (e.g., loss of air), as a practical matter, operators will likely "ride" the main steam safety relief valves (MSSRVs) which could put repeated demands on them (and lead, possibly, to their sticking open).

11. In conditions involving loss of heat sink (e.g., inadequate AFW) or inadequate core cooling (e.g., insufficient SI), the procedures direct an operator to perform a forced cooldown to lower pressure in order to be able to use condensate to feed SGs or dump accumulator inventory into the RCS. Similarly, a forced cooldown is directed for SGTR events, and the act of going to feed and bleed will also induce some cooling with cold SI water on the reactor vessel wall.

12. Conditions calling for use of both EOPs and one or more AOPs (e.g., loss of air or other support system problems) can make the event response more complicated and potentially "stretch" the response resources, although use of the EOP will take precedence as required.

13. Conditions for entering FR-P.1 or FR-P.2 must be quite severe (e.g., RCS temperature in the range of 300F-330F). Possible delay before entering these procedures has already been addressed above. Further, within these procedures, stopping/slowing the cooldown is preferentially performed before dealing with SI termination which may likely allow re-pressurization (as seen in a simulated event) even though an already severe cooldown has occurred.

7.1.4.2 Crew Characterization

Understanding the makeup of the crew and the individual responsibilities of crew members along with communication protocols and other characteristics of the operating crew is important and needs to be

accounted for in any detailed and realistic HRA. Such things as the degree of independence allowed among crew members, the frequency and content of plant status discussions, the amount of review and oversight that takes place to correct inappropriate actions, among other characteristics can be important to ascertaining the likelihood of human errors occurring and going uncorrected.

The operations crew typically consists of:

NSS (SRO) - in charge/provides overall control/emergency director til relieved

ANSS (SRO) - procedure reader/directs crew operations

RO, Reactor Operator - reactor panel/boards A&B

PO, Plant Operator - board-C/balance-of-plant

STA (graduate engineer but no license) - oversees status trees/left-hand page continuous action steps

NLOs - usually 10 on day shift - turbine plant operator, outside, etc.

TSC - when called upon

At least one senior reactor operator (SRO) and one reactor operator (RO) must be present.

Based on discussions with plant staff and observations of simulator cooling transients during a plant visit, it was learned that the crew generally goes through the EOP steps without departing from them; however, there are 3 types of actions which board operators can perform independently. They are:

1. perform the immediate actions from E-0 even though the steps have not yet been formally read by the ANSS in response to the event,

2. manually perform the action where the operator notices the automatic action did not take place and he/she is sure the action should be performed, and

3. perform any of the 6 pre-emptive actions that were listed earlier and are allowed as long as they get concurrence/permission by the ANSS/NSS (senior operators in the control room).

Even if a manual backup to automatic action or a pre-emptive action is taken, when the crew gets to the point in the procedure(s) to carry-out that same action, the crew walks through the procedure to validate that the proper action(s) have indeed been taken.

Further, the crew is very meticulous going thru the EOPs and in fact does not act on critical function status until told to review the critical functions by procedure step or when exiting E-0 to another EOP. When an EOP is entered, it is completed before going to another EOP with the exception that once the critical functions are being responded to, if a higher action is called for (e.g., crew is responding to an orange condition and a red condition develops or crew is responding to a red and a higher (more important) red condition occurs), then a jump is made to the higher critical function response. Hierarchy of critical functions is in the same order (most important to least important) as that provided by the status trees.

Also, the plant fosters members of the crew bringing up anything that bothers them. For instance, anyone can call for a briefing. Briefings are especially encouraged at procedure transitions as long as the crew is not in the middle of a time-critical action. We observed use of a plastic card held up by the NSS/ANSS calling attention for a briefing. Briefings cover (as outlined on the card): what happened/current status, actions in progress, priorities/critical limits or times, and contingencies as well as any questions.

7.1.4.3 Operator Expectations

Actual industry-wide events and particularly Beaver Valley-specific operator experience and training can provide a level of expectation by operators as to the types of overcooling events that may occur and the appropriate actions to take. Section 3.1 of this document has already summarized many of the observations made with regard to types of overcooling events that might occur, as well as the degree and types of challenges to the operators in responding to these events. In general, it could be concluded from the observations in section 3.1 that the more failures and/or cascading effects occur concurrent with the event, the more complicated the response may need to be and perhaps, the more error-prone the situation since the procedural guidance and training becomes more challenged and potentially less adequate.

It can also be observed that in the past twenty years, actual overcooling events have been minor and required only relatively simple responses. Actual events have not generally involved multiple or cascading failure effects making the events more complicated and less certain as to the necessary response. Overall, this experience suggests familiarity with relatively simple overcooling situations, but not with more severe and complicated situations.

At Beaver Valley, operators go through simulated PTS scenarios as part of their training. While some degree of complexity is included in some of these scenarios, it is not clear that multiple failures are generally included in simulated events (e.g., a stuck-open PORV or pressurizer spray valve and a secondary feed or pressure equipment fault such as failure of MFW isolation or a stuck-open MSSRV). But multiple failures are sometimes simulated, such as for Appendix R including a fire with multiple failures. Hence, familiarity of potential overcooling events through training and simulations does exist, but particularly challenging events involving multiple unexpected equipment or indication failures are probably not within operator normal experience and, hence, their expectations.

All this suggests that, not surprisingly, the more complicated overcooling events would seemingly test the operators' knowledge and experience the most since they are generally outside operators' training and expectations. Hence, the HRA included a focus on identifying possible complicated situations (deviations) that might cause more error-prone situations for the operators (discussed further in Section 7.1.5). It is also observed that while the human error rate may be somewhat higher than when responding to uncomplicated overcooling situations, the frequency of complicated events should also be smaller in most cases than that of uncomplicated events thus balancing out concerns as to the overall PTS risk.

7.1.4.4 Scenario Timelines

Potential Beaver Valley PTS scenario timing concerns were investigated as related to the four PTS-relevant plant functions to examine possible TH plant response considerations that may make certain errors more likely. Generally, the sooner the appropriate intervention is enacted, the less severe the overcooling event; so, quick action in some instances is preferred. Summaries of the key concerns with respect to timing for each of the PTS-relevant major functions were developed. From these summaries, the HRA team concluded that:

- it is desirable to control or isolate secondary depressurization and feed problems, if they have occurred, within 10-30 minutes (sometimes sooner depending on the event)

- isolate a primary LOCA (if isolable) and trip the reactor coolant pumps (RCPs), quickly, if a primary breach has occurred.

Otherwise, most actions can be generally done in a somewhat less time-sensitive manner unless the operator must again quickly respond to a new or delayed malfunction. However, desirable actions still should be performed on the order of tens of minutes to avoid serious PTS challenges in the most severe situations.

Based on procedure reviews and simulator observations, there are some potential obstacles to achieving the desired responses. These include:

- getting through E-0 before moving to other procedures and before responding to the critical function status trees

- an apparent tendency to not embark on the pre-emptive actions before they are called for when rigorously following the procedures

- a tendency to fault on the side of providing adequate (or more than adequate) heat sink over worrying about overcooling (especially if potential problems with the heat sink are perceived)

- apparently little concern about SI repressurizing the RCS before terminating it.

While it is not suggested that these practices are bad, they can have some effects on responding to overcooling events by providing some delays in lessening the cooling effects.

7.1.4.5 Operator Action Tendencies and Informal Rules

This aspect of the HRA focused on identifying operator action tendencies and informal rules that if applied might cause or exacerbate an overcooling situation. These tendencies and rules were considered in the evaluations to assign probabilities for the HFEs of interest.

The following operator action tendencies were identified as having the potential to be particularly troublesome if operators incorrectly perceive the noted condition exists:

• Loss of support systems (power, cooling, air, etc.):	The operator tendency is to expend some attention and resources to recovering the lost system. This could be a diversion to other, more pressing needs to control any potential overcooling.
• Low pressurizer level or pressure:	The operator tendency is to increase injection and lessen letdown potentially overpressurizing the RCS relative to ideal control of PTS conditions.

• Low core heat removal or subcooling insufficient:	The operator tendency is to provide more injection and increase cooldown capability.
• Low SG level:	The operator tendency is to increase feed or go to feed and bleed if necessary.
• High SG pressure:	The operator tendency is to increase steam dump or provide additional steam relief.

Regarding Beaver Valley informal rules or other tendencies with potential relevance to PTS, the following was noted:

- The procedures and training address cooldown fairly early in most procedures but do not check/direct SI termination until generally quite late in the procedure steps. This can potentially delay SI termination until well after RCS re-pressurization has occurred because of the time it takes to get to those steps or if other problems further delay when those steps are reached.

- There is an apparent bias toward ensuring adequate heat sink over worrying about overcooling especially when some concern exists for the continued viability of the heat sink, even though more than adequate heat sink capability is actually indicated.

- There is a culture of strong compliance with procedures, Technical Specifications, etc., and deviations/short-cuts are generally not allowed. This could exacerbate the SI issue mentioned above as well as possibly delay taking the allowed pre-emptive actions.

- The operators are taught to respond conservatively (e.g., protect equipment) and are encouraged to do self-verification (e.g., touch the switch, then operate).

- Following the “yellow path” in the critical safety function status trees is at the discretion of the operators. In the past, operators have not necessarily followed up in those instances.

In addition, some of the insights obtained in an investigation of cognitively demanding simulated scenarios done for two Westinghouse plants [NUREG/CR-6208] appear applicable to the analysis of PTS at BV (although the scenarios addressed in NUREG/CR-6208 are different). In particular, the investigation found that:

- discriminating between RCS behavior due to cooldown and RCS behavior due to a LOCA was a difficult cognitive task

- when manual and automatic actions were occurring constantly, changing the pattern of influences on the RCS, operators had difficulty predicting RCS behavior and discriminating between expected and unexpected RCS behavior.

7.1.5 Deviation Analysis

The purpose of the deviation analysis step is to identify scenarios and associated conditions that might deviate from the more simple, nominal (expected) sequence of events and be particularly troublesome

(i.e., have potentially higher probabilities of operator failure) because the scenarios and conditions enable or otherwise take advantage of any vulnerabilities found in the procedures, training, timeline issues, crew characterization, crew expectations, or operator tendencies and uses of formal and informal rules or practices. Depending on the potential likelihood of such deviation scenarios, they should be (and were made) part of the PTS PRA modeled sequences as part of the closely coordinated PRA and HRA efforts. Further, the associated human failure probabilities should generally be higher than the human failure probabilities for the simple (nominal or expected) types of overcooling scenarios also in the PTS PRA model.

NUREG-1624 describes this step as a brainstorming step that involves four different types of searches:

1. Searches for initiator and scenario progression deviations from the base case (nominal) scenarios,
2. Searches regarding the use of relevant rules that could be troublesome,
3. Searches for support system dependencies and their failures and effects that could make the scenarios more complex, add to the workload, become further distractions, etc., and
4. Searches regarding operator tendencies and error types that could be troublesome.

The reader is referred to the ATHEANA methodology [NUREG-1624] for more details regarding the search process and the use of “guide words” to conduct the search.

The deviation analysis for Beaver Valley was adapted from the Oconee PTS deviation analysis (having been performed first), and modified as necessary to account for differences between the two plants. A single HRA analyst was responsible for performing the Beaver Valley deviation search with review and input from other HRA team members. It was found that the performance of the first type of search, as it was performed for the Beaver Valley PTS HRA, also inherently addressed the other types of searches adequately. Consequently, only the first search is discussed here.

An important part of this activity was a preliminary re-cap of previously collected information. Discussion of the deviation analysis is divided into two sections below. The first section addresses the preliminary re-cap while the second section addresses the specific searches performed as part of the overall search for initiator and scenario progression deviations, and their results.

7.1.5.1 Preliminary Re-Cap

The first step performed for conducting the deviation search brainstorming was integration of previously collected information, such as:

- the possible types of initiators and other failures being considered for the analysis (see Section 3.1 & Table 3.3 of this document)
- the PTS-relevant functions, individually, as well as in combinations (see Section 2 of this document)
- the potential HFEs applicable to the failed functions (see Table 7.2)
- the previously identified potential vulnerabilities summarized in Section 7.1.4 above.

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Four topics, in particular, were considered in preparation for the deviation searches:

- HFE definitions
- Beaver Valley-specific procedures
- Beaver Valley crew characterization
- Other initiator/scenario-specific vulnerabilities.

Regarding HFE definitions, it was noted that there is no obvious endpoint for the success of the action for overcooling scenarios. As long as overcooling occurs, the RCS temperature will continue to fall. At some point and if quick enough, the temperature will get low enough that depending on the RCS pressure, a crack could develop in the vessel. The probability of a crack increases as the overcooling situation worsens. This situation has implications for modeling and quantifying human errors and their probabilities, requiring the HRA task to provide several human failure probabilities for a single HFE associated with human actions of interest at different times (e.g., failure to perform the action by 1 minute, by 10 minutes, by 30 minutes). At the time of the deviation analysis, updated thermal-hydraulic (TH) and fracture mechanics information were just becoming available[13] to determine these critical times. As a result, the HRA task needed to define times likely to be PTS-relevant for consideration during HRA quantification. Such times were estimated based on the earlier PTS analyses and refined as updated TH and fracture mechanics information became available. It turned out that few adjustments had to be made to these human action times.

Regarding Beaver Valley-specific procedures and crew characterization, the material in Sections 7.1.4.1 and 7.1.4.2 were considered. As for consideration of other potential vulnerabilities, the HRA team found it helpful to review the previously collected information, especially potential vulnerabilities as discussed in Section 7.1.4, but in an initiator/scenario type specific format. Elements of this review have already been provided in Section 3.1 of this document and summarized in Tables 3.2 and 3.3. Highlights of potential vulnerabilities of most concern are provided in Table 7.3.

On the basis of all of the above considerations, it was concluded that the deviation analysis needed to focus on scenario complicating factors that involved multiple failures of equipment associated with one or more of the PTS-relevant functions, support system faults (e.g., instrument air or power) and their sometimes unexpected cascading effects, as well as potential differences in the timing sequence of events. These types of complications would seem to increase the gap between operator familiarity and expectations, and the actual event. Such deviation scenarios might increase the human failure probabilities for the actions of interest and hence be particularly worthy of modeling and quantitative evaluation.

7.1.5.2 Deviation Searches and Results

Using the first type of deviation search approach, eight separate deviation searches were conducted in all:

1. An unconstrained search for initiator/sequence progression deviations for the reactor trip initiator.

[13] Probability of crack is function of time history of temperature profile across the vessel wall (from inner to outer wall), & vessel pressure. Preliminary estimates were that it takes at least about 1000 seconds or about 15 minutes at a “cold” temperature to make enough of a difference between inner & outer wall temperature to obtain the stress needed to make a crack.

Table 7.3. Highlights of potential vulnerabilities by sequence type.

Sequence Type	Potential Vulnerabilities
Reactor trip and other complications	• There is limited industry-generic "recent" experience with main feedwater overfeeds and secondary pressure control losses occurring most often. • Beaver Valley operating crews have simulator experience of "minor" complexities. However, scenarios involving multiple failures, "sneaky" cascading or common cause failures, unexpected timing of failures, etc. are not generally trained. • There is a tendency to not take shortcuts, including the pre-emptive actions, but follow the procedure steps meticulously and not getting to the critical function checks until E-0 is completed. • There seems to be a general belief that there is 'plenty of time' to respond to plant conditions.
Loss of instrument air or cooling systems (examples of a concurrent support system failure)	Such events are not generally expected. • If such a failure would occur, it could pose a distraction for operators who are directed to recover the system and other effects (e.g., potential loss of component cooling water with loss of air) • The scenarios tend to be more complex and can cause exacerbating effects on cooldown such as, in the loss of air: – Normal letdown closes down (i.e., RCS pressure goes up) and operators must align an alternate letdown path. – RCP seal injection increases – Steam dumps, ADVs, RHR heat release valves fail closed, placing more demand on the MSSRVs. – CCW could be lost. Once CCW is lost, the temperature goes up on the major loads (e.g., RCPs). Eventually, this results in trip. Also, the operators will eventually have to trip the RCPs thereby losing forced/mixing flow. – Use of both EOPs and one or more AOPs can 'stretch' response resources.
Main steamline breaks or similar	• These are unexpected events. • Beaver Valley does some periodic training. • See reactor trip entries above.
Small LOCAs	• These events are unexpected or, at least, are infrequent (e.g., a PORV sticking open). • Beaver Valley does some training on SLOCAs. • See reactor trip entries above.
Miscellaneous such as loss of heat sink, SGTRs, inadequate RCS injection	• Such events generally require actions that add to cooldown (e.g., depressurize to low pressure feed systems or use feed and bleed) and must be properly controlled.
Low power	• Low power operations involve many transitions including transfer to auto control. • Operators do not spend lots of time (i.e., are less experienced) in this mode. • Certain auto-protections are not in place or not as redundant. • During low power, there is the potential for much more heat removal then heat generation (i.e., the situation is worse than at full-power from a TH standpoint).

2. The reactor trip initiator, in which the focus is on possible PTS-relevant failures of secondary feed and primary flow/pressure.

3. The loss of cooling water initiator.

4. The loss of electric power initiator.

5. The loss of offsite power initiator.

6. The loss of instrument air initiator.

7. The main steam line break initiator.

8. The small LOCA initiator.

Tables were created summarizing each search. Table 7.4 provides an example of these tables by showing a portion of the deviation analysis summary table for the unconstrained reactor trip search.

The following were the team's conclusions from the deviation analysis:

1. From the unconstrained search for the reactor trip initiator, the most potentially interesting scenario that was identified involves an inadvertent SI, especially at low power. Such a scenario could be worthy of pursuit from a HRA perspective because, with scram, the event starts with already too much high head safety injection (HHSI) that must be decreased or even shutdown. (Failures or delays in cutting back HHSI were addressed later in the SLOCA deviation search.) If other faults occur, such as secondary side failures, operator attention initially may be on those faults, delaying the decrease of HHSI. Such an event is similar to events starting with a secondary side problem that causes HHSI initiation, except that in this case, HHSI flow is "too much" right from the start. However, as later discovered by the updated TH analyses, inadvertent HHSI represents a relatively small overcooling situation as compared with many other types of events. Primarily for this reason, this specific type of scenario was not analyzed but other events involving a secondary side problem with the subsequent need to decrease HHSI were analyzed in the PRA and HRA.

2. For the deviation search focused on secondary feed anomalies along with a reactor trip, it was concluded that there seem to be three general types of "deviation" scenarios related to feed anomalies that are of most interest from an operator challenge perspective:

    - MFW does not isolate and/or ramps up (in response to a trip or, in the case of ramping up, is the initiator, especially at low power). In such cases, fast response may be required (seconds to minutes) in order to mitigate any cooling effect (especially at low power). Such a MFW failure will probably require failure of hi-hi SG level trip as part of the "deviation" scenario. Any problems the operators have in getting MFW tripped or isolated (e.g., multiple failures of valves and pump-off controls) could further delay getting to the procedure step for SI cutback/termination.

Table 7.4. Summary table (only a portion is shown) for the unconstrained reactor trip search.

Guide Word	Possible/Example Deviation	Significance/ Comments	Comments/ Observations
No/not	No Rx trip -> ATWS (one or more rods don't insert)	1 rod - distraction Many - distraction + real problem	Tends to keep you hot; more of a core damage (CD) problem than an overcooling. If RX didn't trip & turbine didn't trip, everything should be OK re: PTS. If RX didn't trip but turbine does, temperature goes up, pressure goes up, something breaks (LOCA), then pressure drops, boiling, RX shuts down. (No worse PTS than SLOCA & much less likely.) If late scram, rods go in, T_{av} goes down, MFW trips, AFW = feed OK. (Need other failures.) Probability of late scram & further problem seems much less than just transient & problem (by 5 orders of magnitude). Doesn't seem worth pursuing.
More	More boration. Pure water in BWST - prompt critical when inserted. Spurious SI or auto-SI signal at 25%		More boration - not significant problem. Pure water in BWST - seems very improbable and then must still have other failures for overcooling and challenge to operator. SI- just another scram reason but with cold HHSI already entering - maybe need to consider especially at low power.
Less	Partial rod insertion - see above		

- Any problem with the status of equipment checked in E-0 could delay getting to SI termination. This is especially true if there is a problem with inadequate AFW. Due to the necessary reliance that AFW be working properly so that heat sink is okay, operators could spend some time on any AFW problem ,especially if it is considered inadequate. Also, if AFW comes on full, at first, such that the operators must throttle it down, problems associated with concerns about heat sink adequacy could bog down the crew and delay both AFW throttling and SI termination. This was observed in the simulator exercises during the Beaver Valley plant visit.

- For loss of heat sink (LOHS) where there is no MFW and no AFW and underfeeding is the concern, operators will preferentially try to use the condensate system (if available). In order to use the condensate system, the operators must induce a cooldown by dumping steam, as directed by procedure. During this cooldown, subcooling may be lost with RCPs being

shutdown and HHSI will start on low RCS pressure. Since the condensate pumps have a higher flow capacity than the AFW pumps, operators may have some difficulty controlling condensate flow at first. If instead, operators have to perform feed and bleed, this strategy could have a cooling effect since, to accomplish feed and bleed, three PORVs are opened, cold HHSI is fed to RCS, and RCPs are most likely shutdown.

3. From the deviation search for scenarios involving loss of cooling water and particularly river water at Beaver Valley, the HRA team concluded (for both full and partial losses) that:

   - This case is very similar to cases in which loss of MFW has occurred. However, the operators will experience other diversion/concerns (e.g., load heatup issues). For example, if the loss of cooling water is complete and prolonged, then condensate booster pumps and HHSI may also be affected by heatup. This adds other complexities and "attention-getters" that could affect the timeliness of operator responses to any overcooling.

   - The results from the constrained search of the reactor trip initiator that addressed the cases of loss of MFW and loss of AFW appear to apply to the loss of cooling water initiator deviation analysis. However, the loss of cooling water analysis must address additional factors related to more distractions, workload, etc.

   - This sequence type does differ from a non-complicated reactor trip in that it is an example of those cases where RCPs are tripped early in the scenario (which might be due to actual/perceived imminent damage, seal failure, etc.) and the RCPs may not be restarted (until the threat of pump damage is eliminated). Shutdown of the RCPs translates to worse overcooling conditions because of loss of forced flow mixing.

   - In this case, MFW (and eventually condensate) pumps also may have to be tripped to avoid damage.

   - Steam dumps also may close due to loss of condenser vacuum caused by loss of service water. This could increase demand on MSSRVs with a greater than normal potential of MSSRV(s) sticking open, causing an overcooling event that requires operator responses while dealing with an unisolable secondary fault.

   - The above added complexities of such a scenario could make this more challenging with regard to successful and timely operator response to the overcooling situation.

4. From the deviation search involving loss of bus(es) electric power, the team concluded that:

   - This type of support failure needs to be considered due to its potential added workload, and loss of equipment redundancy effects which could affect operator response and timing to the overcooling with added workload to restore the problems.

5. From the deviation search for scenarios involving loss of offsite power, the team concluded that:

   - The additional potential complications of this type of scenario could delay, somewhat, necessary responses to the overcooling. Ensuring or troubleshooting the alternate ac supply,

and potentially dealing with station blackout conditions could add other distractions and workload for the operators. Further, it is likely that condenser vacuum will be lost at Beaver Valley and a "close" signal is generated to the steam dump valves adding some complexity since steam control cannot be through the normal path.

6. From the deviation search for scenarios involving loss of instrument air, the team concluded that:

   - This type of scenario will involve additional diversion and workload issues due to some complexities resulting from the effects of loss of air. If operators do not know that the plant is experiencing a loss of air (i.e., the reactor trips, for some reason, and there are no "first out" indications of air problems), the operators may be puzzled by the scenario, as seemingly multiple and unconnected failures develop . If loss of air is due to contamination, the air compressor still may seem to be working normally, which also may be a puzzle to operators.

   - This is another scenario in which, because of its potential effect on CCW (i.e., possible loss of the component cooling water system should a diaphragm leak occur in a containment isolation valve), MFW and RCPs will need to be shutdown at or near the start of the scenario.

   - Consideration of this type of scenario must include thinking about what the effect of a fast or total loss of air are on operator performance versus that for a slow/contamination/partial loss of air.

7. From the deviation search for scenarios involving a main steam line break or similar significant uncontrolled secondary depressurization, the team concluded that:

   - It seems improbable for operators to misdiagnose the affected SG (i.e., the deviation search did not identify any compelling circumstances at high enough probability).

   - Isolation of the affected SG (including AFW) is a critical action. Overcooling starts immediately with this initiator. The degree of cooling is a function of "time-to-isolate." So, in the quantification step, analysts may need to separately consider multiple times (with associated HEPs).

   - Slips seem easily identifiable and recoverable (because the "bad" SG continues to depressurize) but their occurrence will delay the "time-to-isolate."

   - Operators have a strong tendency to use or recover at least one SG (even if there is more than one affected) so that there is a heat sink available.

   - This event could be a diversion or attention-getter, resulting in the delay or omission of cutting back HHSI (which already seems to have a high chance of occurrence due to how late in the procedures the step for checking and terminating SI occurs).

   - The "small break" as a "deviation" of main steam line break size could be unique. In such cases, overcooling starts, although not as rapidly as in the base case. However, the question is "when or will the operator isolate this break?"

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- For the delayed “break” (e.g., steam dump stuck-open late) as a deviation on scenario timing, a delay in operator identification and isolation of the affected steam path/SG may occur.

- It is not clear if the number of steam lines affected makes a big difference in operator response(s).

8. From the deviation search for scenarios involving a small LOCA, the team concluded that:

- Many of the steps to control cooldown or isolate (if possible) the LOCA are late in E-0 which could cause delay in responses, especially if other problems or nuisances occur. It seems that once procedure E-0 verifies that SI is on, then attention to this function is secondary. In particular, procedure steps for isolation of possible LOCA paths, RCP trip, and SI termination seem late in the procedures which may delay these actions.

- If all the initial E-0 procedure steps are performed successfully (e.g., HHSI starts and supplies required flow) and there is excessive heat transfer, operator attention is likely to be (appropriately) focused on secondary-side problems. So, the most cooling will occur if there is a combination of two problems: 1) a LOCA with an HHSI problem (and heat is being removed out of the primary break) and 2) a break in the secondary (i.e., more heat being removed). In this case, the issue is whether the RCS-primary side problem will be addressed early such that HHSI sufficient flow is achieved. Any problem with HHSI should be an attention-getter since loss of RCS inventory is an important concern (e.g., the check for SI initiation occurs early in procedure E-0). However, this focus could delay actions needed on the secondary side of the plant if there are anomalies there with feed control/depressurization. Such a situation involves serious multiple function problems beyond operator expectations with increasing anxiety, complexity, workload, etc.

- For the cases without other secondary problems, insufficient HHSI alone calls for further depressurization in order to allow low head systems (e.g., accumulators, low head safety injection (LHSI)) to provide injection. This depressurization further adds to the cooling effects. Then, if HHSI is recovered while operators are depressurizing, there is the potential for operators to overreact and re-pressurize with HHSI. This sequence of events sets up the possibility for overcooling and then re-pressurization.

- Just the primary LOCA by itself (i.e., no HHSI problems) may be sufficient to, at least, delay operator attentiveness and response to any secondary problems with feed control or a secondary depressurization (e.g., stuck open MSSRV) and, thus, delay the “time-to-isolate.”

- A later LOCA (e.g., subsequent PORV sticking-open or RCP seal failure) may call attention from current activities and somewhat delay other response actions (e.g., response to secondary problems).

- Regarding the restart of RCPs, there seems to be some operator reluctance to do this due to reactivity insertion concerns.

- In a SGTR event (which is a special type of LOCA), procedures direct operators to perform a cooldown. So, this event, by itself, can be of interest.

- If there is a subsequent or concurrent support system failure with the LOCA, the complexities and attention diversions increase further.

To summarize the above insights, it was the opinion of the HRA team that in general, the human error probabilities for the actions of interest should be higher for scenarios with one or more of the following characteristics (than for actions in scenarios that are simple, nominal types of scenarios):

- concurrent support system (e.g., instrument air or loss of power) faults exist
- numerous equipment faults (e.g., more than two) exist
- more than one of the PTS relevant functions are affected by the faults in the scenario.

These summary observations helped guide the construction of the PTS PRA model and the types of scenarios that ought to be captured by the model. That is, besides the simple or nominal types of scenarios (e.g., one steam dump valve stuck-open), these HRA insights supported the need to also model more complex scenarios with the above characteristics. This would ensure the PTS evaluation also captured somewhat less likely scenarios, but ones that led to greater chances of human error during the response. Additionally, these same observations formed the basis for the relative values of the human error probabilities (HEPs) assessed for the HFEs in the PTS-PRA model.

One other observation should be made with regard to the results of the deviation analysis in particular, and the insights gained from the other aspects of the HRA process. It became clear that in many complicating situations that would be modeled in the PTS PRA, the procedures would direct the operators to take actions that tended to cooldown or even overcool the plant. These typically occur when the existing scenario (including the various faults) is leading toward undercooling the core and more drastic actions have to be taken by the operators to restore adequate core cooling. Such actions include depressurizing the SGs to establish feed with condensate, going to feed and bleed, opening a PORV in response to inadequate core cooling, etc. Given a number of these procedure-directed acts of commission of potentially overcooling the core, it was felt that more complex searches to find other errors of commission were unnecessary. While investigation into such possibilities did occur, the procedures and training were judged to make such possibilities a low likelihood, even with some instrument failures that might provide erroneous information. Thus, for the most part, the commission errors in the model are those procedure-directed acts as mentioned above. Consequently, only a few “errors” of commission were also modeled (e.g., inappropriate trip of the RCPs).

7.1.6 Plant Visits

Early in the performance of the Beaver Valley PTS study, a plant visit was made to the Beaver Valley site by members of the NRC and the NRC contractors working on the PTS study. During this first visit, members of the PTS study team including the PRA, HRA, and TH disciplines collected additional information. More importantly, numerous discussions occurred which clarified aspects of the Beaver Valley design, operating practices, etc. On the basis of the analyses described in the previous sections, the HRA team identified questions for operators and trainers and with Beaver Valley staff cooperation, observed simulator exercises the team wanted to see (e.g., simulated main steamline break event). On the basis of information collected during this plant visit, the HRA team was able to, for example, develop a crew characterization and understand the Beaver Valley procedure implementation strategy and crew communication and interaction protocols. The HRA team came to understand the typical timing to take various actions and they learned the ease, or potential difficulties that might exist with some actions in

certain situations. In addition, the visiting HRA team members strove to examine the potential for various human errors and tried to enlist operators and trainers to validate the potential impact of deviation scenarios. Also, team members were able to screen out some hypothesized EOCs as being very unlikely.

Besides ongoing communications and e-mailed questions and answers during the entire study, a second visit to the plant site also occurred following an initial quantification of the entire PRA-PTS model including some preliminary conditional probabilities of vessel failure. These preliminary results were provided to the Beaver Valley staff (assisted by Westinghouse staff) and discussions took place with regard to the significance of the results, and comments were solicited. As for the HRA part of the analysis, no comments of any consequence were received. Comments related more to the PRA sequence modeling were received and addressed.

Hence, while much of the PRA process was carried out by the NRC contractors including the quantification of the human error probabilities (discussed in the next section), it was all done with considerable and frequent Beaver Valley staff (assisted by Westinghouse staff) input and review. It is felt by the HRA team that in the end, there was a reasonable consensus reached among the NRC contractors and the licensee staff with regard to the human failures included in the model and the associated human error probabilities.

7.1.7 Quantification of the Human Error Probabilities (HEPs)

As noted earlier, HRA quantification for the Beaver Valley PTS PRA involved both initial and detailed quantification. Both used an expert elicitation process for the Beaver Valley PTS HRA.

At a high-level, this two-step quantification process is similar to the standard HRA practice of, first, performing HRA screening analysis and then performing detailed quantification, especially for those human events particularly important to the results. However, while the initial quantification results performed for the Beaver Valley PTS PRA are more conservative than those produced in a detailed analysis, they are different from the screening HRA values typically assigned in initial HRA quantification. In fact, the Beaver Valley PTS initial HRA quantification results are based on scenario context descriptions and analysis that are quite substantial and hence the initial human error probabilities (HEPs) are better characterized as “realistic (not screening values) but conservative”. Hence the Beaver Valley PTS PRA contains human error values from both the initial quantification effort and from the detailed re-analysis of a few human events that are particularly important to the results.

The two subsections below describe the initial and detailed HRA quantification approaches used in the Beaver Valley PTS PRA that was devised specifically for the PTS study but based on principles in the ATHEANA approach [NUREG-1624].

7.1.7.1 Initial Quantification Approach

This section describes the initial HRA quantification approach used for the Beaver Valley PTS PRA. Aspects of the initial HRA quantification that are specific to the Beaver Valley PTS PRA are discussed. Then the approach for developing uncertainty distributions for the assigned human failure probabilities in the Beaver Valley PTS PRA’s initial HRA quantification is described.

7.1.7.1.1 Beaver Valley-Specific Initial Quantification

The process for the initial Beaver Valley PTS HRA quantification is described in six steps below.

Step 1: Describe the HFE and plant-specific associated context

The purpose of Step 1 is to:

a. Collect any supplemental information that is not already collected and that is needed to describe and define the HFEs (and associated contexts),

b. Review all information for clarity, completeness, etc., and

c. Interpret and prioritize all information with respect to relevance, credibility, and significance.

Table 7.5 provides examples of information that serve as inputs to the quantification process, whether collected during the search process or as part of Step 1 of quantification.

The third item (item c) from the above list is especially important if:

- some information is applicable only to certain scenarios, HFEs, or contexts
- there are conflicts between information sources
- information is ambiguous, confusing, or incomplete
- information must be extrapolated, interpolated, etc.

All of the above three items, and especially the third item, were performed as part of an open discussion among the experts (in this case, the HRA team for the study made up of NRC contractors) in the elicitation process. The goal of this discussion is not to achieve a consensus but, rather, to advance the understanding of all experts through the sharing of distributed knowledge and expertise. In each case, the goal is to understand the scenario (or group of similar scenarios) and the HFE in question, and the vulnerabilities and strong points associated with taking the right action.

It is important that a “crew characterization” be developed as part of or prior to performing Step 1. In addition, the significance or relevance of this crew characterization with respect to expected operator performance was discussed by the experts.

Step 2: Identify the key or driving factors of the plant-specific context

The purpose of Step 2 is to identify the key or driving factors on operator behavior/performance for each HFE and associated context. Each expert participating in the elicitation process individually identifies these factors. Usually, these factors are not formally documented until Step 4.

Typically, there will be multiple factors deemed most important to assessing the probability for the HFE in question. This is due to the focus of the ATHEANA search process on combinations of factors that are more likely to result in an integrated context. When there is only a single driving factor, it is usually one that is so overwhelming that it alone can easily drive the estimated probability. For example, if the time available is shorter than the time required to perform the actions associated with the HFE, quantification becomes much simpler and does not need to consider other factors.

Table 7.5. Examples of information useful to HFE quantification.

Information Type	Examples
Plant conditions & behavior for base case scenarios	Thermal-hydraulic conditions as a function of time, expected plant indications as a function of time, system/equipment operations, expected operator actions.
Plant conditions & behavior for deviations of the scenarios	Expansion of the above including reasonably possible unusual plant behavior and failures of systems, equipment, and indications, especially those that may be unexpected or difficult to diagnose by operators.
Critical plant functions for accident mitigation	Specific equipment operation, requirements for operator action, possible operator recovery actions for failed systems/equipment.
Operating crew characteristics (i.e., crew characterization)	Crew structure, communication style, emphasis on crew discussion of "big picture", behaviors observed in simulator exercises and/or identified by training staff.
Features of procedures	Structure, how implemented by operating crews, opportunities for "big picture" assessment and monitoring of critical safety functions, emphasis on relevant issue (e.g., PTS), priorities, any potential mismatches with deviation scenarios.
Relevant informal rules	Experience, training, practice, ways of doing things - especially those that may conflict with informal rules or otherwise lead operators to take inappropriate actions.
Timing	Plant behavior and requirements for operator intervention versus expected timing of operator response in performing procedure steps, etc.; input from training staff and results of simulator exercises; based upon perceived needs of the PRA, multiple times or time frames may need to be considered for each HFE.
Relevant vulnerabilities	Any potential mismatches between deviation scenarios and expected operator response with respect to timing, formal and informal rules, biases from operator experience and training, etc.
Error mechanisms	Any that may be particularly relevant by plant context or implied by vulnerabilities; applicable mechanisms depend upon whether HFE is a slip or mistake. Examples include: failures of attention, possible tunnel vision, conflicts in priorities, biases, missing or misleading indications, complex situations, lack of technical knowledge, timing mismatches and delays, workload and human-machine interface concerns.
Performance shaping factors	Those deemed associated with or triggered by the relevant plant conditions and error mechanisms.

Step 3: Generalize the plant-specific context by matching it with generic, contextually-anchored rankings or ratings

In Step 3, each expert participating in the elicitation process must answer the following question for each HFE:

- Based upon the factors identified in Step 2, how difficult or challenging is this context?

Answering this question involves independent assessments by each expert. In order to perform this assessment, the specifics of the context defined for a HFE must be generalized or characterized. These characterizations or generalizations then must be matched to general categories of failures and associated failure probabilities.

In the initial HRA quantification for the Beaver Valley PTS PRA, quantification of the HFEs was constrained to four values and associated categories of failure:

Category	HEP (human error probability)
"Likely" to make the error	0.5
"Infrequent" errors expected	1E-1
"Unlikely" to make the error	1E-2
"Extremely unlikely" to make the error	1E-3

For exceptional cases, the quantification approach also allowed a HEP of 1.0 to be used when failure was deemed essentially certain.

The above categories of failures and associated failure probabilities can be (and were) further interpreted in the following way to aid the experts in arriving at their HEP judgments:

- 0.5 Given an understanding of the HFE and the context, including the range of possible plant conditions represented by deviations of the nominal context, general crew characteristics, and variability among crews, one can imagine 5 of 10 crews failing the action associated with this HFE.

- 0.1 Given an understanding of the HFE and the context, including the range of possible plant conditions represented by deviations of the nominal context, general crew characteristics, and variability among crews, one can imagine 1 of 10 crews failing the action associated with this HFE.

- 1E-2 Given an understanding of the HFE and the context, including the range of possible plant conditions represented by deviations of the nominal context, general crew characteristics, and variability among crews, one can realistically foresee a crew failing the action associated with this HFE, but at a rate considerably less than 1 in 10 crews.

- 1E-3 Given an understanding of the HFE and the context, including the range of possible plant conditions represented by deviations of the nominal context, general crew characteristics, and variability among crews, it is difficult to foresee how, realistically, a crew could fail the action associated with this HFE, but must acknowledge that it could happen.

Step 4: Discuss and justify the matches made in Step 3

In Step 4, each expert was asked to independently provide his/her estimate for each HFE. As noted in Step 3, the assignment of failure probabilities was generally constrained to four values. However, if any expert needed to express uncertainty in making a failure probability assignment, the analyst was allowed to report that his/her best estimate lies somewhere between two of the above values.

Once all the expert estimates were recorded, each expert was asked to describe the reasons why he/she chose a particular failure probability. In describing his/her reasons, each expert should identify what factors (positive and negative) were thought to be key to characterizing the context and how this characterization fit the failure category description.

After the original elicited estimates were provided, a discussion was then held that addressed not only the individual expert estimates but also differences and similarities among the context characterizations, key factors, and failure probability assignments made by all of the experts. This discussion allowed the identification of any differences in the technical understanding or interpretation of the HFE versus differences in judgment regarding the assignment of failure probabilities. Examples of factors important to HFE quantification that might be revealed in the discussion include:

- differences in key factors and their significance, relevance, etc. based upon expert-specific expertise and perspective
- differences in interpretations of context descriptions
- simplifications made in defining the context
- ambiguities and uncertainties in context definitions

A consensus opinion was not required following the discussion.

Step 5: Refinement of HFEs, associated contexts, and assigned HEPs (if needed)

Based upon the discussion in Step 4, the experts formed a consensus on whether or not the HFE definition must be refined or modified, based upon its associated context. If the HFE must be refined or re-defined, this is done in Step 5. If such modifications were necessary, the experts "re-estimated" based upon the newly defined context for the HFE (or new HFEs, each with an associated context).

The experts participating in the elicitation process also were allowed to change their estimate after the discussion in Step 4, whether or not the HFE definition and context were changed. Once again, a consensus was not required.

Step 6: Determine final HEP for HFE and associated context

The final probability estimate (from the initial quantification process) that is incorporated into the PRA for each HFE is determined in Step 6.[14]

The failure probabilities assigned in the initial HRA quantification are similar to traditional HRA screening values in that these values are expected to be conservative. For the initial HRA quantification approach used here, the principal source of conservatism is that the failure probability that was assigned to each HFE for the Beaver Valley PTS PRA was determined by choosing the highest assigned probability among the final estimates of the experts participating in the expert elicitation process.

Nevertheless, as illustrated by the above process, more supporting detail was used to make the initial quantification estimates than is typical for HRA screening. Even with a more detailed context, there may

[14] It is important that HRA and other PRA analysts communicate throughout the HRA/PRA modeling process in order to have a common understanding of what the HFE represents in the PRA model. This interface is especially important if HFE contexts (e.g., timing of operator actions) are not explicitly modeled by the PRA (i.e., simplifications, interpolations, or extrapolations must be made because of limited resources, etc.).

be some gaps in understanding or information, or some simplifications in representing context (e.g., wide varieties of plant scenarios or ranges of plant conditions, all represented by a single context description). Such gaps can be tolerated in the initial HRA quantification process. However, if the HFE was later determined to be important to the overall results, such gaps or simplifications were re-investigated in detailed HRA quantification.

Dependencies among multiple HFEs in a scenario

It is important to note, here, how dependencies among multiple HFEs appearing in the same scenario were handled. Given the detail provided in the contextual development for each HFE, the HRA team was careful to identify cases where the HFE being considered was one of multiple HFEs that were part of the overall scenario of concern. For example, if it was known that one scenario involved multiple PTS-relevant functional failures that would require multiple human actions in the same sequence of events vs. another scenario where this was not the case for the HFE of interest, then human error values were estimated both for cases where the HFE of interest would appear among other multiple HFEs and where it would not. This was possible since (1) the PRA model, being largely an event tree model, easily displayed where multiple HFEs would appear in a given scenario and (2) given the close integration of the PRA and HRA efforts, the HRA team was well aware of where these multiple HFEs applied. In this way, the HRA team was able to know, in large part, where there might be multiple and dependent HFEs needing to be quantified within the same scenario context and the resulting elicited estimates already accounted for such possible dependencies.

The need to handle these dependencies was minimized to some degree on the basis of the observed simulations at Beaver Valley and talking with Beaver Valley staff about the crew member roles and protocols used at Beaver Valley. It was observed that the actions of the board operators (one primarily handling primary system functions and the other secondary system functions) were somewhat independent of each other, at least early in the scenario response. Further, with the independent checking of plant parameters and conditions by the control room SRO and the technical advisor, possible common errors tend to be minimized or caught and rectified, further minimizing the dependencies among actions. This tended to result in low dependency effects among the actions in the minds of the experts, which was factored into their judgments.

Nevertheless, after the PRA sequences were quantified, an additional check was made where multiple HFEs appeared in a scenario to ensure that dependencies among the events (and hence the effect on quantification) had been properly taken into account. In a few cases, minor adjustments were made, using approximately 1E-5 (because of the independence and checking observed among operator actions at Beaver Valley) as a lower combined probability threshold for the HFEs in a sequence.

7.1.7.1.2 Beaver Valley-Specific Initial Assignment of Uncertainties

In initial HRA quantification, uncertainty estimates were based on the following three considerations:

1. the typical ranges of individual expert estimates for point values,
2. suggested ranges of error factors based on Swain's HRA guidance [NUREG/CR-1278], and
3. any other qualitative considerations considered relevant (e.g., time is very short so upper bound should be purposefully high).

Generally, the following "rules" were applied considering the above. In applying these rules, the chosen HEP from Step 6 was assumed to be a mean value (rather than upper end value based on the elicited estimates) further providing some "built-in" conservatism during initial quantification.

- If the mean is 0.5, then set the 95% percentile at 0.9 and the 5% percentile at 1E-2.
- If the mean is 1E-1, then set the 95% percentile at 0.5 and the 5% percentile at 1E-2.
- If the mean is 1E-2, then set the 95% percentile and 5% percentile at +/- factor of approximately 10 from the mean.
- If the mean is 1E-3, then set the 95% percentile and the 5% percentile at +/- factor of approximately 10 from the mean.

However, exceptions to the above cases were allowed, with justification. The recommended distribution shape was assumed to be lognormal or some other similar skewed distribution.

7.1.7.2 Detailed HRA Quantification

As the final Beaver Valley PTS PRA results were becoming apparent, considering not only the PRA sequence frequencies but also the conditional probabilities of vessel failure for the sequences based on the fracture mechanics results, it was observed that a few human actions were particularly important to the overall Beaver Valley PTS results. Given the purposely conservative bias performed during the initial HRA quantification, it was decided that these few actions should be revisited and quantified even more realistically with a deeper and simultaneous consideration of the specific context and factors that would affect both the mean and uncertainty estimates for the actions of interest. This process was referred to earlier as the "quantification-including-uncertainty" approach.

The process essentially parallels the six step process outlined for the initial quantification, but with two major differences. First, the context associated with the human action of interest is even more specifically defined since at this stage, the specific sequence and related failures are known based on the interim PRA results from "running" the PRA model. Second, when the experts provide their estimates, they do not provide just a point estimate to which an uncertainty distribution is separately applied. Instead, considering reasonable deviations such as the possibility of different crew experiences, time of day, possible instrument or other equipment failures, nuisance alarms, etc. (i.e., possible variations not explicitly described by the PRA sequence model), the experts provide their estimate of the entire probability distribution (at whatever shape) for the human error being quantified (hence the "quantification-including-uncertainty" label for the approach). This distribution accounts both for the variability in conditions (e.g., different crews) for the scenario beyond that described by the level of the PRA model, as well as a reasonable range of different conditions (e.g., existence of other failures or nuisances) about the PRA described context. In this way, the uncertainty expressed for the HFE being evaluated captures not only the uncertainty in the human response for the PRA given context, but also, to some degree, the uncertainty in the context itself (e.g., a steam dump valve stuck open event with no nuisance alarms vs. the same event but with the random possibility of nuisance failures and alarms also occurring). Because of this approach, it has been observed that the uncertainties described here generally are much wider than typical uncertainties evaluated using other HRA methods and tools.

In examining the context more fully, a worksheet was developed as an aid for the experts to consider nearly fifty factors that might influence either or both the mean and uncertainty estimates. That worksheet is provided as Table 7.6 and is still undergoing improvement in other ATHEANA-applied applications. For the HFE of interest, the expert elicitation included an evaluation and discussion of the relevancy of these factors and the specifics regarding those factors (e.g., a specific instrument that could be particularly influential for the action being analyzed) in assessing the likelihood of the human error being considered.

During these discussions, it was noted whether a factor was largely aleatory or epistemic in nature, whether it might affect primarily the mean or the uncertainty (or both) in the human error estimate, the likelihood of variations in the factor occurring, and ultimately, which few factors seemed to be most critical to deriving the human error probability distribution estimate. Based on these discussions, the experts then provided their individual probability distributions and refined those distributions using the same steps 4 through 6 described for the initial HRA quantification. At the end of this process, a single distribution describing the human error probability was agreed upon by the experts and that distribution, described as a histogram, was provided to the PRA modelers for inclusion into the model.

Table 7.6. Worksheet for detailed evaluation of human failure events.

WORKSHEET **Human Event** _____ **Date** _____	
Factor	**Notes**
Plant Context Factors	
Operations/Maintenance factors	
Time available for action	
Instrumentation or controls unavailable due to maintenance	
Multi-train (or all-train) maintenance has been performed, contrary to Technical Specifications	
Technical Specification requirements (e.g., tank levels) may not be met at the time of the plant trip	
Impacts of support systems that affect control of other systems can cause very confusing plant response, e.g., IA, inst. AC, I&C	
Management decisions regarding plant configurations can result in defeated plant defenses and additional burdens on operators, e.g., • scheduling of maintenance and testing activities • on-line corrective maintenance and entering Limiting Condition for Operation (LCO) statements in technical specifications • special configurations or exceptions from Technical Specifications to address persistent hardware problems	
Time of day	
Systems Factors	
Instrumentation/controls fail	
Spurious actuations	

Table 7.6. Worksheet for detailed evaluation of human failure events.

Plant scenario behavior with respect to variations in speed, timing, ordering, etc. that are not treated explicitly in the PRA scenario definition	
Systems do not always fail at t=0 in accident sequence	
Systems and components are not truly binary state (i.e., they can experience a range of degraded conditions between optimal performance and catastrophic failure)	
Detailed timing of events, the dynamic nature of the accident sequence, can affect the progress of the accident	
Cross-system common cause failures can and do occur	
Electrical “sneak circuits” can occur	
Selective tripping (coordination) failures of electrical circuit breakers are possible	
Plant power at time of trip may be < 100%	
Operational/testing evolutions may be in progress	
Preexisting Conditions not Usually Modeled in PRA	
Instrumentation pre-accident failure (human and hard-ware-caused)	
History of false/spurious/ automatic actions	
Work-arounds	
Configuration anomalies	
Plant evolutions in progress	
Power level	
Specific, detailed causes of initiating events (especially those caused by humans)	
The recovery of "slips" may be complicated (e.g., unexpected difficulties in re-setting I&C)	
Crews/Operator Behavior Factors *(if plant context is fixed?)*	
Time at which action occurs	
Duration of action (Time to complete, given start)	
Crew characteristics, e.g., • team aspects (i.e., how does a crew perform regarding communication, problem-solving, use of procedures, other team skills w/r to general, site-specific crew characteristics) • understanding of plant-specific priorities, goals, deep technical knowledge, etc. • experience level • time together • (need help from psychologist-types to fill out the team aspects list)	

Table 7.6. Worksheet for detailed evaluation of human failure events.

Procedure design, incorporation of technical knowledge into procedures	
“Informal” procedures, work practices, etc.	
Instrumentation problems that cause operators to not use it	
The instrumentation used by operators is not necessarily all that is available to them or what designers expect them to use	
Operators often will believe valve position indicators in spite of contradictory indications	
Operators can misunderstand how instrumentation & control (I&C) systems work resulting in erroneous explanations for their operation and indication	
One plausible explanation can create a "group mindset" for an operating crew	
Operators will persist in the recovery of failed systems if, e.g., • the alternatives have negative consequences • recovery is imminent (in the operators' opinion) • they were the cause of the system failure (i.e., recoverable failure)	
A variety of environmental factors have been shown to affect operator performance such as:	
• time of day	
• day of shift	
• room color and lighting	
• quality and physical location of audible alarm sound sources	
• instrument panel layout	
Context-triggered PSFs	
Effect of support system failures (degrading conditions)	
Mismatches between plant conditions and procedures	
Mismatches between plant conditions and training	
Workload	
Reports of hazardous conditions in the plant	
Reports of serious injuries in the plant	

In coming up with the distribution estimates, each expert was asked to provide the following information:

- Provide the distribution describing the probability of this human error by providing the following probability values for that distribution: the 1 percentile value (i.e., there is judged to be only a 1% chance that the true value, if it could be known, is less than the probability value provided), the 10 percentile value, the 25th, the 50th (median), the 75th, the 90th, and the 99th.

In developing these distributions, the experts were asked to perform the following in the order given:

1. Based on the discussion about the factors, build a rationale for a high end bound for the probability of failure based on the worst set of reasonably conceivable conditions for the PRA modeled context under which this action might need to be performed. Estimate the likelihood of the error and consider this the 99th percentile value of the distribution.

2. Based on the discussion about the factors, build a rationale for a low end bound for the probability of failure based on the most ideal set of reasonably conceivable conditions for the PRA modeled context under which this action might need to be performed. Estimate the likelihood of the error and consider this the 1st percentile value of the distribution.

3. Based on the discussion about the factors, build a rationale for estimating the 50th percentile value considered to be that probability for which if many crews were "tested" for this human action, half of them would fail at a probability less than the 50th probability and half of them would fail at a probability higher than the 50th probability.

4. Fill-in the rest of the distribution while also testing your curve to see if you really believe that:

   - it is equally likely that the failure probability is above and below the 50th percentile

   - it is equally likely that the failure probability is (between 25th -75th) or (below 25th or above 75th)

   - it is equally likely that the failure probability is below the 10th or above the 90th.

5. In estimating these probabilities, the experts were encouraged to think about how many crews out of a total number of crews (e.g., 100) would fail, to help them convert their qualitative judgments into quantitative probabilities.

As already stated, when all the experts' distributions were provided and discussed, a consensus distribution was agreed upon and ultimately provided for incorporation into the PRA model.

The above detailed analysis process was applied to the final "most important" HFEs to the Beaver Valley PTS results. These are:

- Failure to throttle HHSI and otherwise control RCS pressure within allowable pressure-temperature limits within 1 minute or otherwise within 10 minutes after the allowable throttling criteria is reached in the scenario involving a sudden reclosure of two pressurizer safety relief valves (SRVs) that have been opened for a long time (taken as a representative 6000 seconds in the PRA model) since the initial reactor trip and start of the overcooling event. (Note: throttling is actually performed by terminating HHSI pumps at Beaver Valley).

- Failure to throttle HHSI and otherwise control RCS pressure within allowable pressure-temperature limits within 30 minutes or otherwise within 60 minutes after the allowable throttling criteria is reached in the scenario involving a significant steam generator depressurization event (e.g., main steamline break) when the crew has previously successfully isolated the feed to the affected steam generator (hence consider the possible dependency of the previous success on this human action).

- Failure to throttle HHSI and otherwise control RCS pressure within allowable pressure-temperature limits within 30 minutes or otherwise within 60 minutes after the allowable throttling criteria is reached in the scenario involving a significant steam generator depressurization event (e.g., main steamline break) when the crew has previously failed to isolate the feed to the affected steam generator (hence consider the possible dependency of the previous failure on this human action).
- Failure to properly control RCS pressure within 1 minute or 10 minutes after transitioning from feed and bleed and getting SG cooling back and thus needing to reclose the PORVs (thus a repressurization potential) and rely on SG cooling.

7.2 HRA Results

7.2.1 Results of Initial Quantification

The results of the Beaver Valley PTS HRA analysis consist of:

- identified human failures
- failure probabilities and associated uncertainties for each human failure.

Beaver Valley HRA results are provided for full-power and low power conditions. Tables 7.7 and 7.8 provide the list of identified HFEs, and the associated failure probabilities and uncertainty distributions for full-power and low power, respectively, based on the initial quantification effort. For reasons described later in Section 7.2.3, these human failure probabilities were modified somewhat for final inclusion into the Beaver Valley PTS PRA. Additionally, some of the human failure estimates were not needed in the final model (much of the HRA effort preceded the finalization of the PRA and hence some human events were quantified based on an anticipated need in the model). Section 7.2.3 provides the list of human events actually modeled in the Beaver Valley PTS PRA and explains how these PRA human events are related to the human failures shown in Tables 7.7 and 7.8. Also note that as indicated in Table 7.7, a few of the HFEs associated with HHSI termination for full power conditions were re-analyzed during detailed quantification and it is those values that were used in the Beaver Valley PTS PRA. No detailed quantification adjustments were required for any of the low power HFEs beyond that re-assessed for full power.

7.2.1.1 HFEs for Full Power Conditions

The results for the initial quantification of full-power HFEs are shown in Table 7.7. This table documents:

- the HFE description
- applicable scenarios and plant conditions
- the key factors influencing the failure probability for the HFE (e.g., error mechanisms, performance shaping factors), as identified by the HRA team
- the recommended error factor from NUREG/CR-1278, Table 7-2, as well as the range of the expert elicitation estimates for the HFE
- the mean human failure probability passed on for inclusion in the PTS PRA model
- estimated 95th and 5th percentiles of a skewed (lognormal) distribution passed on for inclusion in the PTS PRA model.

Table 7.7. HFE results and analysis for Beaver Valley PTS PRA: Full-Power.

HFE #	HFE	Condition When Applied	Dominant Considerations Most Affecting the HFE Estimate	Error Factor from NUREG/CR-1278, Table 7-2 & (Range of Experts' Estimates)	HRA Mean[1] and Uncertainty Values
1	Operators fail to control or throttle AFW	Case (a)(1): Reactor trip, uncomplicated. Secondary feed failed (i.e., overfeeding). All other functions are OK; primary conditions & secondary pressure OK). SI assumed to not be actuated.	Use timing of E-0 step performance in BV simulator trials as benchmark though in this case, will transition to ES0.1 at Step 7: Step 13 & 14 @ ~3 min and Step 19 @ t=7-8 min ("base case" like); Step 25 @ 22 min (for major complications in MFW & AFW). Not so concerned about full AFW @ 10 minutes because it has minimum cooling effect (due to U-tube design & large SGs). Hence considerable time available (10's of minutes) and action is proceduralized.	Item 4 or 5 or 8 EF= 5 or 10 (Consensus: 1E-3)	**1E-3 = mean**; (95%, 5%) = 1E-2, 1E-4
		Case (a)(2): Like case(a)(1) except SI actuates & evaluated for HFE at 10 min. Case (a)(3): Like case (a)(2) except evaluated for 20 min.	Same as (a) except that SI has actuated sometime. Because SI is on, if not controlled, then could cause a SLOCA by pushing opening a PORV. Therefore, must either throttle AFW or SI to avoid PTS. ONLY FOR CASES WHERE COOLDOWN IS OBVIOUS (i.e, preemptive action could be applied). Argument for high value (0.1): crew seems to have no urgency to do; best thing to do is to do methodically. Argument for lower value(0.01): Uncomplicated scenario; also, should not be as bad as HEPs to more complicated scenarios. For 20 min, sufficient time to make success high.	Case (a)(2): Item 5 or 8 EF= 5 or 10 (1E-1 to 1E-2) Case (a)(3): Item 4 or 5 or 8 EF= 5 or 10 (Consensus: 1E-3)	Case (a)(2): **1E-1 = mean**; (95%, 5%) = 0.5, 1E-2 Case (a)(3): **1E-3 = mean**; (95%, 5%) = 1E-2, 1E-4

Table 7.7. HFE results and analysis for Beaver Valley PTS PRA: Full-Power.

HFE #	HFE	Condition When Applied	Dominant Considerations Most Affecting the HFE Estimate	Error Factor from NUREG/CR-1278, Table 7-2 & (Range of Experts' Estimates)	HRA Mean[1] and Uncertainty Values
1 cont'd		Case (b): Like (a)(2) & (a)(3) cases above except there is a concurrent functional problem (e.g., depressurization in another SG or SLOCA)	Like above but now more complex with other potential "attention-getters". E-0 doesn't address LOCA, faulted SG, etc until after step that address AFW throttling (i.e., Steps 23, 25 &26, 27) so these other conditions may not affect AFW throttling. Argument A: Rarely seem that they adjust the speed with which they proceed through procedure and they've argued that they don't need to. Argument B: "Real" situation may cause them to push, especially if faulted SG or LOCA.	Case (b)(1) 10 min: Item 5 or item 8 EF = 5 or 10 (Consensus: 0.1) Case (b)(2) 20 min: Item 4 or 5 or 8 EF = 5 or 10 (Consensus: 1E-3)	Case (b)(1) 10 min: **1E-1 = mean**; (95%, 5%) = 0.5, 1E-2 Case (b)(2) 20 min: **1E-3 = mean**; (95%, 5%) = 1E-2, 1E-4
		Case (c): Involves a concurrent support system problem (e.g., loss of air) regardless of status of other functions. Evaluated for 10, 20, 45 min.	Like above. Additional complication of potentially using EOP and AP at same time; may assign one board operator to AP (not formalized). Argument A: Possible resource issue slowing down getting thru E-0. Argument B: Crew can be tenacious in getting thru E-0. Argument C: In complicated simulator run, took crew 30 min to isolaye AFW but they were not in E-0. By 45 min - seems high chance of success.	Case (c)(1) 10 min: Item 5 or item 8 EF = 5 or 10 (0.5 to 1E-1) Case (c)(2) 20 min: Item 5 or item 8 EF = 5 or 10 (1E-1 to 1E-2) Case (c)(3) 45 min: Item 4 or 5 or 8 EF = 5 or 10 (Consensus: 1E-3)	Case (c)(1) 10 min: **0.5 = mean**; (95%, 5%) = 0.9, 1E-2 (perhaps as good as other 10 min assessments) Case (c)(2) 20 min: **1E-1 = mean**; (95%, 5%) = 0.5, 1E-3 (seems low end should overlap other 20 min assessments) Case (c)(3) 45 min: **1E-3 = mean**; (95%, 5%) = 1E-2, 1E-4

Table 7.7. HFE results and analysis for Beaver Valley PTS PRA: Full-Power.

HFE #	HFE	Condition When Applied	Dominant Considerations Most Affecting the HFE Estimate	Error Factor from NUREG/CR-1278, Table 7-2 & (Range of Experts' Estimates)	HRA Mean[1] and Uncertainty Values
2	Operators fail to trip turbine manually if auto trip fails (within ~15 to 30 sec)	All	Step 3 of E-0. One of the immediate actions to verify/do regardless of event/scenario. Memorized step. Essentially an "auto rule."	Either item 4 or 5 EF = 5 or 10 (Consensus: 1E-3)	**1E-3 = mean** (95%, 5%) = 1E-2, 1E-4
3	Operators fail to trip RCPs when required	Whenever meet RCP shutdown criteria (e.g., such as in a LOCA). See E-0, Step 24 (differential pressure between RCS and SG & HHSI flow), foldout page (standing condition), abnormal procedure for pump alarms.	More of a core damage (CD) concern. Otherwise, don't care about this event so much for PTS. When operators see RCS pressure getting down to ~1300 psig, they know to start checking dP to see if RCPs should be tripped (via foldout page).	Item 4 or 5 or 8 EF = 5 or 10 (Consensus: 1E-3)	**1E-3= mean**; (95%, 5%) = 1E-2, 1E-4
4	Operators trip RCPs when not required to do so	All	General tendency is to keep them running. Seems only "likely" if operators perceive potential damage/problem with pump operation. [Note, operators will likely trip RCPs (assume 1.0) on loss of containment air/loss of CCW due to heatup of pump seals/bearings.]	Item 4 or 5 or 8 EF = 5 or 10 (Consensus: 1E-2)	**1E-2= mean**; (95%, 5%) = 1E-1, 1E-3

Table 7.7. HFE results and analysis for Beaver Valley PTS PRA: Full-Power.

HFE #	HFE	Condition When Applied	Dominant Considerations Most Affecting the HFE Estimate	Error Factor from NUREG/CR-1278, Table 7-2 & (Range of Experts' Estimates)	HRA Mean[1] and Uncertainty Values
5	Operators fail to restart RCPs when required	All situations where RCPs have been stopped but criteria for restart is met. Case (a): severe overcooling and entered FR–P.1via orange or red path (see steps 7 and 17)	Time to get to this step is tens of minutes unless there was a delay in the start of the overcooling, so likely not as affected by start of scenario as other actions. Supposedly this is an intentional step to warm the vessel wall. Some reluctance exists because of re-criticality concerns (push cold water slug through core).	Item 5 EF = 5 (Consensus: 0.5)	**0.5 = mean**; (95%, 5%) = 0.9, 0.1 (May be conservative - can revisit if important)
		Case (b): Same as case (a) except for recovery situations (e.g., recovering from shutdown for pump protection, loss of RCPs, etc.). Restart conditions have been met: subcooling, RVLIS, PZR level, heat sink)	Probably lots of time. Trainer thought that if operators need to turn on RCPs, they would. On the other hand, if restarting is a control issue, then operators may talk to TSC before restarting (some reluctance). Argument for ~1E-3: Lots of time. Don't think this event & sequence matters. Argument for ~1E-2: Worst case is 1E-2 with operators persistent in believing to not do it, though eventually, will turn on.	Item 5 EF = 5 (1E-2 to 1E-3)	**1E-2= mean**; (95%, 5%) = 1E-1, 1E-3 (assumed ~30 min into event as part of the context)
6	Operators <u>successfully</u> use feed & bleed when suppose to	All initiators/ situations when heat sink is lost and feed and bleed becomes necessary.	Among the known and trained options when heat sink is lost. Since likely to perform, conservative success value for PTS is 1.0	- - - (Consensus: 1.0)	**1.0 (point value)**

Table 7.7. HFE results and analysis for Beaver Valley PTS PRA: Full-Power.

HFE #	HFE	Condition When Applied	Dominant Considerations Most Affecting the HFE Estimate	Error Factor from NUREG/CR-1278, Table 7-2 & (Range of Experts' Estimates)	HRA Mean[1] and Uncertainty Values
7	Operators fail to recover from MFW overfeed	All initiators/ situations where MFW continues to overfeed beyond high level trip (which fails)	MFW expected to trip. Step 13 in E-0 checks for trip/isolation and typically takes ~3 min or less to get to this step. May get alarms pending failure mode of high level trip.	Either item 5 or 8 EF = 5 or 10 (Consensus: 1E-3)	(Assumed needs to be done in ~10 min for context) **1E-3 = mean**; (95%, 5%) = 1E-2, 1E-4
8	Operators fail to isolate feed (particularly AFW including steam paths) to faulted SG - evaluated at different times.	Case (a): Secondary depressurization event by itself or with another functional failure (e.g., SLOCA) or support system fault, where breach does not self-isolate (e.g., MSIV closure).	MFW most likely trips, MSIVs don't isolate or breach is inside MSIVs. E-0 Step 21 directs "throttle", but not necessarily "isolate" so maybe won't occur until Step 25 and transfer to E-2, Step 5. Also a possible pre-emptive action but crew tendency seems to be to not use these as much. Up to ~3-5 min seems barely enough time to get to proper step(s) if pre-emptive action not taken with thought of "just follow the procedures." So success likely due to taking pre-emptive action or possibly getting thru E-0 quickly. 30 min seems plenty of time (even in complex scenarios), hence 10 min case is a reflection of being between these time periods.	Case (a)(1): 2 min or less Either item 5 or 8 EF = 5 or 10 (0.5 to 0.1) Case (a)(2): 5 min Either item 5 or 8 EF = 5 or 10 (0.5 to 0.1) Case (a)(3): 10 min Either item 5 or 8 EF = 5 or 10 (1E-1 to 1E-2) Case (a)(4): 30 min Item 4 or 5 or 8 EF = 5 or 10 (Consensus = 1E-3)	Case (a)(1): 2 min or less **0.5 = mean**; (95%, 5%) = 0.9,1E-1 Case (a)(2): 5 min **0.5 = mean**; (95%, 5%) = 0.9,1E-2 (lower bound credits more time) Case (a)(3): 10 min **1E-1 = mean**; (95%, 5%) = 0.5, 1E-3 (to account for even more time) Case (a)(4): 30 min **1E-3 = mean**; (95%, 5%) = 1E-2, 1E-4
9	Operators fail to close PORV/its block valve upon stuck-open PORV	Applies to all initiators/ scenarios	Have about 20-25 min before any concern based on prelim TH, so evaluated for this time. Should be plenty of time to get to this proceduralized, trained step (Step 23 in E-0), so probably more of a "slip."	Item 4 or 5 or 8 EF = 5 or 10 (Consensus: 1E-3)	**1E-3 = mean**; (95%, 5%) = 1E-2, 1E-4

Table 7.7. HFE results and analysis for Beaver Valley PTS PRA: Full-Power.

HFE #	HFE	Condition When Applied	Dominant Considerations Most Affecting the HFE Estimate	Error Factor from NUREG/CR-1278, Table 7-2 & (Range of Experts' Estimates)	HRA Mean[1] and Uncertainty Values
10	Operators fail to terminate HHSI & depressurize to control within allowable P-T limits	Case (a): All situations (e.g., SLOCA, minor depressurization event, support system failure(s)) EXCEPT for severe cooldown where entry into FR-P.1 is likely.	Proceduralized but probably will take ~20-30 min or more to get to appropriate steps especially with methodical attitude of crews with no apparent urgency to perform this action in either the procedures or in training (no shortcuts for this act).So this may be earliest possible time to take action. Transitions to E-1: E-0, Step 23 (only unisolable LOCA). E-0, Step 27-probably transition to E-1, Step 7, transfer to ES-1.1, SI termination. ES-1.1 takes ~10-15 min to complete steps for isolating SI plus it seems to take ~15 min to get to transfer to ES-1.1 based on observed simulations. TH NOT YET AVAILABLE so decided to use screening value for all times considered. Will revisit in final quantification in dominant scenarios.	Either item 5 or item 8 EF = 5 or 10 (Decided to use screening value (to be revisited later) for all time periods considered- 30, 60, 90 min into scenario: 0.5)	TH NOT YET AVAILABLE so decided to use screening value for all times considered. Will revisit in final quantification in dominant scenarios. Screening value: **0.5 = mean** **NOTE: values changed later during detailed quantification for specific scenario cases of higher importance.**

Table 7.7. HFE results and analysis for Beaver Valley PTS PRA: Full-Power.

HFE #	HFE	Condition When Applied	Dominant Considerations Most Affecting the HFE Estimate	Error Factor from NUREG/CR-1278, Table 7-2 & (Range of Experts' Estimates)	HRA Mean[1] and Uncertainty Values
		Case (b) When have to enter FR-P.1 (severe cooldown)	Similar to above. Proceduralized, and timing suggested by simulations that suggest it will likely take ~20-30 min to enter FR-P.1 with further delays possible if any problems. FR-P.1, Step 7 checks if SI can be terminated (subcooling & RVLIS). Steps 8-14 must be done to terminate SI. Step 17 verifies SI not needed. Step 20 depressurizes RCS. IN simulated event, RCS had already repressurized & it took ~42 min into event to perform termination. Crews persisted on being methodical though PORV was opening on repressurization. Further crew did not recognize need to do rapid depressurization (seemed to not sense were nearing PTS limit concerns) so a factor is success of depressurization after terminating SI.	Case (b)(1): by 15 min after entered FR-P.1 Either item 5 or item 8 EF = 5 or 10 (Consensus: 0.5) Case (b)(2): by 30 min after entered FR.P-1 Either item 5 or item 8 EF = 5 or 10 (1E-1 to 1E-3)	Case (b)(1): by 15 min after entered FR.P-1 **0.5 = mean**; (95%, 5%) = 0.9, 1E-2 Case (b)(2): by 30 min after entered FR.P-1 **For HHSI termination part:** **1E-1 = mean**; (95%, 5%) = 0.5, 1E-3 (may be quite conservative, can revisit if important) **For depressurization part:** Screening value: **0.5 = mean** (Use the case (a) screening value and revisit if necessary; hence overrides the above 0.1 estimate for the HHSI termination part) **NOTE: values changed later during detailed quantification for specific scenario cases of higher importance.**

Table 7.7. HFE results and analysis for Beaver Valley PTS PRA: Full-Power.

HFE #	HFE	Condition When Applied	Dominant Considerations Most Affecting the HFE Estimate	Error Factor from NUREG/CR-1278, Table 7-2 & (Range of Experts' Estimates)	HRA Mean[1] and Uncertainty Values
11	Operators fail to trickle/throttle condensate into SG(s) - implements SG de-pressurization & flow control actions	Loss of heat sink (MFW tripped off, AFW failed) All initiators and conditions where use of condensate is possible, including support system problems.	Operator bias is to worry about heat sink. May be slow about throttling condensate. If operators de-pressurize too slowly, they will have to go to F&B. If go too fast, SI actuated, isolates MS lines, & will have to go to F&B. (Trainers & operators say that it's really hard to strike proper balance.) So an implementation issue.	Either item 5 or 8 EF = 5 or 10 (1E-1 to 1E-2)	**1E-1 = mean**; (95%, 5%) = 0.5, 1E-2 (not too low because of implementation difficulties)
12	Operators fail to trickle/throttle condensate into SG(s) - implements condensate control actions	See above but especially for secondary depressurization events.	See above. Have to watch out for running out of water in SGs and going too fast thus possibly tripping MS lines with some overcooling.	Either item 5 or 8 EF = 5 or 10 (Consensus: 0.5)	**0.5 = mean**; (95%, 5%) = 0.9, 1E-1 (may be quite conservative but can revisit if important. Overrides depressurization part estimated above).
13	Operators isolate wrong SG	All initiators and situations	Probably would be a Slip: Used Table 13-3, item 3 of NUREG-1278.	Item 4 or 5 or 8 EF = 5 or 10 (Consensus: 1E-3)	**1E-3 = mean**; (95%, 5%) = 1E-2, 1E-4

Table 7.7. HFE results and analysis for Beaver Valley PTS PRA: Full-Power.

HFE #	HFE	Condition When Applied	Dominant Considerations Most Affecting the HFE Estimate	Error Factor from NUREG/CR-1278, Table 7-2 & (Range of Experts' Estimates)	HRA Mean[1] and Uncertainty Values
14	Operators fail to restore good SG and isolate bad SG if isolated wrong SG initially	All initiators and situations	With 3 instead of 2 SGs, crew may not be as concerned. Assumed about 10 min to take this action for purposes of setting a context & to prevent too much cooldown. Have to consider that wrong SG was originally isolated so could be a higher chance of error of this recovery.	Either item 5 or 8 EF = 5 or 10 (Consensus: 0.5)	**0.5 = mean**; (95%, 5%) = 0.9, 1E-2 (10 min a fair amount of time so purposely low value for lower bound)

[1] When mean values and associated 95th and 5th percentiles are provided, these values are intended to represent a skewed (e.g., lognormal) distribution.

Table 7.8. HFE results and analysis for Beaver Valley PTS PRA: Low Power.

HFE #	HFE	Condition When Applied	HRA Mean[1] and Uncertainty for Full Power	HRA Mean[1] and Uncertainty for Low Power	Notes/Basis for Low Power Estimates
1	Operators fail to control/throttle AFW	Case (a)(1): Uncomplicated trip & SI not actuated	**1E-3 = mean** (95%, 5%) = 1E-2, 1E-4	**1E-2 = mean** (95%, 5%) = 1E-1, 1E-3	Since a plant condition might be more likely present at low power that could hinder correct diagnosis, we will simply assume an order of magnitude higher.
		Case (a)(2): Like (a)(1) but SI actuated and evaluated for 10 min	**1E-1 = mean** (95%, 5%) = 0.5, 1E-2	**1E-1 = mean** (95%, 5%) = 0.5, 1E-2	Value already seems high enough.
		Case (a)(3): Like (a)(2) but evaluated for 20 min	**1E-3 = mean** (95%, 5%) = 1E-2, 1E-4	**1E-2 = mean** (95%, 5%) = 1E-1, 1E-3	Since a plant condition might be more likely present at low power that could hinder correct diagnosis, we will simply assume an order of magnitude higher.
		Case (b)(1): Like case (a)(2) above except concurrent functional problem (e.g., SLOCA)	**1E-1 = mean** (95%, 5%) = 0.5, 1E-2	**1E-1 = mean** (95%, 5%) = 0.5, 1E-2	Value already seems high enough.
		Case (b)(2): Like case (a)(3) above except concurrent functional problem (e.g., SLOCA)	**1E-3 = mean** (95%, 5%) = 1E-2, 1E-4	**1E-2 = mean** (95%, 5%) = 1E-1, 1E-3	Since a plant condition might be more likely present at low power that could hinder correct diagnosis, we will simply assume an order of magnitude higher.
		Case (c)(1): Involves a concurrent support system fault(s) and evaluated for 10 min	**0.5 = mean** (95%, 5%) = 0.9, 1E-2	**0.5 = mean** (95%, 5%) = 0.9, 1E-2	Value already seems high enough.

Table 7.8. HFE results and analysis for Beaver Valley PTS PRA: Low Power.

HFE #	HFE	Condition When Applied	HRA Mean[1] and Uncertainty for Full Power	HRA Mean[1] and Uncertainty for Low Power	Notes/Basis for Low Power Estimates
		Case (c)(2): Like case (c)(1) but evaluated for 20 min	**1E-1 = mean** (95%, 5%) = 0.5, 1E-3	**0.5 = mean** (95%, 5%) = 0.9, 1E-2	Since a plant condition might be more likely present at low power that could hinder correct diagnosis, we assumed a higher likelihood.
		Case (c)(3): Like case (c)(1) but evaluated for 45 min	**1E-3 = mean** (95%, 5%) = 1E-2, 1E-4	**1E-2 = mean** (95%, 5%) = 1E-1, 1E-3	Since a plant condition might be more likely present at low power that could hinder correct diagnosis, we will simply assume an order of magnitude higher.
2	Operators fail to trip turbine when auto trip fails	Applies for all events under all circumstances	**1E-3 = mean** (95%, 5%) = 1E-2, 1E-4	**1E-3 = mean** (95%, 5%) = 1E-2, 1E-4	Nearly an auto/early action - see no reason to change.
3	Operators fail to trip RCPs when required	Applies for all events under all circumstances when meet shutdown criteria	**1E-3 = mean** (95%, 5%) = 1E-2, 1E-4	**1E-3 = mean** (95%, 5%) = 1E-2, 1E-4	Protective of RCPs - see no reason to change.
4	Operators trip RCPs when not required to do so	Applies for all events under all circumstances.	**1E-2 = mean** (95%, 5%) = 1E-1, 1E-3	**5E-2 = mean** (95%,5%)= 0.5, 5E-3	Since a plant condition might be more likely present at low power that could hinder correct diagnosis, we assumed a higher likelihood.

Table 7.8. HFE results and analysis for Beaver Valley PTS PRA: Low Power.

HFE #	HFE	Condition When Applied	HRA Mean[1] and Uncertainty for Full Power	HRA Mean[1] and Uncertainty for Low Power	Notes/Basis for Low Power Estimates
5	Operators fail to restart RCPs when required	Applies to situations where RCPs have been stopped but criteria for restart is met. Case (a): Severe overcooling & entered FR-P.1 via orange or red path.	**0.5 = mean** (95%, 5%) = 0.9, 0.1	**0.5 = mean** (95%,5%) = 0.9, 0.1	For high power, it was argued this event was relatively independent of event/scenario (because it occurs so late in the scenario when things are being cleaned up). That notion would still seem to apply, so don't see a strong reason to change estimate. Besides, value already quite high.
		Case (b): Like above except for recovery situations (e.g., recovering from pump shutdown for protection).	**1E-2 = mean** (95%, 5%) = 1E-1, 1E-3	**1E-1 = mean** (95%, 5%) = 0.9, 1E-2	Since a plant condition might be more likely present at low power that could hinder correct diagnosis, we will simply assume an order of magnitude higher.
6	Operators <u>successfully</u> use feed and bleed when suppose to	Applies to all events when there is a loss of heat sink & these actions are necessary.	**1.0 (success)**	**1.0 (success)**	1.0 is the most conservative case from a PTS perspective and as this is a success, should be near 1.0 anyway - so use same value.
7	Operators fail to recover from MFW overfeed	Applies to all initiators where MFW continues to overfeed.	**1E-3 = mean** (95%, 5%) = 1E-2, 1E-4	**1E-2 = mean** (95%, 5%) = 1E-1, 1E-3	Since a plant condition might be more likely present at low power that could hinder correct diagnosis, we will simply assume an order of magnitude higher.

Table 7.8. HFE results and analysis for Beaver Valley PTS PRA: Low Power.

HFE #	HFE	Condition When Applied	HRA Mean[1] and Uncertainty for Full Power	HRA Mean[1] and Uncertainty for Low Power	Notes/Basis for Low Power Estimates
8	Operators fail to isolate feed (particularly AFW including steam paths) to faulted SG - evaluated at different times.	Case (a)(1): Secondary depressurization event by itself or with another functional failure (e.g., SLOCA) or support system fault; for 2 min or less.	**0.5 = mean** (95%,5%)= 0.9, 1E-1	**0.5 = mean** (95%,5%)= 0.9, 1E-1	Value already seems high enough.
		Case (a)(2): Like above but for 5 min	**0.5 = mean** (95%,5%)= 0.9, 1E-2	**0.5 = mean** (95%,5%)= 0.9, 1E-1	Value already seems high enough. Did raise lower bound.
		Case (a)(3): Like above but for 10 min	**1E-1 = mean** (95%,5%)= 0.5, 1E-3	**0.5 = mean** (95%, 5%) = 0.9, 1E-1	Since a plant condition might be more likely present at low power that could hinder correct diagnosis, we assumed a higher likelihood.
		Case (a)(4): Like above but for 30 min	**1E-3 = mean** (95%,5%)= 1E-2, 1E-4	**1E-2 = mean** (95%, 5%) = 1E-1, 1E-3	Since a plant condition might be more likely present at low power that could hinder correct diagnosis, we will simply assume an order of magnitude higher.
9	Operators fail to close PORV/its block valve upon stuck-open PORV	Applies to all initiators/ scenarios	**1E-3 = mean** (95%,5%)= 1E-2,1E-4	**1E-3 = mean** (95%,5%)= 1E-2,1E-4	Lots of time (nearly ½ hour) - see no reason to change.
10	Operators fail to terminate HHSI & depressurize to control within allowable P-T limits	All cases.	**0.5 = mean (screening value)**	**0.5 = mean (screening value)**	Screening value - high enough already.

Table 7.8. HFE results and analysis for Beaver Valley PTS PRA: Low Power.

HFE #	HFE	Condition When Applied	HRA Mean[1] and Uncertainty for Full Power	HRA Mean[1] and Uncertainty for Low Power	Notes/Basis for Low Power Estimates
11	Operators fail to trickle/throttle condensate into SG(s) - both depressurization & flow control	All initiators/ situations involving loss of heat sink but condensate available.	**1E-1 = mean** (95%,5%)= 0.5, 1E-2	**1E-1 = mean** (95%,5%)= 0.5, 1E-2	Value already seems high enough.
12	Operators fail to trickle/throttle condensate into SG(s) - during secondary depressurization events	All initiators/ situations involving loss of heat sink & secondary depressurization but condensate available.	**0.5 = mean** (95%,5%)= 0.9, 1E-1	**0.5 = mean** (95%,5%)= 0.9, 1E-1	Value already seems high enough.
13	Operators isolate wrong SG	All initiators/ situations	**1E-3 = mean** (95%,5%)= 1E-2, 1E-4	**1E-2 = mean** (95%,5%)=1E-1,1E-3	Since a plant condition might be more likely present at low power that could hinder correct diagnosis, will simply assume an order of magnitude higher.
14	Operators fail to restore good SG & isolate bad SG if isolated wrong SG initially	All initiators/ situations	**0.5 = mean** (95%,5%)= 0.9, 1E-2	**0.5 = mean** (95%,5%)= 0.9, 1E-2	Value already seems high enough.

[1] When mean values and associated 95th and 5th percentiles are provided, these values are intended to represent a skewed (e.g., lognormal) distribution.

In some cases, HRA results are given for multiple times. These results were developed in anticipation of the needs of the overall PTS PRA study and while most times were based on earlier work and selected before much of the updated TH and fracture mechanics calculations were available, few adjustments had to be made in finalizing the HRA effort.

It should be noted that the point estimate values given in Table 7.7 are considered to "tend" toward conservative estimates. Also, the uncertainty estimates are "rough" estimates about the point estimates (used as means) and are thought to reasonably approximate the degree of uncertainty (although they are biased toward the conservative end). Particularly, where different values have been estimated for different times for the same error, the analysis has considered "recovery" by the operators due to prolonged conditions and/or cues of the need to take the action as well as new cues that the action still needs to be taken. So "recovery" has already been accounted for in the HRA. Finally, and as explained earlier, it should be noted that the analysts tried to account for dependencies among functions and/or human errors and the effect on multiple human error probabilities in the same scenario in their estimates (e.g., if more than one function has anomalies, generally higher values are used, but crediting the actions of at least 2 or more operators).

7.2.1.2 HFEs for Low Power (i.e., Hot Zero Power) Conditions

To perform the HRA for low power conditions, information was collected to understand possible differences between Beaver Valley full-power and low power operations. Then, the HRA results for the full power conditions were modified to reflect PTS-relevant differences between full- and low-power conditions. Consequently, the HRA analysis for low power conditions can be considered a "deviation analysis" from the full power results provided above.

Table 7.8 summarizes the HRA input to the Beaver Valley PTS PRA with regard to relevant HFEs during low power operation (i.e., turbine is not yet on line and the reactor is either subcritical or at very low power).

The resulting HFEs and their quantification are based largely on questions and answers exchanged between the NRC contractors and the Beaver Valley staff. From those questions and answers, primarily what was learned was:

1. crew response to adverse plant conditions (e.g., overcooling) should be generally the same at low power as at high power since the same procedures and training are used;

2. it is possible that plant circumstances (conditions) could exist while at low power (e.g., continue low power operation with instrument deficiencies or other workarounds not normally experienced at high power) that could explain (incorrectly) what the crew is seeing, and so some higher likelihood of error was judged to be possible.

Based on these summary observations and the specific bases noted in Table 7.8, the HFEs and their quantification for low power operation were estimated. The uncertainty estimates are based on similar values used for the high power uncertainty analysis.

7.2.2 Results of Detailed Quantification of Important HFEs

As the PTS PRA model was solved and quantified, it became apparent that certain HFEs were particularly important to the Beaver Valley results since they appeared among the most dominant PTS-risk scenarios. The analysis of these HFEs was re-visited to lessen the conservative bias of the initial quantification and to provide the most realistic estimate for the failure probabilities associated with these HFEs. The process followed to perform the detailed quantification has been described in Section 7.1.7.2 above. The HFEs requiring detailed analysis have also been delineated in Section 7.1.7.2. The following text documents the revised, detailed quantification of these most important HFEs and the primary bases for the estimated failure probabilities and uncertainties (expressed as histograms described by the following percentiles of the probability distribution: 1st, 10th, 25th, 50th (median), 75th, 90th, and 99th).

HFE

Failure to throttle HHSI and otherwise control RCS pressure within allowable pressure-temperature limits within 1 minute after the allowable throttling criteria is reached in the scenario involving a sudden reclosure of two pressurizer safety relief valves (SRVs) that have been opened for a long time (taken as a representative 6000 seconds in the PRA model) since the initial reactor trip and start of the overcooling event. (Note “throttling” is actually performed by terminating various HHSI pumps, thus throttling the overall flowrate).

General Context

In the scenario type of interest, two primary safety relief valves (SRV) have stuck open (they have been open for a significant period of time, such as approximately 1 to 2 hours, resulting in a small LOCA). The crew has stabilized the SLOCA. HHSI is working and is “on full” or nearly so. Given the TH characteristics of the scenario so far, significant cooling has occurred in the downcomer region with a minimum downcomer temperature of about 100 degrees F. The issue of concern is what happens when the SRVs suddenly close. It will take ~15 minutes from when the SRVs close for primary pressure to begin to rise very sharply from the less than 300 psia at time of SRV closure. Initially, primary pressure will go up very slowly, with the criteria for throttling/terminating HHSI being met ~ 10 minutes or less after the SRVs close. The operating crew must wait for the HHSI throttling/terminating criteria to be met, but then must respond quickly to keep RCS pressure from rising sharply thus repressurizing the RCS.

If the crew is in the LOCA procedure (E.1), four criteria must be met before procedures instruct that the crew can terminate injection. They include: 1) reaching ~50 degrees F subcooling, 2) having adequate feedwater flow and acceptable level (32%) in at least 1 SG, 3) stable or rising RCS pressure, and 4) having > 39% level in the pressurizer (½ full). The instruction is a continuous action statement in the procedure and can be done at anytime after the criteria are met.

When the SRVs close, there are no audible alarms or other “compelling signals.” The crew would have to notice that the acoustic meters on the SRVs have stopped and that pressure and subcooling are going back up (although recall that initially pressure and subcooling are changing slowly). The issue for this HEP is whether crews would be monitoring plant conditions well enough to recognize that the SRVs closed and would they be ready to respond when the criteria for throttling/terminating HHSI have been reached.

7. Human Reliability Analysis

The crew will likely be in one of two procedure paths when the SRVs close. They will be in either the LOCA procedure (E.1) or they may be in or going into FR-P.1, which is the imminent PTS procedure. In either case, there are a set of steps that must be followed in order to throttle/terminate HHSI. If the crew were in E.1, they would have to enter ES 1.1 when they recognize that the throttling criteria have been met. Steps required in ES.1.1 would require slightly more time to complete than those required if they were in FR-P.1, introducing some variability in the time required to complete the action.

It is important to emphasize that the throttling criteria will likely not be met immediately when the SRVs close and the crew would be doing things other than only monitoring the relevant parameters. Nevertheless, if they realize that the SRVs have closed, they will probably be monitoring relevant parameters fairly closely. In this scenario, they initially will have adequate feedwater flow and acceptable level (32%) in at least 1 SG and will have reached > 39% level in the pressurizer. Thus, they will mainly be looking for subcooling of ~50 degrees F and the accompanying increase in RCS pressure. If they are in FR-P.1, they will be checking for reactor vessel level (RIVLIS) to be reading more than 64%, monitoring subcooling, and completing other steps.

As noted above, the closing of the SRVs would be an unexpected event and the crew would not receive any alarms indicating that they had closed other than the possible ending of an acoustic signal which could go unnoticed. In addition, there is at least some possibility that the crew could have a LOCA "mindset" and that they would have the sense that the "event is over." Moreover, they would probably not be anxious to throttle/terminate HHSI unless they were sure that the SRVs had closed. They could be thinking that such an action might cause them to lose control of the LOCA and verifying closure of the SRVs could take at least some time, even though there would be supporting indications that the SRV closure had occurred.

Aleatory Factors

There were several factors identified that were judged to have likely aleatory effects on the probability of failure to throttle/terminate HPI. That is, to the extent the factors vary randomly, variations in the probability of failure would be expected; thereby contributing to the uncertainty associated with estimates of the human error probability. Some aspects of the factors would be expected to improve the probability of success and others would increase the probability of failure. Key factors identified included:

- whether the crew would be in E.1 or FR-P.1
- instrumentation or controls unavailable due to maintenance or failure
- impacts of support systems that affect control of other systems (can cause very confusing plant response, e.g., instrument air, instrument AC, instrumentation and control system [I&C])
- time of day
- crew "having bad day" (for any number of possible reasons)
- proactive crew vs. a more complacent crew

Epistemic Factors

Of course, the analysts must also consider the fact that they cannot be exactly sure how all of the various factors will influence performance. Thus, they must also take into account the impact of epistemic uncertainty in developing their distributions for the probability of failure.

Basis for the Consensus Distribution

All of the different types of uncertainty were considered together in deriving each individual's uncertainty distribution. The initial distributions for the three analysts, along with the consensus distribution, which was derived in the general manner described in 7.1.7.2 above, are presented below.

In reaching a consensus, two basic arguments were considered, along with the impact of the set of aleatory and epistemic factors. First, the crew has successfully stabilized the SLOCA, but they remain in a SLOCA condition until the SRVs close. Water has been entering the containment and a serious event has occurred. The crew may be in FR-P.1 and even if not, it is reasonable to expect that they would at least be thinking about PTS as a possibility and that someone may be carefully monitoring critical plant parameters. In addition, observation of the Beaver Valley crews in the simulator supports the belief that the procedures would be attended to and that the crew would be carefully monitoring critical parameters.

On the other hand, the Beaver Valley crew observed in the simulator did not seem to have a strong sense of urgency with regard to throttling/terminating HHSI. They trusted that their procedures would get them there in time and were therefore methodical about executing the procedures. Thus, even if they promptly detect the SRVs closing, and are monitoring primary pressure and subcooling, they may not always successfully get through the procedure within 1 minute after the criteria are reached.

Furthermore, as noted above, the event is a bit of a "surprise." The crew could be in LOCA "mindset" and would be thinking that they had the event under control. Thus, they might not recognize and adjust quickly to the changing conditions. The emergency safeguards (ES) logic must be reset before HHSI can be terminated and there is at least some concern that the crew may take the time to do some investigation before cutting back HHSI. That is, they might be concerned about taking such an action because it might lead them to lose control of the LOCA that they currently have under control (e.g., they may not yet know for sure that the stuck open SRVs have closed).

The consensus distribution (Table 7.9) was based on the analysts weighing the relative strengths of the above arguments and their consideration of the impact of the different types of uncertainty on the distribution. Essentially, with the very small amount of time available, the lack of compelling signals for the SRVs closing, and the general approach to procedure implementation at Beaver Valley, the analysts were not confident that the action would be completed very often within 1 minute after reaching the safety injection throttle criteria.

Table 7.9. Uncertainty distributions for HFE involving operators fail to throttle/terminate high pressure injection & control RCS pressure within 1 minute after throttle criteria is met.

Analyst	Percentiles						
	1st	10th	25th	50th	75th	90th	99th
#1	0.1	0.3	0.5	0.7	0.8	0.9	0.99
#2	0.1	0.25	0.4	0.6	0.7	0.85	0.99
#3	0.1	0.4	0.5	0.75	0.8	0.9	0.99
Consensus	0.1	0.3	0.5	0.7	0.8	0.9	0.99

HFE

Failure to throttle/terminate HHSI and otherwise control RCS pressure within allowable pressure-temperature limits within 10 minutes after the allowable throttling criteria is reached in the scenario involving a sudden reclosure of two pressurizer safety relief valves (SRVs) that have been opened for a long time (taken as a representative 6000 seconds in the PRA model) since the initial reactor trip and start of the overcooling event. (Note “throttling” is actually performed by terminating various HHSI pumps, thus throttling the overall flowrate).

General Context

The general context for this event is identical to that for the 1 minute case addressed immediately above. However, in this scenario, the estimate of interest is the probability that the crew would fail to throttle HHSI within 10 minutes (rather than 1 minute) after the criteria have been reached.

However, in this case, along with the very rapid increase in RCS pressure, high pressure alarms would sound and repeated PORV openings would be occurring. Thus, multiple cues would be available to further indicate the need for the crew to throttle HHSI.

Aleatory and Epistemic Factors

The factors identified as being likely to have effects on the probability of failure to throttle HHSI within 10 minutes are the same as for the 1 minute case.

Basis for the Consensus Distribution

It is expected that given that the operators had stabilized the SLOCA, they would remain vigilant about what was occurring in the plant. That is, even though the SLOCA is under control, until they determine the SRVs have closed, they would believe that they are still in a SLOCA and that water is entering containment. Moreover, a serious event has occurred. Once the SRVs close, they will have the opportunity to see pressure increasing gradually at first and then suddenly raising thereafter. Given the crews usual vigilance and “board coverage” noted in the simulator exercises, and the potential for being in the PTS procedure (FRP.1), there is a very reasonable expectation that the crew will recognize that

pressure is increasing and that the SRVs may be closed (or closing). Given the ten minutes for this evaluation, there would appear to be a higher likelihood of eventually responding to the repressurization and regaining control of the situation, especially given the additional alarms/indications of very high RCS pressure. As a result, there was a high degree of confidence that the Beaver Valley crews would respond within 10 minutes after the criteria were reached.

The consensus distribution (Table 7.10) was based on the analysts weighing the relative strengths of the above arguments and their consideration of the impact of the different types of uncertainty on the distribution.

Table 7.10. Uncertainty distributions for HFE involving operators fail to throttle/terminate high pressure injection & control RCS pressure within 10 minutes after throttle criteria is met.

Analysts	Percentiles						
	1st	10th	25th	50th	75th	90th	99th
#1	.0001	.0005	.001	.005	.01	.1	.3
#2	.001	.002	.005	.01	.02	.05	.1
#3	.003	.01	.03	.05	.08	.1	.3
Consensus	.001	.002	.005	.01	.05	.1	.3

HFE

Failure to throttle HHSI and otherwise control RCS pressure within allowable pressure-temperature limits within 30 minutes after the allowable throttling criteria is reached in the scenario involving a significant steam generator depressurization event (e.g., main steamline break) when the crew has previously successfully isolated the feed to the affected steam generator (hence consider the possible dependency of the previous success on this human action).

General Context

In the scenarios of interest, a MSLB or other secondary side breach has occurred and the crew has, by the time periods of interest (i.e., 30 min) isolated the feed to the SG with the break. In this initially excessive steam demand event (ESDE), the question is what is the probability that the crew would fail to terminate HHSI and depressurize in order to keep temperature and pressure within allowable limits by 30 minutes after the throttling/termination criteria are met.

With a significant faulted SG first occurs, subcooling will increase and pressurizer level and pressure will both drop (because of the overcooling) inducing HHSI auto-start. Very quickly after HHSI starts, the throttling criteria will be met since pressurizer level will be restored, subcooling will be adequate and rising, one good SG is still likely to be available, and RCS pressure will be stabilizing or rising.

In the given scenarios, the crews will first enter E-0 and complete various activities before entering either the excessive steam demand (ESDE) procedure or FR-P.1 (the imminent PTS procedure) if the cooling is

severe enough. Based on discussions with operators and trainers, crews will generally take around 10 to 20 minutes to get through E-0, depending on the event. Furthermore, both the (ESDE) procedure and FR-P.1 require a number of steps to be completed before the crew will get to the steps directing them to terminate HHSI. Once the crews realize that they are in the midst of a serious cooldown as indicated by relevant parameters, they will need to enter the ESDE or perhaps a FR-P procedure. Estimates suggest that another 10 - 20 minutes might be required to get to the actual termination steps in these procedures. The crews at Beaver Valley are not inclined to take shortcuts to the termination steps. Taking the collective time to get to the termination steps, it appears marginal that operating crews would be expected to throttle HHSI within 30 minutes on a regular basis. In fact, in a very severe MSLB simulator exercise observed during the analysis, the participating crew was very methodical about working through the relevant procedures and in spite of a significant cooldown, which was clearly indicated and which the crew was clearly aware of (along with the PORVs chattering), they did not initiate throttling/termination of HHSI until after 40 minutes after the event began. It took about 18 minutes to reach the appropriate step in FRP.1 once the procedure was entered. Discussions with the crew and trainers afterwards suggested that this would be a “high end” value for the time to throttle/terminate, because a number of additional distractions/failures were included during the simulation.

In this context, the crew has completed isolation of the faulted steam generator(s), thus there is at least a recognition of the type of the event and the subsequent actions that are needed.

Aleatory and Epistemic Factors

The factors identified as being likely to have effects on the probability of failure to throttle HHSI in this event are the same as for the previous events analyzed above. However, note that a full distribution was not developed for the human error probability (HEP) for this event. This event was shown to be in relatively low frequency scenarios but that an analysis better than simply using the 0.5 screening value for HHSI termination was justified. Thus it was decided that the resources required for developing the full distributions would not be used, but only the mean and 95th percentile values were identified and uncertainty was treated using a lognormal for the distribution.

Basis for the HEP

Beaver Valley operating crews are methodical about stepping through procedures and based on the number of steps required and their own judgments about how long it generally takes them to work through the various relevant procedures, it appeared marginal that they would reach the HHSI throttling criteria under the MSLB conditions in 30 minutes more than about half of the time. This conclusion was supported by observation of an MSLB simulator exercise. Thus, the group consensus value for the mean HEP was 0.5, with the 95th percentile value being 0.99.

HFE

Failure to throttle HHSI and otherwise control RCS pressure within allowable pressure-temperature limits within 60 minutes after the allowable throttling criteria is reached in the scenario involving a significant steam generator depressurization event (e.g., main steamline break) when the crew has previously successfully isolated the feed to the affected steam generator (hence consider the possible dependency of the previous success on this human action).

General Context

The general context for this event is identical to that for throttling HHSI within 30 minutes, which is addressed immediately above. However, in this scenario, the estimate of interest is the probability that the crew would fail to terminate HHSI and regain control of RCS pressure within the allowable pressure-temperature limits by 60 minutes of when the throttling/termination criteria are met.

Aleatory and Epistemic Factors

The factors identified as being likely to have effects on the probability of failure to throttle HHSI in this event are the same as for the previous events analyzed above. However, note that a full distribution was not developed for the human error probability (HEP) for this event. This event was shown to be in relatively low frequency scenarios but that an analysis better than simply using the 0.5 screening value for HHSI termination was justified. Thus it was decided that the resources required for developing the full distributions would not be used, but only the mean and 95th percentile values were identified and uncertainty was treated using a lognormal for the distribution.

Basis for the HEP

The basis for the consensus HEP is in general the same as for the 30 minute case, with the understanding that the extra time would reduce the potential effects of various kinds of delays or distractions on the likelihood of success within the time period. Only a significant misunderstanding of the event (e.g., caused by instrument problems) should prevent the crew from successfully terminating HHSI and depressurizing the RCS within 60 minutes. Observation of MSLB and other simulator exercises indicated that relevant parameters would be closely monitored and that the crew would be very likely to know the degree of cooldown. Thus, the most likely factor delaying throttling would be their systematic step through the relevant procedures. Moreover, the extra time would allow the crew to deal with events such as personnel being injured from the steam in the turbine building and/or problems in attempting to isolate the faulted SG. Thus, the HRA analysts agreed that additional credit beyond that given for the 30 minute case would be appropriate. The analysts agreed on a consensus mean HEP of 0.005 and a 95th percentile value of about an order of magnitude above this value.

HFE

Failure to throttle HHSI and otherwise control RCS pressure within allowable pressure-temperature limits within 30 minutes or otherwise within 60 minutes after the allowable throttling criteria is reached in the scenario involving a significant steam generator depressurization event (e.g., main steamline break) when the crew has previously failed to isolate the feed to the affected steam generator (hence consider the possible dependency of the previous failure on this human action).

General Context

The general context for this event is identical to the two events above for throttling HHSI within 30 or 60 minutes. However, in this scenario, the operating crew has failed to stop feedwater to the faulted steam generator. Stopping feedwater under these conditions is clearly called out in E-0 and it is one of six major actions that the crew is allowed to do outside of the main procedure as a pre-emptive action. The action is also called out in E-2 and FR-P.1. Pressure in the faulted SG would be falling dramatically,

cues would be clear, and the procedural guidance would be substantial. Thus, if the operating crew has failed to accomplish the isolation action, it is likely that the crew is confused in some way. The estimate of interest is the probability that the crew would fail to terminate HHSI and depressurize the RCS in order to keep temperature and pressure within acceptable limits by 30 and 60 minutes of when the throttling criteria are met, considering the prior failure by the crew to isolate feed to the SG with the breach.

Aleatory and Epistemic Factors

The factors identified as being likely to have effects on the probability of failure to throttle HHSI in this event are the same as for the previous events analyzed above. However, note that a full distribution was not developed for the human error probability (HEP) for this event for the two time periods (i.e., 30 & 60 min). This event was shown to be in relatively low frequency scenarios but that an analysis better than simply using the 0.5 screening value for HHSI termination was justified. Thus it was decided that the resources required for developing the full distributions would not be used, but only the mean and 95th percentile values were identified and uncertainty was treated using a lognormal for the distribution.

*Basis for the HEP*s

Given that the analysis above argues that the HEP for throttling/terminating HHSI within 30 minutes is 0.5, the assumption that the crew has failed to stop feeding the faulted steam generator suggests that some important problem exists. Under such conditions, it is reasonable to expect that the crew will be on the high end of the time required to complete the required procedural steps in E-0, E-2 and/or FR-P.1 before they reach the step to terminate HHSI. Therefore, for the 30 minute case, the consensus HEP value for the mean value was 1.0.

For the 60 minute case above, it was argued that only a significant misunderstanding of the event (e.g., caused by instrument problems) should prevent the crew from successfully terminating HHSI and depressurizing the RCS within 60 minutes. However, even though confusion is likely to exist in this scenario, it still seems unlikely that the crew would not to be alerted to the fact that they are outside the allowable pressure-temperature limits and that a correction is needed. Observation of MSLB and other simulator exercises indicated that relevant parameters would be closely monitored and that the crew would be very likely to know the degree of cooldown. Thus, regardless of the problems associated with stopping feedwater, the cooldown rate, along with the pressure and temperature levels, would clearly indicate overcooling with pressure rising. Procedural guidance would be clear and given the independence allowed board operators for critical actions, it is reasonable to expect that by this time (i.e., 60 min), either someone would inform the shift supervisor (SS) and take the appropriate action or that the SS would direct the action. For the 60 minute case, the consensus HEP value for the mean value was 0.05, with the 95th percentile value set at 0.1.

HFE

Failure to properly control RCS pressure within 1 minute or 10 minutes after transitioning from feed and bleed and getting SG cooling back and thus needing to reclose the PORVs (thus a repressurization potential) and rely on SG cooling.

General Context

In this situation, the crew has so far successfully handled a loss of heat sink event by cooling the core using feed and bleed cooling. However, they have been trying to recover a SG feed source and eventually do so. When feed is restored, they want to match the feed flow with the required cooling they have been getting using feed and bleed. They will perform calculations to determine the appropriate feed flow and will then start feed and close the PORV(s). The resulting repressurization will not be a surprise as in the case where SRVs unexpectedly close. The crew will be planning for the repressurization and should be prepared to throttle HHSI when the PORVs are closed. The question of interest is the probabilities that the crew will fail to appropriately throttle HHSI within 1 minute and 10 minutes of transitioning to SG cooling and closing the PORVs.

Aleatory and Epistemic Factors

The factors identified as being likely to have effects on the probability of failure to throttle HHSI in this event are similar to those for the previous events analyzed above. However, note that a full distribution was not developed for the human error probability (HEP) for this event for the two time periods (i.e., 1 & 10 min). This event was shown to be in relatively low frequency scenarios but that an analysis better than simply using the 0.5 screening value for HHSI termination was justified. Thus it was decided that the resources required for developing the full distributions would not be used, but only the mean and 95th percentile values were identified and uncertainty was treated using a lognormal for the distribution.

Basis for HEPs

Since the crew has planned this action and will clearly know the effect of closing the PORVs, it is reasonable to expect that they will immediately control HHSI. However, one minute is not much time to get HHSI under control and given the long-term loss of cooling event they have been in, there is at least some chance that PTS may not be so great enough concern that the crew would immediately control HHSI. Thus, the group consensus mean HEP for responding within 1 minute was estimated at 0.1, with the 95th percentile equal to 0.5.

With 10 minutes available, it seemed very likely that the crews would appropriately control HHSI. Again, they have successfully handled a complicated scenario and have appropriately planned to start SG feed and close the PORVs. Given their training, the explicit PTS related procedures, the obvious effects of closing the PORVs, and the clear cues for the action, the group consensus mean HEP for responding within 10 minutes was estimated at 0.001, with the 95th percentile equal to about an order of magnitude higher.

Hot Zero Power

For hot zero power conditions, given the already fairly high HEPs in most cases and/or in some cases the relative late timing to allow the correct action to take place, it was decided that no changes to the full power detailed assessments would be made for treatment of the same events under hot zero power conditions.

7.2.3 Incorporation Into the PTS PRA Model

The failure probabilities reported in Tables 7.7, 7.8, and section 7.2.2 were modified before final incorporation into the PTS PRA model. Depending on the specific input, there are four reasons why this final modification took place.

1. Incorporation of the uncertainty bounds provided in the HRA initial quantification was an approximation process, in order to arrive at a smooth but skewed probability distribution. The process attempted to duplicate the provided mean, 5th, and 95th percentile values for each HFE, as closely as possible. During this process, the final mean value used for each HFE in the PTS PRA was forced to be as close to the estimated mean as possible, and while attempting to fit the 95th and 5th values, priority was given to coming as close to the 95th while letting the 5th percentile value be the loosest fit of all three values. Hence the final PTS HRA values are slightly different from that provided by the initial quantification.

2. Incorporation of the histograms provided by the detailed quantification of the most important HFEs required a slight expansion of the distribution to create values for the end points (0th and 100th). This was accomplished by adding 10% to the last value to produce the 100th percentile and subtracting 10% from the first value to produce the 0th percentile.

3. For the HFE probabilities with different time periods associated with the action (e.g., by 1 minute, by 10 minutes, etc.), adjustments were necessary to translate the HRA provided values and uncertainties into the PTS PRA model. This process, is summarized below.

4. A combination of the above.

With regard to item 3 above, while the PRA end states are related to time durations, the HRA task necessarily focused on the logical time sequencing of accident progression that is the operator's perspective. In other words, the HRA analysts determined what action cues and plant conditions would be expected to occur over time. These cues and conditions suggested logical time points for HRA evaluation. For example, human failure probabilities were generated on the basis of what cues and conditions would have accumulated by certain times (e.g., 1 and 10 minutes) and assigned probabilities that the operators would have failed to perform the necessary mitigative action (e.g., throttle/terminate HHSI) on the basis of these contexts. Using these example times and actions, the Beaver Valley PTS PRA model required, for instance, three human events:

1. The successful cutback of HHSI by 1 minute (assumed to occur right at 1 minute in the model).

2. The failure to cutback by 1 minute, but successful by 10 minutes (i.e., termination/cutting back is assumed to occur at 10 minutes in the model, resulting in 9 more minutes of exposure to rising pressure conditions).

3. The failure to cutback HHSI by 10 minutes (assumed, therefore, to never occur for modeling purposes).

The first event is not a failure at all. This probability of success is the complement of the failure probability assigned for the 1-minute HRA case. Hence, for the PTS PRA, the complement of the mean and uncertainty distribution was used to express this success probability. The third event is equivalent to the 10-minute HRA case and is a direct translation of that probability distribution. The second event is the most complicated of all, involving failure by 1 minute but success by 10 minutes. Simplistically, this failure probability is calculated by subtracting the failure probability of the 10-minute case from that for the 1-minute case.[15] This was performed by using LHS software [SAND98-0210] to create a new distribution for the second case where this new distribution is defined as the results of subtracting the 10-minute-case distribution from the 1-minute-case distribution using a sample size of 1000. The resulting distribution was then incorporated into SAPHIRE [SAPHIRE] by way of a 20-point uncertainty histogram.

Accounting for the above modifications, Table 7.11 shows the HFEs and their respective probabilities as they were actually included in the full-power and low power Beaver Valley PTS PRA models.

[15] In practice, this subtraction involved not simply the mean values but the failure probability distributions for each case.

Table 7.11. Modeled HFE values for Beaver Valley PTS PRA: Full & Low Power.

HFE #	HFE	Condition When Applied	HRA Mean and Uncertainty for Full Power (original estimate)	HRA Mean and Uncertainty for Low Power (original estimate)	PTS PRA Modeled HFE Name	PTS PRA Model Mean Value (Full Power / Low Power)	PTS PRA Model Uncertainty Factor (Full Power / Low Power)
1	Operators fail to control/throttle AFW	Case (a)(1): Uncomplicated trip & SI not actuated	1E-3 = mean (95%, 5%) = 1E-2, 1E-4	1E-2 = mean (95%, 5%) = 1E-1, 1E-3	Not used in final model[1]	Not used in final model	Not used in final model
		Case (a)(2): Like (a)(1) but SI actuated and evaluated for 10 min	1E-1 = mean (95%, 5%) = 0.5, 1E-2	1E-1 = mean (95%, 5%) = 0.5, 1E-2	Not used in final model	Not used in final model	Not used in final model
		Case (a)(3): Like (a)(2) but evaluated for 20 min	1E-3 = mean (95%, 5%) = 1E-2, 1E-4	1E-2 = mean (95%, 5%) = 1E-1, 1E-3	AFW_REC_FL-20AB FW_REC_FL-20AB	1E-3 / 1E-2 1E-3 / 1E-2	10 lognormal/ 10 lognormal 10 lognormal/ 10 lognormal
		Case (b)(1): Like case (a)(2) above except concurrent functional problem (e.g., SLOCA)	1E-1 = mean (95%, 5%) = 0.5, 1E-2	1E-1 = mean (95%, 5%) = 0.5, 1E-2	Not used in final model	Not used in final model	Not used in final model
		Case (b)(2): Like case (a)(3) above except concurrent functional problem (e.g., SLOCA)	1E-3 = mean (95%, 5%) = 1E-2, 1E-4	1E-2 = mean (95%, 5%) = 1E-1, 1E-3	AFW_REC_FL-20AB FW_REC_FL-20AB	1E-3 / 1E-2 1E-3 / 1E-2	10 lognormal/ 10 lognormal 10 lognormal/ 10 lognormal

[1] Events typically not used because likelihood of plant state and original conservative HFE estimate showed this situation had too low a frequency or the event is associated with unimportant TH timing/cases..

Table 7.11. Modeled HFE values for Beaver Valley PTS PRA: Full & Low Power.

HFE #	HFE	Condition When Applied	HRA Mean and Uncertainty for Full Power (original estimate)	HRA Mean and Uncertainty for Low Power (original estimate)	PTS PRA Modeled HFE Name	PTS PRA Model Mean Value (Full Power / Low Power)	PTS PRA Model Uncertainty Factor (Full Power / Low Power)
1 cont'd		Case (c)(1): Involves a concurrent support system fault(s) and evaluated for 10 min	0.5 = mean (95%, 5%) = 0.9, 1E-2	0.5 = mean (95%, 5%) = 0.9, 1E-2	Not used in final model	Not used in final model	Not used in final model
		Case (c)(2): Like case (c)(1) but evaluated for 20 min	1E-1 = mean (95%, 5%) = 0.5, 1E-3	0.5 = mean (95%, 5%) = 0.9, 1E-2	AFW_REC_FL-20C FW_REC_FL-20C TAFW_REC_FL-20C	9.6E-2 / 4.9E-1 9.7E-2 / 4.8E-1 9.4E-2 / 4.8E-1	histogram / histogram histogram / histogram histogram / histogram
		Case (c)(3): Like case (c)(1) but evaluated for 45 min	1E-3 = mean (95%, 5%) = 1E-2, 1E-4	1E-2 = mean (95%,5%)= 1E-1, 1E-3	AFW_REC_FL-45C FW_REC_FL-45C TAFW_REC_FL-45C	1E-3 / 1E-2 1E-3 / 1E-2 1E-3 / 1E-2	10 lognormal / 10 lognormal 10 lognormal / 10 lognormal 10 lognormal / 10 lognormal
2	Operators fail to trip turbine when auto trip fails	Applies for all events under all circumstances	1E-3 = mean (95%, 5%) = 1E-2, 1E-4	1E-3 = mean (95%, 5%) = 1E-2, 1E-4	Not used in final model	Not used in final model	Not used in final model
3	Operators fail to trip RCPs when required	Applies for all events under all circumstances when meet shutdown criteria	1E-3 = mean (95%, 5%) = 1E-2, 1E-4	1E-3 = mean (95%, 5%) = 1E-2, 1E-4	Not used in final model	Not used in final model	Not used in final model
4	Operators trip RCPs when not required to do so	Applies for all events under all circumstances	1E-2 = mean (95%, 5%) = 1E-1, 1E-3	5E-2 = mean (95%,5%)= 0.5, 5E-3	RCP_INADV_TRIP	1.0E-2 / 5.0E-2	10 lognormal / 10 lognormal

Table 7.11. Modeled HFE values for Beaver Valley PTS PRA: Full & Low Power.

HFE #	HFE	Condition When Applied	HRA Mean and Uncertainty for Full Power (original estimate)	HRA Mean and Uncertainty for Low Power (original estimate)	PTS PRA Modeled HFE Name	PTS PRA Model Mean Value (Full Power / Low Power)	PTS PRA Model Uncertainty Factor (Full Power / Low Power)
5	Operators fail to restart RCPs when required	Applies to situations where RCPs have been stopped but criteria for restart is met Case (a): severe overcooling	0.5 = mean (95%, 5%) = 0.9, 0.1	0.5 = mean (95%,5%) = 0.9,0.1	RCP_RESTART_F	5.0E-1 / 5.0E-1	9.0E-2 to 1.0 max entropy / 9.0E-2 to 1.0 max entropy
		Case (b): For recovery situations	1E-2 = mean (95%, 5%) = 1E-1, 1E-3	1E-1 = mean (95%, 5%) = 0.9, 1E-2	Not used in final model	Not used in final model	Not used in final model
6	Operators <u>successfully</u> use feed and bleed when suppose to	Applies to all events when there is a loss of heat sink & these actions are necessary.	1.0 (success)	1.0 (success)	Not used in final model	Not used in final model	Not used in final model
7	Operators fail to recover from MFW overfeed	Applies to all initiators where MFW continues to overfeed.	1E-3 = mean (95%, 5%) = 1E-2, 1E-4	1E-2 = mean (95%, 5%) = 1E-1, 1E-3	MFW_REC_F **(success of event)**	9.99E-1 / 9.9E-1	point value / point value
8	Operators fail to isolate feed (particularly AFW including steam paths) to faulted SG - evaluated at different times.	Case (a)(1): Secondary depressurization event by itself or with another functional failure (e.g., SLOCA) or support system fault; for 2 min or less.	0.5 = mean (95%,5%)= 0.9,1E-1	0.5 = mean (95%,5%)= 0.9, 1E-1	Not used in final model	Not used in final model	Not used in final model

Table 7.11. Modeled HFE values for Beaver Valley PTS PRA: Full & Low Power.

HFE #	HFE	Condition When Applied	HRA Mean and Uncertainty for Full Power (original estimate)	HRA Mean and Uncertainty for Low Power (original estimate)	PTS PRA Modeled HFE Name	PTS PRA Model Mean Value (Full Power / Low Power)	PTS PRA Model Uncertainty Factor (Full Power / Low Power)
8 cont'd		Case (a)(2): Like above but for 5 min	0.5 = mean (95%,5%)= 0.9,1E-2	0.5 = mean (95%,5%)= 0.9, 1E-1	Not used in final model	Not used in final model	Not used in final model
		Case (a)(3): Like above but for 10 min	1E-1 = mean (95%,5%)= 0.5,1E-3	0.5 = mean (95%,5%)= 0.9, 1E-1	AFW_ISO_FL10	9.4E-2 / 4.9E-1	histogram / histogram
		Case (a)(4): Like above but for 30 min	1E-3 = mean (95%,5%)= 1E-2, 1E-4	1E-2 = mean (95%,5%)= 1E-1, 1E-3	AFW_ISO_FL30	1E-3 / 1E-2	10 lognormal / 10 lognormal
9	Operators fail to close PORV/its block valve upon stuck-open PORV	Applies to all initiators/ situations	1E-3 = mean (95%,5%)= 1E-2, 1E-4	1E-3 = mean (95%,5%)= 1E-2, 1E-4	PORV_ISO_F	1.0E-3 / 1.0E-3	10 lognormal / 10 lognormal

Table 7.11. Modeled HFE values for Beaver Valley PTS PRA: Full & Low Power.

HFE #	HFE	Condition When Applied	HRA Mean and Uncertainty for Full Power (original estimate)	HRA Mean and Uncertainty for Low Power (original estimate)	PTS PRA Modeled HFE Name	PTS PRA Model Mean Value (Full Power / Low Power)	PTS PRA Model Uncertainty Factor (Full Power / Low Power)
10	Operators fail to terminate HHSI & depressurize to control within allowable P-T limits	All cases (see specific scenario evaluations under detailed analysis)	0.5 = mean **(screening value)**	0.5 = mean **(screening value)**	HHSI_SCREEN30MIN (used except for cases below) HHSI_TERM_0SRV-1 (used for 1 min throttle case in SRV reclosure scenarios) HHSI_TERM_0SRV-10 (used for 10 min throttle case in SRV reclosure scenarios) HHSI_TERM_FB-1 (used for 1 min throttle case when transitioning from F&B to SG cooling) HHSI_TERM_FB-10 (used for 10 min throttle case when transitioning from F&B to SG cooling) HHSI_TERM_MSLB-30A (used for 30 min throttle case when secy breach & feed isolated HHSI_TERM_MSLB-60A (used for 60 min throttle case when secy breach & feed isolated HHSI_TERM_MSLB-60B (used for 60 min throttle case when secy breach & feed not isolated	0.5 / 0.5 5.9E-1 / 5.5E-1 4.2E-2 / 4.2E-2 9.3E-2 / 9.3E-2 1E-3 / 1E-3 5E-1 / 5E-1 5E-3 / 5E-3 5E-2 / 5E-2	point value / point value histogram / histogram histogram / histogram histogram / histogram 10 lognormal / 10 lognormal histogram / histogram 10 lognormal / 10 lognormal 3 lognormal / 3 lognormal

Table 7.11. Modeled HFE values for Beaver Valley PTS PRA: Full & Low Power.

HFE #	HFE	Condition When Applied	HRA Mean and Uncertainty for Full Power (original estimate)	HRA Mean and Uncertainty for Low Power (original estimate)	PTS PRA Modeled HFE Name	PTS PRA Model Mean Value (Full Power / Low Power)	PTS PRA Model Uncertainty Factor (Full Power / Low Power)
11	Operators fail to trickle/throttle condensate into SG(s) - both depressurization & flow control	All initiators/ situations involving loss of heat sink but condensate available.	1E-1 = mean (95%, 5%) = 0.5, 1E-2	1E-1 = mean (95%, 5%) = 0.5, 1E-2	CBP_GEN_OVERFD	1E-1 / 1E-1	5 lognormal / 5 lognormal
12	Operators fail to trickle/throttle condensate into SG(s) - during secondary depressurization events	All initiators/ situations involving loss of heat sink & secondary depressurization but condensate available.	0.5 = mean (95%, 5%) = 0.9, 1E-1	0.5 = mean (95%, 5%) = 0.9, 1E-1	CBP_SLB_OVERFD	5E-1 / 5E-1	1.8 lognormal / 1.8 lognormal
13	Operators isolate wrong SG	All initiators/ situations	1E-3 = mean (95%,5%)= 1E-2, 1E-4	1E-2 = mean (95%,5%)=1E-1, 1E-3	Not used in final model	Not used in final model	Not used in final model
14	Operators fail to restore good SG and isolate bad SG if isolated wrong SG initially.	All initiators/ situations	0.5 = mean (95%, 5%) = 0.9, 1E-2	0.5 = mean (95%, 5%) = 0.9, 1E-2	Not used in final model	Not used in final model	Not used in final model

8. DATA ANALYSIS

This section discusses the probabilities assigned to each of the basic events in the Beaver Valley pressurized thermal shock (PTS) models with the exceptions of the initiating events (see section 3) and the human action events (see section 7). The information provided includes the event's:

- name (i.e., identifier),
- description,
- probability,
- uncertainty distribution, if applicable, and
- the source used to estimate the probability and uncertainty distribution.

Table 8.1 provides the above information.

Table 8.1. Basic events: value and uncertainty information.

Name	Description	Calc. Probability	Unc Type Unc Value 1 Unc Value 2	Corr. Class	Source Discussion
AREA-FRAC-1	Area Fraction #1	5.64E-01	Point Value		UMD uncertainty report [Chang] Used to represent fraction of open area of one stuck open SRV(could be partially or full open) important to PTS.
AREA-FRAC-2	Area Fraction #2	4.00E-01	Point value		UMD uncertainty report Used to represent fraction of open area of a stuck open SRV when 2 were initially stuck-open but one reclosed, & important to PTS.
AREA-FRAC-3	Area Fraction #3	5.00E-01	Point value		UMD uncertainty report Used to represent fraction of open area of two stuck open SRVs (either/both could be partially or fully open) important to PTS.
FRAC-MLOCA-1	Conditional MLOCA Probability #1	3.50E-01	Point Value		UMD uncertainty report Used to represent uncertainty associated with medium LOCA.
FRAC-MLOCA-2	Conditional MLOCA Probability #2	3.00E-01	Point Value		UMD uncertainty report Used to represent uncertainty associated with medium LOCA.
FRAC-MLOCA-3	Conditional MLOCA Probability #3	3.50E-01	Point Value		UMD uncertainty report Used to represent uncertainty associated with medium LOCA.
FRAC-SLOCA-1	Conditional SLOCA Probability #1	2.3E-01	Point Value		UMD uncertainty report Used to represent uncertainty associated with small LOCA.
FRAC-SLOCA-2	Conditional SLOCA Probability #2	1.8E-01	Point Value		UMD uncertainty report Used to represent uncertainty associated with small LOCA.

Table 8.1. Basic events: value and uncertainty information.

Name	Description	Calc. Probability	Unc Type Unc Value 1 Unc Value 2	Corr. Class	Source Discussion
FRAC-SLOCA-3	Conditional SLOCA Probability #3	1.8E-01	Point Value		UMD uncertainty report Used to represent uncertainty associated with small LOCA.
FRAC-SLOCA-4	Conditional SLOCA Probability #4	1.8E-01	Point Value		UMD uncertainty report Used to represent uncertainty associated with small LOCA.
FRAC-SLOCA-5	Conditional SLOCA Probability #5	2.3E-01	Point Value		UMD uncertainty report Used to represent uncertainty associated with small LOCA.
DUMMY-1	ET-top Developed Event	1.00E+00	Point Value		Dummy event used to create large and medium LOCA sequences.
AFW_DED	AFW dedicated pump train fails	1.00E-01	Lognormal EF=3		Engineering judgment
AFW_FAIL	AFW fails to function (no flow)	1.07E-05	Lognormal EF=2.5		Beaver Valley IPE AF1 event [Beaver Valley IPE]
AFW_MDP_FAIL	AFW fails to function (1 MDP train unavailable)	6.82E-04	Lognormal EF=2		Beaver Valley IPE AF5 event [Beaver Valley IPE]
AFW_1_OF	Overfeed 1 SG using AFW	1.60E-03	Beta 3.13E+02		Used same as Oconee experience. Performed Bayes update using non-informative prior Beta (0.5, 0.5) with 0 failures in 312 demands to yield posterior Beta (0.5, 312.5).
AFW_3_OF	Overfeed 3 SGs using AFW	4.50E-02	Beta 1.05E+01		Assumed to be the same as for MFW_3_OF event
AFW_MDP_1_OF	Overfeed 1 SG using AFW (1 MDP train unavailable)	1.60E-03	Beta 3.13E+02		Assumed sufficiently similar to AFW_1_OF event
AFW_MDP_3_OF	Overfeed 3 SGs using AFW (1 MDP train unavailable)	4.50E-02	Beta 1.05E+01		Assumed sufficiently similar to AFW_3_OF event

Table 8.1. Basic events: value and uncertainty information.

Name	Description	Calc. Probability	Unc Type Unc Value 1 Unc Value 2	Corr. Class	Source Discussion
AFW_REC_NONE	AFW does not recover (no feed) after a SG dries out	5.00E-01	Beta 1.005E+00		Table 4 of NUREG/CR-5500, Volume 1 [NUREG/CR-5500-V1] provides several non recovery probabilities. Using the range of values provided, we estimated the non recovery of AFW to be 0.5 with a Beta of 1.005.
AFW_TDP_1_OF	Overfeed 1 SG using AFW (both MDP trains unavailable)	1.60E-03	Beta 3.13E+02		Assumed sufficiently similar to AFW_1_OF event
AFW_TDP_3_OF	Overfeed 3 SGs using AFW (both MDPs unavailable)	4.50E-02	Beta 1.05E+01	2	Assumed sufficiently similar to AFW_3_OF event
A_SEC_COOL_REC_F	Secondary Cooling Recovery - AFW, after having had to go to feed & bleed	5.00E-01	Max Entropy 0.1, 0.9		Engineering judgment used to set value to determine if this event is important.
BLUE	Likelihood AC bus loss is the 120V AC Blue Bus	2.50E-01	Point value		One of four possible modeled busses
COND_FAIL	Condensate fails to function (no flow)	1.00E-01	Lognormal EF = 3		Assumption Engineering judgment used to set value to determine whether operation of CBPs important.
DG_A	Emergency power - Train A unavailable	1.08E-01	Lognormal EF=1.6		Beaver Valley IPE AO2 event [Beaver Valley IPE]
DG_B	Emergency power - Train B unavailable	9.94E-02	Lognormal EF=1.0		Beaver Valley IPE BP6 event [Beaver Valley IPE]
DG_B_GIVEN_A	DG Train B fails given Train A failed	1.49E-01	Lognormal EF=1.0		Beaver Valley IPE BP5 event [Beaver Valley IPE]
FW_REC_C-FT	Success of this fault tree top event solution used in model (not really a basic event)	3.683E-01 (failure)	---		Min cut upper bound value from fault tree solution.
FW_REC_FT-T-AB	Success of this fault tree top event solution used in model (not really a basic event)	1,00E-03 (failure)	---		Min cut upper bound value from fault tree solution.
FW_REC_FT-T-C	Success of this fault tree top event solution used in model (not really a basic event)	9.76E-02 (failure)	---		Min cut upper bound value from fault tree solution.

Table 8.1. Basic events: value and uncertainty information.

Name	Description	Calc. Probability	Unc Type Unc Value 1 Unc Value 2	Corr. Class	Source Discussion
HHSI_INIT_F	HHSI Initiation Top Event	2.20E-03	Beta 2.25E+02		NUREG/CR-5500, Vol. 9 [NUREG/CR-5500-V9], page xi. Performed Bayes update using non-informative prior Beta (0.5, 0.5) with 0 failures in 224 demands to yield posterior Beta (0.5, 224.5).
HHSI_PUMP_FTS	HHSI pump train fails to start	3.40E-03	Beta 2.25E+02		NUREG/CR-5500, Vol. 9, page 46, Table 10.
HHSI_PUMP_OOS	HHSI pump train out of service	5.20E-03	Beta 2.25E+02		NUREG/CR-5500, Vol. 9, page 45, Table 9.
HHSI_REC_F	HHSI Recovered	7.00E-01	Beta 4.00E-01		Table 4 of NUREG/CR-5500, Volume 9 provides several non recovery probabilities. Using the range of values provided, we estimated the non recovery of HHSI to be 0.7 with a Beta of 0.4.
HZP-FRACTION	Fraction of time at HZP	2.00E-02	Max Entropy 5.00E-03 4.00E-02		Beaver Valley & Oconee experience Review of recent experience indicated plants in hot zero power approximately 1 – 2 percent of year.
HZP-MULTIPLIER	HZP Multiplier for RTTT & LOMF initiators	2.00E-01	Max Entropy 1.00E-01 3.00E-01		Engineering judgment Factor of 10 increase to HZP-FRACTION to account for increased likelihood of reactor/turbine trips due to transient conditions that arise as a result of changing feedwater and steam conditions along with changing power and other parameters in the plant.
MFW_COND_NR	Non recovery of MFW/Condensate	6.00E-01	Max Entropy 6.00E-02 1.00E+00		NUREG/CR-4550, Vol. 1, Rev. 1 [NUREG/CR-4550 V1R1] Table 8.2-10 (70-120).

Table 8.1. Basic events: value and uncertainty information.

Name	Description	Calc. Probability	Unc Type Unc Value 1 Unc Value 2	Corr. Class	Source Discussion
MFW_3_OF	Overfeed 3 SGs using MFW	4.50E-02	Beta 1.05E+01		Assumption event similar to Oconee Performed Bayes update using non-informative prior Beta (0.5, 0.5) with 0 failures in assumed ~10 demands to yield posterior Beta (0.5, 10.5).
MFW_TRIP_F	MFW Fails to Trip on High SG Level	7.00E-03	Beta 7.05E+01		Based on LER data. Performed Bayes update using non-informative prior Beta (0.5, 0.5) with 0 failures in 70 demands to yield posterior Beta (0.5, 70.5).
ORANGE	Likelihood DC bus loss is the 125V DC Orange Bus	5.00E-01	Point value		One of two possible modeled busses
PCCW_VALVE_F	Likelihood of PCCW Valve Closure thru diaphragm leakage given loss of air	1.00E-01	Lognormal EF=10		Engineering judgment used to set value to determine if this event is important.
PORV_CLOSE_1	Number (Fraction) of 1 PORV combinations that can be closed/isolated	6.70E-01	Point value		Based on number of 1 PORV combinations that can be closed used in LOSP initiator event tree.
PORV_SELF_CLOSE1	1 Stuck-Open PORV Fails to Self Close	2.50E-01	Lognormal EF = 1.5		Assumed to be same as SRV_ISO_F_1.
PORV_SELF_CLOSE2	2 Stuck-Open PORVs Self Close	5.00E-01	Lognormal EF=1.4		Two (2) times SRV_ISO_F_1.
PORV_SO_2	2 Primary PORVs Stuck Open	3.30E-06	Beta 1.53E+05		NUREG/CR-5750-Addendum, Table D-4 & Assumption. Performed Bayes update using non-informative prior Beta (0.5, 0.5) with 0 failures in 1535 demands to yield posterior Beta (0.5, 1535.5). Then assumed 1% chance for 2nd valve.
PURPLE	Likelihood DC bus loss is the 125V DC Purple Bus	5.00E-01	Point value		One of two possible modeled busses
RCP_TRIP_PORV	RCPs Tripped (loss of RCS subcooling) given stuck open PORV	1.00E-00	Point value		Engineering judgment Assumed subcooling lost implying operators trip pumps under this condition.

Table 8.1. Basic events: value and uncertainty information.

Name	Description	Calc. Probability	Unc Type Unc Value 1 Unc Value 2	Corr. Class	Source Discussion
RED	Likelihood AC bus loss is the 120V AC Red Bus	2.50E-01	Point value		One of four possible modeled busses
SEC_COOL_REC_F	Secondary Cooling Recovery - MFW or AFW after having had to go to feed & bleed.	5.00E-01	Max Entropy 0.1, 0.9		Engineering judgment used to set value to determine if this event is important.
SRV-CLOSES-3000-SEC	Likelihood SRV(s) Reclose at 3000 seconds	5.00E-01	Point value		Assumed for valve reclosures, that ½ the time the reclosure occurred ~3000 sec and ½ the time the reclosure occurred ~6000 sec to account for uncertainty as to when reclosures would occur.
SRV-CLOSES-6000-SEC	Likelihood SRV(s) Reclose at 6000 seconds	5.00E-01	Point value		Assumed for valve reclosures, that ½ the time the reclosure occurred ~3000 sec and ½ the time the reclosure occurred ~6000 sec to account for uncertainty as to when reclosures would occur.
SRV_ISO_F_0	2 Stuck-Open Primary SRVs Isolate (i.e., both isolate)	5.625E-01	Lognormal EF=1.3		Based on the success of the SRV_ISO_F_1 event for both valves (0.75 * 0.75)
SRV_ISO_F_1	1 Stuck-Open Primary SRV Fails to Isolate	2.50E-01	Lognormal EF=1.5		Appendix I Section 1 of NUREG/CR-5750 indicates three (3) of four (4) stuck open PWR SRVs closed or "nearly closed." Thus, probability of stuck open SRV failing to close is 0.25.
SRV_ISO_F_1OF2	1 of 2 Stuck-Open Primary SRVs Fail to Isolate	3.75E-01	Lognormal EF=1.7		Based on 2 combinations of the success (one valve) & failure (one valve) of the SRV_ISO_F_1 event [2*(0.75 * 0.25)]
SRV_ISO_F_2	2 Stuck-Open Primary SRVs Fail to Isolate (i.e., both fail to isolate)	6.25E-02	Lognormal EF=1.3		Based on the failure of the SRV_ISO_F_1 event for both valves (0.25 * 0.25)

Table 8.1. Basic events: value and uncertainty information.

Name	Description	Calc. Probability	Unc Type Unc Value 1 Unc Value 2	Corr. Class	Source Discussion
SRV_SO	1 Primary SRV stuck open	1.60E-03	Beta 1.53E+03		NUREG/CR-5750-Addendum, Table D-4 Performed Bayes update using non-informative prior Beta (0.5, 0.5) with 2 failures in 1535 demands to yield posterior Beta (2.5, 1535.5).
SRV_SO_2	2 Primary SRVs stuck open	1.60E-05	Beta 1.53E+05		NUREG/CR-5750-Addendum, Table D-4 & Assumption. Performed Bayes update using non-informative prior Beta (0.5, 0.5) with 2 failures in 1535 demands to yield posterior Beta (2.5, 1535.5). Then assumed 1% chance for 2nd valve.
WHITE	Likelihood AC bus loss is the 120V AC White Bus	2.50E-01	Point value		One of four possible modeled busses
YELLOW	Likelihood AC bus loss is the 120V AC Yellow Bus	2.50E-01	Point value		One of four possible modeled busses

9. QUANTIFICATION

This section describes how the frequencies for the final thermal-hydraulic (TH) bins were estimated and provides frequency distribution information for each bin. The TH bin frequency distribution information was transmitted to the Nuclear Regulatory Commission's contractor at Oak Ridge National Laboratory who had responsiblity for the probabilistic fracture mechanics (PFM) calculations. It was used as one of the inputs in producing an estimate of the through-wall-crack frequency (TWCF) for each TH bin. This TWCF estimate was produced by combining the TH bin frequency with the conditional probability of failure (CPF) of the reactor vessel given the specific TH conditions represented by the bin. Details of how the CPFs and TWCFs were calculated are provided in [Dickson].

9.1 Process for Estimating TH Bin Frequencies

The process for estimating the frequency of each of the final TH bins was relatively simple and straightforward. SAPHIRE [SAPHIRE] was used to perform an uncertainty analysis, using Latin Hypercube sampling, on the set of cut sets in each of the final TH bins. A sample size of 1000 was chosen to help ensure the robustness of the uncertainty calculation.

9.2 TH Bin Frequency Distributions

Distribution information for each of the 62 final TH bins was produced using the process described in section 9.1. Table 9.1 presents selected information (e.g., mean, maximum and minimum sampled values) from the uncertainty analysis for each TH bin. Table 9.2 presents the detailed quantile information for each TH bin. (NOTE: TH bin numbers in Table 9.1 that appear in parentheses, for example (86), have been replaced by new TH bin numbers, reflecting the updated implementation of HHSI throttling criteria discussed in Footnote 8. In Table 9.2, braces have been used to identify the TH bin numbers that have been replaced.

Table 9.1. Selected information from uncertainty analysis for final Beaver Valley TH bins.

End State (TH Bin)	Minimum Cut Upper Bound	Mean	5th	Median	95th	Minimum	Maximum	Standard Deviation	Skewness	Kurtosis	Samples	Seed
2	1.22E-04	1.23E-04	3.29E-05	9.89E-05	2.97E-04	1.22E-05	1.21E-03	9.43E-05	3.21E+00	2.52E+01	1000	12345
3	9.73E-05	9.76E-05	2.61E-05	7.85E-05	2.36E-04	9.71E-06	9.62E-04	7.49E-05	3.21E+00	2.52E+01	1000	12345
7	2.10E-05	2.11E-05	7.92E-07	7.90E-06	7.82E-05	9.36E-08	1.02E-03	5.02E-05	1.05E+01	1.72E+02	1000	12345
9	7.00E-06	6.99E-06	2.64E-07	2.63E-06	2.60E-05	1.76E-08	3.28E-04	1.64E-05	1.02E+01	1.66E+02	1000	12345
14	2.25E-04	2.22E-04	4.33E-05	1.72E-04	5.59E-04	6.50E-06	1.12E-03	1.69E-04	1.60E+00	6.25E+00	1000	12345
31	3.21E-07	3.10E-07	1.80E-08	1.96E-07	9.26E-07	1.15E-10	3.20E-06	3.51E-07	2.94E+00	1.59E+01	1000	12345
34	4.97E-07	4.95E-07	8.99E-08	4.11E-07	1.19E-06	1.55E-08	2.81E-06	3.66E-07	1.79E+00	8.37E+00	1000	12345
56	1.22E-04	1.23E-04	3.29E-05	9.89E-05	2.97E-04	1.22E-05	1.21E-03	9.43E-05	3.21E+00	2.52E+01	1000	12345
59	3.46E-04	3.46E-04	6.18E-05	2.82E-04	8.76E-04	1.31E-05	2.14E-03	2.63E-04	1.75E+00	7.58E+00	1000	12345
60	2.16E-05	2.15E-05	8.27E-07	1.08E-05	7.98E-05	1.38E-07	3.28E-04	3.19E-05	3.87E+00	2.51E+01	1000	12345
61	1.78E-06	1.79E-06	2.94E-07	1.36E-06	4.80E-06	3.78E-08	1.13E-05	1.46E-06	1.92E+00	8.30E+00	1000	12345
62	1.11E-07	1.08E-07	4.58E-09	5.24E-08	3.91E-07	1.98E-10	1.35E-06	1.54E-07	3.18E+00	1.69E+01	1000	12345
64	8.82E-08	8.67E-08	1.41E-08	6.97E-08	2.16E-07	1.89E-09	4.59E-07	7.00E-08	1.90E+00	8.04E+00	1000	12345
65	1.05E-09	1.04E-09	9.77E-11	5.27E-10	3.62E-09	7.51E-12	1.62E-08	1.53E-09	4.09E+00	2.62E+01	1000	12345
66	1.19E-06	1.18E-06	2.01E-07	9.23E-07	3.12E-06	3.81E-08	7.96E-06	9.62E-07	2.04E+00	9.72E+00	1000	12345
67	1.19E-06	1.18E-06	2.01E-07	9.23E-07	3.12E-06	3.81E-08	7.96E-06	9.62E-07	2.04E+00	9.72E+00	1000	12345
68	1.41E-08	1.33E-08	1.28E-09	6.99E-09	4.70E-08	8.25E-11	2.42E-07	1.84E-08	4.27E+00	3.47E+01	1000	12345
69	2.02E-08	2.09E-08	7.69E-10	9.24E-09	7.90E-08	3.53E-11	5.30E-07	3.71E-08	5.82E+00	5.63E+01	1000	12345
70	2.02E-08	2.09E-08	7.69E-10	9.24E-09	7.90E-08	3.53E-11	5.30E-07	3.71E-08	5.82E+00	5.63E+01	1000	12345
71	3.92E-06	3.74E-06	1.92E-07	1.81E-06	1.29E-05	2.28E-08	8.62E-05	6.13E-06	5.73E+00	5.66E+01	1000	12345
72	4.92E-07	5.14E-07	4.31E-08	2.36E-07	1.80E-06	1.06E-08	1.31E-05	8.54E-07	6.25E+00	6.73E+01	1000	12345
73	6.45E-08	6.56E-08	1.38E-09	1.69E-08	2.87E-07	2.07E-10	1.53E-06	1.32E-07	4.83E+00	3.68E+01	1000	12345
74	1.22E-06	1.46E-06	3.49E-08	3.10E-07	5.02E-06	5.22E-09	1.85E-04	7.31E-06	1.88E+01	4.33E+02	1000	12345
75	3.04E-04	2.95E-04	3.74E-06	1.06E-04	1.25E-03	1.73E-07	7.51E-03	6.04E-04	5.58E+00	4.65E+01	1000	12345
76	1.06E-04	1.06E-04	1.81E-06	3.17E-05	4.09E-04	4.88E-08	4.93E-03	2.69E-04	8.82E+00	1.24E+02	1000	12345
78	3.51E-08	3.25E-08	6.03E-10	1.07E-08	1.16E-07	2.70E-12	8.50E-07	7.11E-08	6.51E+00	5.92E+01	1000	12345
81	2.38E-06	2.65E-06	1.64E-09	3.07E-07	1.17E-05	1.36E-13	1.22E-04	8.85E-06	7.15E+00	6.88E+01	1000	12345
82	1.48E-06	1.51E-06	1.37E-07	7.39E-07	5.90E-06	8.48E-09	2.14E-05	2.15E-06	3.63E+00	2.17E+01	1000	12345
83	3.31E-06	3.51E-06	4.86E-08	9.57E-07	1.48E-05	3.49E-10	1.49E-04	9.03E-06	7.84E+00	9.29E+01	1000	12345
119 (86)	6.84E-07	6.84E-07	1.26E-07	5.61E-07	1.73E-06	2.18E-08	4.20E-06	5.32E-07	1.91E+00	8.60E+00	1000	12345
120 (87)	9.88E-07	9.98E-07	1.30E-07	7.51E-07	2.74E-06	1.73E-08	6.06E-06	8.63E-07	1.76E+00	6.95E+00	1000	12345
121 (88)	1.34E-07	1.33E-07	2.27E-08	9.96E-08	3.58E-07	1.84E-09	8.55E-07	1.13E-07	1.99E+00	8.54E+00	1000	12345
122 (89)	1.34E-07	1.33E-07	2.27E-08	9.96E-08	3.58E-07	1.84E-09	8.55E-07	1.13E-07	1.99E+00	8.54E+00	1000	12345

Table 9.1. Selected information from uncertainty analysis for final Beaver Valley TH bins.

End State (TH Bin)	Minimum Cut Upper Bound	Mean	5th	Median	95th	Minimum	Maximum	Standard Deviation	Skewness	Kurtosis	Samples	Seed
123 (90)	1.61E-07	1.65E-07	1.90E-08	1.16E-07	4.75E-07	3.11E-09	1.42E-06	1.65E-07	2.57E+00	1.25E+01	1000	12345
124 (91)	1.61E-07	1.65E-07	1.90E-08	1.16E-07	4.75E-07	3.11E-09	1.42E-06	1.65E-07	2.57E+00	1.25E+01	1000	12345
92	2.12E-07	2.13E-07	3.06E-08	1.53E-07	6.27E-07	3.02E-09	2.63E-06	2.13E-07	3.63E+00	2.79E+01	1000	12345
93	2.12E-07	2.13E-07	3.06E-08	1.53E-07	6.27E-07	3.02E-09	2.63E-06	2.13E-07	3.63E+00	2.79E+01	1000	12345
94	3.98E-05	4.10E-05	5.53E-06	3.01E-05	1.16E-04	7.57E-07	3.94E-04	3.91E-05	2.68E+00	1.49E+01	1000	12345
125 (95)	1.33E-04	1.34E-04	2.45E-05	1.07E-04	3.26E-04	6.24E-06	7.61E-04	1.01E-04	1.76E+00	7.60E+00	1000	12345
126 (96)	1.92E-04	1.87E-04	2.82E-05	1.47E-04	4.91E-04	3.02E-06	1.06E-03	1.49E-04	1.71E+00	7.41E+00	1000	12345
97	3.92E-06	3.74E-06	1.92E-07	1.81E-06	1.29E-05	2.28E-08	8.62E-05	6.13E-06	5.73E+00	5.66E+01	1000	12345
127 (98)	2.60E-05	2.59E-05	4.27E-06	1.96E-05	7.07E-05	8.89E-07	1.89E-04	2.18E-05	2.24E+00	1.15E+01	1000	12345
128 (99)	2.60E-05	2.59E-05	4.27E-06	1.96E-05	7.07E-05	8.89E-07	1.89E-04	2.18E-05	2.24E+00	1.15E+01	1000	12345
129 (100)	3.13E-05	3.09E-05	4.17E-06	2.20E-05	8.27E-05	2.37E-07	2.26E-04	2.80E-05	2.24E+00	1.03E+01	1000	12345
130 (101)	3.13E-05	3.09E-05	4.17E-06	2.20E-05	8.27E-05	2.37E-07	2.26E-04	2.80E-05	2.24E+00	1.03E+01	1000	12345
102	1.04E-04	1.02E-04	3.82E-06	4.03E-05	4.81E-04	2.78E-07	9.94E-04	1.54E-04	2.83E+00	1.17E+01	1000	12345
103	1.07E-05	1.07E-05	2.61E-06	9.47E-06	2.32E-05	3.30E-07	4.51E-05	6.75E-06	1.20E+00	4.83E+00	1000	12345
104	1.02E-04	1.09E-04	2.50E-06	3.73E-05	4.96E-04	5.20E-08	1.64E-03	2.00E-04	3.72E+00	1.94E+01	1000	12345
105	1.07E-05	1.07E-05	1.56E-06	7.77E-06	2.86E-05	2.38E-07	5.42E-05	9.16E-06	1.60E+00	5.98E+00	1000	12345
106	2.18E-06	2.21E-06	1.26E-07	9.09E-07	8.09E-06	1.31E-08	1.44E-04	5.87E-06	1.56E+01	3.50E+02	1000	12345
107	4.36E-07	4.31E-07	1.67E-08	1.63E-07	1.57E-06	1.54E-09	1.13E-05	9.18E-07	5.97E+00	4.97E+01	1000	12345
108	6.61E-04	6.46E-04	2.43E-05	2.56E-04	3.06E-03	1.77E-06	6.32E-03	9.77E-04	2.83E+00	1.17E+01	1000	12345
109	6.81E-05	6.81E-05	1.66E-05	6.03E-05	1.48E-04	2.10E-06	2.87E-04	4.30E-05	1.20E+00	4.83E+00	1000	12345
110	6.52E-04	6.91E-04	1.59E-05	2.37E-04	3.15E-03	3.31E-07	1.05E-02	1.28E-03	3.72E+00	1.94E+01	1000	12345
111	6.82E-05	6.82E-05	9.90E-06	4.95E-05	1.82E-04	1.51E-06	3.45E-04	5.83E-05	1.60E+00	5.98E+00	1000	12345
112	1.39E-05	1.41E-05	8.02E-07	5.78E-06	5.15E-05	8.32E-08	9.16E-04	3.73E-05	1.56E+01	3.50E+02	1000	12345
113	2.77E-06	2.74E-06	1.06E-07	1.03E-06	1.00E-05	9.82E-09	7.18E-05	5.84E-06	5.97E+00	4.97E+01	1000	12345
114	9.73E-05	9.76E-05	2.61E-05	7.85E-05	2.36E-04	9.71E-06	9.62E-04	7.49E-05	3.21E+00	2.52E+01	1000	12345
115	9.73E-05	9.76E-05	2.61E-05	7.85E-05	2.36E-04	9.71E-06	9.62E-04	7.49E-05	3.21E+00	2.52E+01	1000	12345
116	1.80E-05	1.81E-05	6.79E-07	6.77E-06	6.71E-05	8.03E-08	8.71E-04	4.31E-05	1.05E+01	1.72E+02	1000	12345
117	2.10E-05	2.11E-05	7.92E-07	7.90E-06	7.82E-05	9.36E-08	1.02E-03	5.02E-05	1.05E+01	1.72E+02	1000	12345
118	7.76E-06	9.30E-06	2.22E-07	1.97E-06	3.19E-05	3.32E-08	1.18E-03	4.65E-05	1.88E+01	4.33E+02	1000	12345

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U05-(TH-002)	0.5	0.5	1.704e-05	1.220e-05	1.961e-05
	1.0	0.7	1.961e-05	1.628e-05	2.342e-05
	2.5	1.0	2.680e-05	2.225e-05	2.843e-05
	5.0	1.4	3.292e-05	2.874e-05	3.535e-05
	10.0	1.9	4.242e-05	3.846e-05	4.496e-05
	20.0	2.5	5.578e-05	5.330e-05	5.908e-05
	25.0	2.7	6.173e-05	5.903e-05	6.525e-05
	30.0	2.9	6.890e-05	6.468e-05	7.243e-05
	40.0	3.1	8.350e-05	7.786e-05	8.674e-05
	50.0	3.2	9.892e-05	9.388e-05	1.048e-04
	60.0	3.1	1.171e-04	1.099e-04	1.228e-04
	70.0	2.9	1.405e-04	1.325e-04	1.487e-04
	75.0	2.7	1.542e-04	1.474e-04	1.632e-04
	80.0	2.5	1.720e-04	1.629e-04	1.847e-04
	90.0	1.9	2.328e-04	2.148e-04	2.496e-04
	95.0	1.4	2.965e-04	2.709e-04	3.245e-04
	97.5	1.0	3.564e-04	3.308e-04	3.973e-04
	99.0	0.7	4.547e-04	3.933e-04	6.152e-04
	99.5	0.5	6.001e-04	4.547e-04	1.211e-03
U03-(TH-003)	0.5	0.5	1.352e-05	9.705e-06	1.555e-05
	1.0	0.7	1.555e-05	1.293e-05	1.857e-05
	2.5	1.0	2.132e-05	1.766e-05	2.257e-05
	5.0	1.4	2.614e-05	2.283e-05	2.807e-05
	10.0	1.9	3.373e-05	3.051e-05	3.568e-05
	20.0	2.5	4.445e-05	4.235e-05	4.695e-05
	25.0	2.7	4.904e-05	4.687e-05	5.188e-05
	30.0	2.9	5.483e-05	5.138e-05	5.752e-05
	40.0	3.1	6.625e-05	6.188e-05	6.893e-05
	50.0	3.2	7.853e-05	7.455e-05	8.332e-05
	60.0	3.1	9.312e-05	8.730e-05	9.773e-05
	70.0	2.9	1.118e-04	1.055e-04	1.183e-04
	75.0	2.7	1.226e-04	1.170e-04	1.300e-04
	80.0	2.5	1.366e-04	1.299e-04	1.470e-04
	90.0	1.9	1.850e-04	1.706e-04	1.986e-04
	95.0	1.4	2.360e-04	2.150e-04	2.577e-04
	97.5	1.0	2.846e-04	2.644e-04	3.154e-04
	99.0	0.7	3.611e-04	3.123e-04	4.875e-04
	99.5	0.5	4.784e-04	3.611e-04	9.619e-04

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U06-(TH-007)	0.5	0.5	2.107e-07	9.363e-08	3.010e-07
	1.0	0.7	3.010e-07	1.910e-07	4.017e-07
	2.5	1.0	5.191e-07	3.851e-07	6.224e-07
	5.0	1.4	7.924e-07	6.397e-07	9.325e-07
	10.0	1.9	1.316e-06	1.114e-06	1.511e-06
	20.0	2.5	2.428e-06	2.138e-06	2.730e-06
	25.0	2.7	3.077e-06	2.719e-06	3.438e-06
	30.0	2.9	3.785e-06	3.372e-06	4.231e-06
	40.0	3.1	5.547e-06	4.943e-06	6.161e-06
	50.0	3.2	7.895e-06	7.082e-06	8.762e-06
	60.0	3.1	1.124e-05	1.006e-05	1.259e-05
	70.0	2.9	1.642e-05	1.468e-05	1.847e-05
	75.0	2.7	2.031e-05	1.810e-05	2.284e-05
	80.0	2.5	2.570e-05	2.275e-05	2.906e-05
	90.0	1.9	4.740e-05	4.118e-05	5.560e-05
	95.0	1.4	7.824e-05	6.713e-05	9.690e-05
	97.5	1.0	1.242e-04	1.013e-04	1.630e-04
	99.0	0.7	2.122e-04	1.562e-04	3.513e-04
	99.5	0.5	3.087e-04	2.122e-04	1.016e-03
U09-(TH-009)	0.5	0.5	6.477e-08	1.759e-08	1.012e-07
	1.0	0.7	1.012e-07	5.643e-08	1.326e-07
	2.5	1.0	1.707e-07	1.261e-07	2.044e-07
	5.0	1.4	2.635e-07	2.127e-07	3.101e-07
	10.0	1.9	4.400e-07	3.726e-07	5.035e-07
	20.0	2.5	8.103e-07	7.110e-07	9.089e-07
	25.0	2.7	1.023e-06	9.082e-07	1.144e-06
	30.0	2.9	1.262e-06	1.124e-06	1.411e-06
	40.0	3.1	1.845e-06	1.647e-06	2.060e-06
	50.0	3.2	2.634e-06	2.360e-06	2.923e-06
	60.0	3.1	3.758e-06	3.361e-06	4.185e-06
	70.0	2.9	5.456e-06	4.888e-06	6.154e-06
	75.0	2.7	6.778e-06	6.040e-06	7.613e-06
	80.0	2.5	8.542e-06	7.567e-06	9.690e-06
	90.0	1.9	1.573e-05	1.375e-05	1.860e-05
	95.0	1.4	2.601e-05	2.223e-05	3.205e-05
	97.5	1.0	4.115e-05	3.334e-05	5.291e-05
	99.0	0.7	7.124e-05	5.151e-05	1.121e-04
	99.5	0.5	9.853e-05	7.124e-05	3.282e-04

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U10-(TH-014)	0.5	0.5	1.682e-05	6.498e-06	1.967e-05
	1.0	0.7	1.967e-05	1.182e-05	2.589e-05
	2.5	1.0	2.942e-05	2.468e-05	3.324e-05
	5.0	1.4	4.331e-05	3.517e-05	4.865e-05
	10.0	1.9	6.078e-05	5.613e-05	6.491e-05
	20.0	2.5	8.771e-05	8.128e-05	9.379e-05
	25.0	2.7	1.022e-04	9.358e-05	1.095e-04
	30.0	2.9	1.143e-04	1.080e-04	1.230e-04
	40.0	3.1	1.426e-04	1.337e-04	1.546e-04
	50.0	3.2	1.721e-04	1.638e-04	1.836e-04
	60.0	3.1	2.181e-04	2.010e-04	2.309e-04
	70.0	2.9	2.649e-04	2.528e-04	2.846e-04
	75.0	2.7	2.944e-04	2.807e-04	3.157e-04
	80.0	2.5	3.369e-04	3.145e-04	3.585e-04
	90.0	1.9	4.334e-04	4.140e-04	4.835e-04
	95.0	1.4	5.586e-04	5.255e-04	6.106e-04
	97.5	1.0	6.727e-04	6.145e-04	7.732e-04
	99.0	0.7	8.237e-04	7.719e-04	9.324e-04
	99.5	0.5	9.194e-04	8.237e-04	1.115e-03
U13-(TH-031)	0.5	0.5	1.439e-09	1.152e-10	2.517e-09
	1.0	0.7	2.517e-09	1.426e-09	6.038e-09
	2.5	1.0	9.145e-09	6.000e-09	1.225e-08
	5.0	1.4	1.796e-08	1.333e-08	2.398e-08
	10.0	1.9	4.071e-08	3.010e-08	4.681e-08
	20.0	2.5	7.670e-08	6.665e-08	8.404e-08
	25.0	2.7	9.384e-08	8.353e-08	1.036e-07
	30.0	2.9	1.130e-07	1.019e-07	1.232e-07
	40.0	3.1	1.543e-07	1.411e-07	1.682e-07
	50.0	3.2	1.959e-07	1.829e-07	2.140e-07
	60.0	3.1	2.618e-07	2.413e-07	2.846e-07
	70.0	2.9	3.451e-07	3.174e-07	3.645e-07
	75.0	2.7	3.874e-07	3.599e-07	4.134e-07
	80.0	2.5	4.545e-07	4.126e-07	4.983e-07
	90.0	1.9	7.077e-07	6.579e-07	7.935e-07
	95.0	1.4	9.262e-07	8.895e-07	1.097e-06
	97.5	1.0	1.302e-06	1.128e-06	1.518e-06
	99.0	0.7	1.781e-06	1.494e-06	2.236e-06
	99.5	0.5	2.202e-06	1.781e-06	3.200e-06

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U11-(TH-034)	0.5	0.5	3.117e-08	1.549e-08	4.787e-08
	1.0	0.7	4.787e-08	2.781e-08	5.384e-08
	2.5	1.0	6.636e-08	5.350e-08	7.855e-08
	5.0	1.4	8.994e-08	8.099e-08	9.898e-08
	10.0	1.9	1.276e-07	1.085e-07	1.410e-07
	20.0	2.5	1.957e-07	1.822e-07	2.245e-07
	25.0	2.7	2.413e-07	2.240e-07	2.551e-07
	30.0	2.9	2.707e-07	2.521e-07	2.892e-07
	40.0	3.1	3.358e-07	3.162e-07	3.536e-07
	50.0	3.2	4.112e-07	3.822e-07	4.362e-07
	60.0	3.1	4.889e-07	4.669e-07	5.126e-07
	70.0	2.9	5.989e-07	5.684e-07	6.283e-07
	75.0	2.7	6.771e-07	6.194e-07	7.051e-07
	80.0	2.5	7.516e-07	7.045e-07	7.828e-07
	90.0	1.9	9.537e-07	8.897e-07	1.011e-06
	95.0	1.4	1.194e-06	1.086e-06	1.290e-06
	97.5	1.0	1.384e-06	1.311e-06	1.572e-06
	99.0	0.7	1.723e-06	1.569e-06	2.396e-06
	99.5	0.5	2.326e-06	1.723e-06	2.809e-06
U01-(TH-056)	0.5	0.5	1.704e-05	1.220e-05	1.961e-05
	1.0	0.7	1.961e-05	1.628e-05	2.342e-05
	2.5	1.0	2.680e-05	2.225e-05	2.843e-05
	5.0	1.4	3.292e-05	2.874e-05	3.535e-05
	10.0	1.9	4.242e-05	3.846e-05	4.496e-05
	20.0	2.5	5.578e-05	5.330e-05	5.908e-05
	25.0	2.7	6.173e-05	5.903e-05	6.525e-05
	30.0	2.9	6.890e-05	6.468e-05	7.243e-05
	40.0	3.1	8.350e-05	7.786e-05	8.674e-05
	50.0	3.2	9.892e-05	9.388e-05	1.048e-04
	60.0	3.1	1.171e-04	1.099e-04	1.228e-04
	70.0	2.9	1.405e-04	1.325e-04	1.487e-04
	75.0	2.7	1.542e-04	1.474e-04	1.632e-04
	80.0	2.5	1.720e-04	1.629e-04	1.847e-04
	90.0	1.9	2.328e-04	2.148e-04	2.496e-04
	95.0	1.4	2.965e-04	2.709e-04	3.245e-04
	97.5	1.0	3.564e-04	3.308e-04	3.973e-04
	99.0	0.7	4.547e-04	3.933e-04	6.152e-04
	99.5	0.5	6.001e-04	4.547e-04	1.211e-03

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U20-(TH-059)	0.5	0.5	1.983e-05	1.314e-05	2.855e-05
	1.0	0.7	2.855e-05	1.948e-05	3.647e-05
	2.5	1.0	4.730e-05	3.598e-05	5.216e-05
	5.0	1.4	6.178e-05	5.358e-05	7.043e-05
	10.0	1.9	9.093e-05	8.163e-05	9.677e-05
	20.0	2.5	1.318e-04	1.231e-04	1.421e-04
	25.0	2.7	1.525e-04	1.416e-04	1.689e-04
	30.0	2.9	1.826e-04	1.676e-04	1.959e-04
	40.0	3.1	2.353e-04	2.149e-04	2.494e-04
	50.0	3.2	2.818e-04	2.673e-04	3.043e-04
	60.0	3.1	3.455e-04	3.269e-04	3.613e-04
	70.0	2.9	4.169e-04	3.916e-04	4.376e-04
	75.0	2.7	4.578e-04	4.352e-04	4.767e-04
	80.0	2.5	4.992e-04	4.766e-04	5.267e-04
	90.0	1.9	6.725e-04	6.335e-04	7.326e-04
	95.0	1.4	8.764e-04	7.994e-04	9.737e-04
	97.5	1.0	1.065e-03	9.846e-04	1.182e-03
	99.0	0.7	1.246e-03	1.174e-03	1.463e-03
	99.5	0.5	1.459e-03	1.246e-03	2.139e-03
U23-(TH-060)	0.5	0.5	3.313e-07	1.375e-07	3.943e-07
	1.0	0.7	3.943e-07	2.814e-07	4.895e-07
	2.5	1.0	5.442e-07	4.886e-07	6.207e-07
	5.0	1.4	8.266e-07	6.416e-07	1.030e-06
	10.0	1.9	1.588e-06	1.308e-06	1.814e-06
	20.0	2.5	2.993e-06	2.552e-06	3.348e-06
	25.0	2.7	3.758e-06	3.341e-06	4.307e-06
	30.0	2.9	4.781e-06	4.228e-06	5.461e-06
	40.0	3.1	7.547e-06	6.717e-06	8.266e-06
	50.0	3.2	1.079e-05	9.772e-06	1.164e-05
	60.0	3.1	1.476e-05	1.323e-05	1.581e-05
	70.0	2.9	2.066e-05	1.842e-05	2.383e-05
	75.0	2.7	2.587e-05	2.302e-05	2.875e-05
	80.0	2.5	3.203e-05	2.875e-05	3.577e-05
	90.0	1.9	5.376e-05	4.654e-05	6.042e-05
	95.0	1.4	7.977e-05	7.342e-05	9.062e-05
	97.5	1.0	1.061e-04	9.169e-05	1.325e-04
	99.0	0.7	1.587e-04	1.301e-04	2.348e-04
	99.5	0.5	2.318e-04	1.587e-04	3.277e-04

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U32-(TH-061)	0.5	0.5	8.599e-08	3.784e-08	1.430e-07
	1.0	0.7	1.430e-07	7.778e-08	1.953e-07
	2.5	1.0	2.312e-07	1.839e-07	2.508e-07
	5.0	1.4	2.938e-07	2.569e-07	3.342e-07
	10.0	1.9	4.392e-07	3.983e-07	4.824e-07
	20.0	2.5	6.703e-07	6.242e-07	7.164e-07
	25.0	2.7	7.868e-07	7.158e-07	8.445e-07
	30.0	2.9	9.087e-07	8.323e-07	9.607e-07
	40.0	3.1	1.106e-06	1.055e-06	1.177e-06
	50.0	3.2	1.355e-06	1.283e-06	1.455e-06
	60.0	3.1	1.701e-06	1.595e-06	1.801e-06
	70.0	2.9	2.121e-06	2.014e-06	2.225e-06
	75.0	2.7	2.365e-06	2.210e-06	2.541e-06
	80.0	2.5	2.717e-06	2.525e-06	2.855e-06
	90.0	1.9	3.485e-06	3.351e-06	3.882e-06
	95.0	1.4	4.800e-06	4.344e-06	5.264e-06
	97.5	1.0	5.797e-06	5.363e-06	6.386e-06
	99.0	0.7	7.127e-06	6.294e-06	8.584e-06
	99.5	0.5	8.561e-06	7.127e-06	1.132e-05
U35-(TH-062)	0.5	0.5	1.255e-09	1.975e-10	1.985e-09
	1.0	0.7	1.985e-09	1.137e-09	2.447e-09
	2.5	1.0	2.966e-09	2.389e-09	3.623e-09
	5.0	1.4	4.582e-09	3.688e-09	5.526e-09
	10.0	1.9	7.830e-09	6.626e-09	8.840e-09
	20.0	2.5	1.418e-08	1.216e-08	1.601e-08
	25.0	2.7	1.799e-08	1.598e-08	2.094e-08
	30.0	2.9	2.321e-08	2.019e-08	2.730e-08
	40.0	3.1	3.625e-08	3.189e-08	3.988e-08
	50.0	3.2	5.240e-08	4.718e-08	5.807e-08
	60.0	3.1	7.415e-08	6.537e-08	8.277e-08
	70.0	2.9	1.101e-07	9.487e-08	1.216e-07
	75.0	2.7	1.364e-07	1.198e-07	1.482e-07
	80.0	2.5	1.678e-07	1.468e-07	1.847e-07
	90.0	1.9	2.688e-07	2.534e-07	3.081e-07
	95.0	1.4	3.909e-07	3.589e-07	4.534e-07
	97.5	1.0	5.843e-07	4.592e-07	6.622e-07
	99.0	0.7	7.725e-07	6.508e-07	1.062e-06
	99.5	0.5	9.996e-07	7.725e-07	1.346e-06

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U15-(TH-064)	0.5	0.5	4.328e-09	1.885e-09	6.516e-09
	1.0	0.7	6.516e-09	4.316e-09	8.443e-09
	2.5	1.0	9.812e-09	8.094e-09	1.211e-08
	5.0	1.4	1.409e-08	1.229e-08	1.558e-08
	10.0	1.9	2.063e-08	1.822e-08	2.241e-08
	20.0	2.5	3.126e-08	2.874e-08	3.399e-08
	25.0	2.7	3.666e-08	3.396e-08	4.049e-08
	30.0	2.9	4.385e-08	3.973e-08	4.648e-08
	40.0	3.1	5.709e-08	5.377e-08	5.979e-08
	50.0	3.2	6.971e-08	6.557e-08	7.450e-08
	60.0	3.1	8.481e-08	7.995e-08	8.977e-08
	70.0	2.9	1.041e-07	9.792e-08	1.107e-07
	75.0	2.7	1.163e-07	1.090e-07	1.210e-07
	80.0	2.5	1.270e-07	1.204e-07	1.349e-07
	90.0	1.9	1.671e-07	1.600e-07	1.815e-07
	95.0	1.4	2.162e-07	1.994e-07	2.520e-07
	97.5	1.0	2.972e-07	2.592e-07	3.229e-07
	99.0	0.7	3.749e-07	3.159e-07	4.193e-07
	99.5	0.5	4.166e-07	3.749e-07	4.590e-07
U11-(TH-065)	0.5	0.5	2.962e-11	7.514e-12	4.345e-11
	1.0	0.7	4.345e-11	1.685e-11	5.221e-11
	2.5	1.0	6.293e-11	4.812e-11	7.319e-11
	5.0	1.4	9.770e-11	8.035e-11	1.110e-10
	10.0	1.9	1.457e-10	1.282e-10	1.682e-10
	20.0	2.5	2.407e-10	2.202e-10	2.610e-10
	25.0	2.7	2.832e-10	2.609e-10	3.011e-10
	30.0	2.9	3.158e-10	2.984e-10	3.346e-10
	40.0	3.1	4.028e-10	3.685e-10	4.445e-10
	50.0	3.2	5.274e-10	4.881e-10	5.708e-10
	60.0	3.1	6.835e-10	6.296e-10	7.455e-10
	70.0	2.9	9.444e-10	8.482e-10	1.068e-09
	75.0	2.7	1.160e-09	1.051e-09	1.294e-09
	80.0	2.5	1.417e-09	1.290e-09	1.546e-09
	90.0	1.9	2.284e-09	2.007e-09	2.767e-09
	95.0	1.4	3.616e-09	3.280e-09	4.521e-09
	97.5	1.0	5.831e-09	4.544e-09	6.869e-09
	99.0	0.7	8.855e-09	6.857e-09	1.006e-08
	99.5	0.5	9.857e-09	8.855e-09	1.618e-08

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U12-(TH-066)	0.5	0.5	5.708e-08	3.814e-08	8.852e-08
	1.0	0.7	8.852e-08	4.312e-08	1.148e-07
	2.5	1.0	1.382e-07	1.147e-07	1.621e-07
	5.0	1.4	2.008e-07	1.654e-07	2.253e-07
	10.0	1.9	2.960e-07	2.726e-07	3.159e-07
	20.0	2.5	4.532e-07	4.126e-07	4.819e-07
	25.0	2.7	5.190e-07	4.811e-07	5.598e-07
	30.0	2.9	5.902e-07	5.483e-07	6.382e-07
	40.0	3.1	7.497e-07	6.974e-07	8.011e-07
	50.0	3.2	9.233e-07	8.639e-07	1.007e-06
	60.0	3.1	1.147e-06	1.083e-06	1.199e-06
	70.0	2.9	1.378e-06	1.293e-06	1.504e-06
	75.0	2.7	1.579e-06	1.490e-06	1.678e-06
	80.0	2.5	1.746e-06	1.677e-06	1.845e-06
	90.0	1.9	2.364e-06	2.234e-06	2.499e-06
	95.0	1.4	3.121e-06	2.766e-06	3.444e-06
	97.5	1.0	3.862e-06	3.515e-06	4.284e-06
	99.0	0.7	4.601e-06	4.200e-06	5.344e-06
	99.5	0.5	5.066e-06	4.601e-06	7.959e-06
U12-(TH-067)	0.5	0.5	5.708e-08	3.814e-08	8.852e-08
	1.0	0.7	8.852e-08	4.312e-08	1.148e-07
	2.5	1.0	1.382e-07	1.147e-07	1.621e-07
	5.0	1.4	2.008e-07	1.654e-07	2.253e-07
	10.0	1.9	2.960e-07	2.726e-07	3.159e-07
	20.0	2.5	4.532e-07	4.126e-07	4.819e-07
	25.0	2.7	5.190e-07	4.811e-07	5.598e-07
	30.0	2.9	5.902e-07	5.483e-07	6.382e-07
	40.0	3.1	7.497e-07	6.974e-07	8.011e-07
	50.0	3.2	9.233e-07	8.639e-07	1.007e-06
	60.0	3.1	1.147e-06	1.083e-06	1.199e-06
	70.0	2.9	1.378e-06	1.293e-06	1.504e-06
	75.0	2.7	1.579e-06	1.490e-06	1.678e-06
	80.0	2.5	1.746e-06	1.677e-06	1.845e-06
	90.0	1.9	2.364e-06	2.234e-06	2.499e-06
	95.0	1.4	3.121e-06	2.766e-06	3.444e-06
	97.5	1.0	3.862e-06	3.515e-06	4.284e-06
	99.0	0.7	4.601e-06	4.200e-06	5.344e-06
	99.5	0.5	5.066e-06	4.601e-06	7.959e-06

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U35-(TH-068)	0.5	0.5	4.787e-10	8.254e-11	6.076e-10
	1.0	0.7	6.076e-10	4.273e-10	7.863e-10
	2.5	1.0	9.286e-10	7.723e-10	1.048e-09
	5.0	1.4	1.282e-09	1.063e-09	1.466e-09
	10.0	1.9	1.988e-09	1.658e-09	2.209e-09
	20.0	2.5	3.049e-09	2.815e-09	3.377e-09
	25.0	2.7	3.624e-09	3.353e-09	4.149e-09
	30.0	2.9	4.462e-09	4.010e-09	4.806e-09
	40.0	3.1	5.609e-09	5.188e-09	6.107e-09
	50.0	3.2	6.993e-09	6.529e-09	7.414e-09
	60.0	3.1	9.176e-09	8.249e-09	1.001e-08
	70.0	2.9	1.244e-08	1.116e-08	1.341e-08
	75.0	2.7	1.434e-08	1.329e-08	1.586e-08
	80.0	2.5	1.756e-08	1.584e-08	1.991e-08
	90.0	1.9	3.270e-08	2.771e-08	3.922e-08
	95.0	1.4	4.696e-08	4.425e-08	5.478e-08
	97.5	1.0	6.960e-08	5.703e-08	7.765e-08
	99.0	0.7	8.546e-08	7.640e-08	1.174e-07
	99.5	0.5	1.068e-07	8.546e-08	2.417e-07
U38-(TH069)	0.5	0.5	2.003e-10	3.530e-11	2.891e-10
	1.0	0.7	2.891e-10	1.495e-10	3.354e-10
	2.5	1.0	4.210e-10	3.199e-10	6.140e-10
	5.0	1.4	7.688e-10	6.234e-10	9.057e-10
	10.0	1.9	1.332e-09	1.066e-09	1.500e-09
	20.0	2.5	2.673e-09	2.271e-09	3.095e-09
	25.0	2.7	3.461e-09	3.094e-09	3.836e-09
	30.0	2.9	4.248e-09	3.691e-09	4.832e-09
	40.0	3.1	6.545e-09	5.773e-09	7.168e-09
	50.0	3.2	9.237e-09	8.355e-09	1.018e-08
	60.0	3.1	1.283e-08	1.159e-08	1.425e-08
	70.0	2.9	1.894e-08	1.698e-08	2.061e-08
	75.0	2.7	2.240e-08	2.035e-08	2.484e-08
	80.0	2.5	2.719e-08	2.478e-08	3.212e-08
	90.0	1.9	5.100e-08	4.800e-08	5.957e-08
	95.0	1.4	7.895e-08	6.817e-08	9.068e-08
	97.5	1.0	1.119e-07	9.720e-08	1.279e-07
	99.0	0.7	1.822e-07	1.248e-07	2.965e-07
	99.5	0.5	2.500e-07	1.822e-07	5.299e-07

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U41-(TH070)	0.5	0.5	2.003e-10	3.530e-11	2.891e-10
	1.0	0.7	2.891e-10	1.495e-10	3.354e-10
	2.5	1.0	4.210e-10	3.199e-10	6.140e-10
	5.0	1.4	7.688e-10	6.234e-10	9.057e-10
	10.0	1.9	1.332e-09	1.066e-09	1.500e-09
	20.0	2.5	2.673e-09	2.271e-09	3.095e-09
	25.0	2.7	3.461e-09	3.094e-09	3.836e-09
	30.0	2.9	4.248e-09	3.691e-09	4.832e-09
	40.0	3.1	6.545e-09	5.773e-09	7.168e-09
	50.0	3.2	9.237e-09	8.355e-09	1.018e-08
	60.0	3.1	1.283e-08	1.159e-08	1.425e-08
	70.0	2.9	1.894e-08	1.698e-08	2.061e-08
	75.0	2.7	2.240e-08	2.035e-08	2.484e-08
	80.0	2.5	2.719e-08	2.478e-08	3.212e-08
	90.0	1.9	5.100e-08	4.800e-08	5.957e-08
	95.0	1.4	7.895e-08	6.817e-08	9.068e-08
	97.5	1.0	1.119e-07	9.720e-08	1.279e-07
	99.0	0.7	1.822e-07	1.248e-07	2.965e-07
	99.5	0.5	2.500e-07	1.822e-07	5.299e-07
U29-(TH-071)	0.5	0.5	3.970e-08	2.275e-08	8.398e-08
	1.0	0.7	8.398e-08	3.784e-08	1.221e-07
	2.5	1.0	1.332e-07	1.135e-07	1.503e-07
	5.0	1.4	1.923e-07	1.524e-07	2.237e-07
	10.0	1.9	3.098e-07	2.663e-07	3.525e-07
	20.0	2.5	5.570e-07	4.843e-07	6.458e-07
	25.0	2.7	7.378e-07	6.416e-07	8.061e-07
	30.0	2.9	9.209e-07	7.950e-07	1.030e-06
	40.0	3.1	1.355e-06	1.212e-06	1.493e-06
	50.0	3.2	1.808e-06	1.682e-06	1.988e-06
	60.0	3.1	2.491e-06	2.249e-06	2.848e-06
	70.0	2.9	3.546e-06	3.230e-06	3.903e-06
	75.0	2.7	4.256e-06	3.809e-06	4.817e-06
	80.0	2.5	5.298e-06	4.763e-06	5.853e-06
	90.0	1.9	8.529e-06	7.715e-06	9.750e-06
	95.0	1.4	1.291e-05	1.109e-05	1.628e-05
	97.5	1.0	1.963e-05	1.650e-05	2.612e-05
	99.0	0.7	2.895e-05	2.472e-05	3.638e-05
	99.5	0.5	3.558e-05	2.895e-05	8.618e-05

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U10-(TH-072)	0.5	0.5	1.759e-08	1.061e-08	2.325e-08
	1.0	0.7	2.325e-08	1.664e-08	2.723e-08
	2.5	1.0	3.199e-08	2.651e-08	3.533e-08
	5.0	1.4	4.309e-08	3.759e-08	4.801e-08
	10.0	1.9	6.449e-08	5.727e-08	7.018e-08
	20.0	2.5	1.017e-07	9.159e-08	1.146e-07
	25.0	2.7	1.231e-07	1.144e-07	1.311e-07
	30.0	2.9	1.399e-07	1.303e-07	1.475e-07
	40.0	3.1	1.833e-07	1.648e-07	2.010e-07
	50.0	3.2	2.359e-07	2.219e-07	2.594e-07
	60.0	3.1	3.163e-07	2.871e-07	3.522e-07
	70.0	2.9	4.616e-07	4.207e-07	5.067e-07
	75.0	2.7	5.573e-07	5.034e-07	6.309e-07
	80.0	2.5	7.113e-07	6.287e-07	8.037e-07
	90.0	1.9	1.289e-06	1.074e-06	1.428e-06
	95.0	1.4	1.803e-06	1.592e-06	2.011e-06
	97.5	1.0	2.655e-06	2.083e-06	3.447e-06
	99.0	0.7	4.092e-06	3.313e-06	6.313e-06
	99.5	0.5	4.909e-06	4.092e-06	1.312e-05
U14-(TH-073)	0.5	0.5	3.316e-10	2.066e-10	4.357e-10
	1.0	0.7	4.357e-10	3.249e-10	8.104e-10
	2.5	1.0	9.570e-10	7.716e-10	1.136e-09
	5.0	1.4	1.383e-09	1.155e-09	1.617e-09
	10.0	1.9	2.209e-09	1.888e-09	2.538e-09
	20.0	2.5	4.117e-09	3.512e-09	4.705e-09
	25.0	2.7	5.246e-09	4.678e-09	6.161e-09
	30.0	2.9	6.871e-09	5.962e-09	7.753e-09
	40.0	3.1	1.075e-08	9.366e-09	1.227e-08
	50.0	3.2	1.688e-08	1.403e-08	1.881e-08
	60.0	3.1	2.745e-08	2.298e-08	3.310e-08
	70.0	2.9	5.014e-08	4.155e-08	5.942e-08
	75.0	2.7	6.590e-08	5.773e-08	7.645e-08
	80.0	2.5	8.721e-08	7.579e-08	1.098e-07
	90.0	1.9	1.727e-07	1.544e-07	2.194e-07
	95.0	1.4	2.866e-07	2.536e-07	3.302e-07
	97.5	1.0	4.258e-07	3.451e-07	5.285e-07
	99.0	0.7	6.525e-07	5.216e-07	1.079e-06
	99.5	0.5	7.896e-07	6.525e-07	1.527e-06

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
TH-074	0.5	0.5	1.326e-08	5.221e-09	1.840e-08
	1.0	0.7	1.840e-08	1.222e-08	2.108e-08
	2.5	1.0	2.311e-08	2.072e-08	2.506e-08
	5.0	1.4	3.494e-08	2.576e-08	4.082e-08
	10.0	1.9	5.692e-08	5.030e-08	6.489e-08
	20.0	2.5	9.739e-08	8.610e-08	1.126e-07
	25.0	2.7	1.270e-07	1.123e-07	1.437e-07
	30.0	2.9	1.571e-07	1.401e-07	1.757e-07
	40.0	3.1	2.208e-07	1.997e-07	2.451e-07
	50.0	3.2	3.095e-07	2.794e-07	3.497e-07
	60.0	3.1	4.550e-07	4.077e-07	5.101e-07
	70.0	2.9	6.796e-07	5.999e-07	7.945e-07
	75.0	2.7	8.952e-07	7.750e-07	1.035e-06
	80.0	2.5	1.151e-06	1.026e-06	1.389e-06
	90.0	1.9	2.532e-06	2.047e-06	2.973e-06
	95.0	1.4	5.017e-06	3.912e-06	7.042e-06
	97.5	1.0	9.247e-06	7.332e-06	1.353e-05
	99.0	0.7	1.858e-05	1.334e-05	3.515e-05
	99.5	0.5	3.368e-05	1.858e-05	1.848e-04
U13-(TH-075)	0.5	0.5	5.078e-07	1.728e-07	1.010e-06
	1.0	0.7	1.010e-06	4.617e-07	1.445e-06
	2.5	1.0	1.990e-06	1.339e-06	2.474e-06
	5.0	1.4	3.737e-06	2.641e-06	4.805e-06
	10.0	1.9	7.731e-06	5.996e-06	9.770e-06
	20.0	2.5	1.941e-05	1.616e-05	2.280e-05
	25.0	2.7	2.727e-05	2.276e-05	3.339e-05
	30.0	2.9	3.735e-05	3.251e-05	4.573e-05
	40.0	3.1	7.009e-05	5.871e-05	8.054e-05
	50.0	3.2	1.057e-04	9.476e-05	1.185e-04
	60.0	3.1	1.598e-04	1.437e-04	1.778e-04
	70.0	2.9	2.304e-04	2.078e-04	2.611e-04
	75.0	2.7	2.874e-04	2.564e-04	3.263e-04
	80.0	2.5	3.849e-04	3.255e-04	4.453e-04
	90.0	1.9	6.663e-04	6.205e-04	8.117e-04
	95.0	1.4	1.254e-03	9.937e-04	1.470e-03
	97.5	1.0	1.701e-03	1.519e-03	2.410e-03
	99.0	0.7	3.182e-03	2.292e-03	4.941e-03
	99.5	0.5	4.290e-03	3.182e-03	7.507e-03

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U17-(TH-076)	0.5	0.5	2.746e-07	4.879e-08	4.704e-07
	1.0	0.7	4.704e-07	2.333e-07	7.037e-07
	2.5	1.0	9.190e-07	6.589e-07	1.269e-06
	5.0	1.4	1.809e-06	1.274e-06	2.080e-06
	10.0	1.9	3.032e-06	2.446e-06	3.603e-06
	20.0	2.5	6.200e-06	5.382e-06	7.780e-06
	25.0	2.7	9.128e-06	7.772e-06	1.056e-05
	30.0	2.9	1.227e-05	1.041e-05	1.453e-05
	40.0	3.1	2.032e-05	1.742e-05	2.281e-05
	50.0	3.2	3.170e-05	2.754e-05	3.571e-05
	60.0	3.1	4.669e-05	4.158e-05	5.335e-05
	70.0	2.9	7.501e-05	6.792e-05	9.028e-05
	75.0	2.7	1.005e-04	8.653e-05	1.107e-04
	80.0	2.5	1.233e-04	1.105e-04	1.407e-04
	90.0	1.9	2.486e-04	2.066e-04	2.872e-04
	95.0	1.4	4.092e-04	3.373e-04	5.171e-04
	97.5	1.0	7.282e-04	5.297e-04	1.016e-03
	99.0	0.7	1.309e-03	9.383e-04	2.030e-03
	99.5	0.5	1.922e-03	1.309e-03	4.927e-03
U13-(TH-078)	0.5	0.5	2.301e-11	2.696e-12	8.594e-11
	1.0	0.7	8.594e-11	2.093e-11	2.084e-10
	2.5	1.0	3.570e-10	1.968e-10	4.323e-10
	5.0	1.4	6.026e-10	4.514e-10	8.065e-10
	10.0	1.9	1.404e-09	1.134e-09	1.718e-09
	20.0	2.5	2.825e-09	2.478e-09	3.240e-09
	25.0	2.7	3.747e-09	3.227e-09	4.232e-09
	30.0	2.9	4.785e-09	4.120e-09	5.305e-09
	40.0	3.1	6.976e-09	6.137e-09	7.843e-09
	50.0	3.2	1.074e-08	8.971e-09	1.271e-08
	60.0	3.1	1.675e-08	1.466e-08	1.881e-08
	70.0	2.9	2.549e-08	2.299e-08	2.925e-08
	75.0	2.7	3.153e-08	2.841e-08	3.783e-08
	80.0	2.5	4.299e-08	3.782e-08	4.973e-08
	90.0	1.9	8.043e-08	6.957e-08	8.813e-08
	95.0	1.4	1.158e-07	1.047e-07	1.409e-07
	97.5	1.0	1.978e-07	1.500e-07	2.587e-07
	99.0	0.7	3.333e-07	2.466e-07	7.287e-07
	99.5	0.5	6.084e-07	3.333e-07	8.496e-07

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
TH-081	0.5	0.5	3.001e-11	1.360e-13	8.039e-11
	1.0	0.7	8.039e-11	1.819e-11	1.404e-10
	2.5	1.0	3.586e-10	1.192e-10	5.923e-10
	5.0	1.4	1.636e-09	8.655e-10	2.491e-09
	10.0	1.9	6.929e-09	4.134e-09	1.076e-08
	20.0	2.5	2.799e-08	2.179e-08	3.688e-08
	25.0	2.7	5.104e-08	3.530e-08	6.878e-08
	30.0	2.9	8.383e-08	6.376e-08	1.087e-07
	40.0	3.1	1.742e-07	1.437e-07	2.085e-07
	50.0	3.2	3.073e-07	2.624e-07	3.809e-07
	60.0	3.1	5.950e-07	4.947e-07	7.188e-07
	70.0	2.9	1.093e-06	9.330e-07	1.290e-06
	75.0	2.7	1.455e-06	1.226e-06	1.682e-06
	80.0	2.5	1.917e-06	1.680e-06	2.502e-06
	90.0	1.9	4.915e-06	4.139e-06	6.223e-06
	95.0	1.4	1.169e-05	8.147e-06	1.685e-05
	97.5	1.0	2.474e-05	1.731e-05	3.398e-05
	99.0	0.7	5.002e-05	3.306e-05	6.930e-05
	99.5	0.5	6.668e-05	5.002e-05	1.215e-04
U23-(TH-082)	0.5	0.5	4.401e-08	8.480e-09	5.673e-08
	1.0	0.7	5.673e-08	3.350e-08	6.489e-08
	2.5	1.0	8.715e-08	6.422e-08	1.032e-07
	5.0	1.4	1.374e-07	1.069e-07	1.581e-07
	10.0	1.9	2.087e-07	1.881e-07	2.212e-07
	20.0	2.5	3.065e-07	2.770e-07	3.390e-07
	25.0	2.7	3.664e-07	3.387e-07	4.030e-07
	30.0	2.9	4.246e-07	3.963e-07	4.742e-07
	40.0	3.1	5.617e-07	5.250e-07	6.026e-07
	50.0	3.2	7.391e-07	6.870e-07	7.946e-07
	60.0	3.1	9.786e-07	9.127e-07	1.067e-06
	70.0	2.9	1.353e-06	1.260e-06	1.504e-06
	75.0	2.7	1.647e-06	1.494e-06	1.858e-06
	80.0	2.5	2.138e-06	1.814e-06	2.300e-06
	90.0	1.9	3.576e-06	3.187e-06	4.145e-06
	95.0	1.4	5.901e-06	5.284e-06	6.476e-06
	97.5	1.0	7.792e-06	6.641e-06	9.515e-06
	99.0	0.7	1.106e-05	9.327e-06	1.386e-05
	99.5	0.5	1.269e-05	1.106e-05	2.138e-05

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U13-(TH-083)	0.5	0.5	2.391e-09	3.490e-10	7.319e-09
	1.0	0.7	7.319e-09	2.228e-09	1.118e-08
	2.5	1.0	2.020e-08	1.115e-08	3.068e-08
	5.0	1.4	4.863e-08	3.243e-08	6.076e-08
	10.0	1.9	1.057e-07	8.408e-08	1.241e-07
	20.0	2.5	2.234e-07	1.840e-07	2.674e-07
	25.0	2.7	3.252e-07	2.633e-07	3.626e-07
	30.0	2.9	4.186e-07	3.527e-07	4.928e-07
	40.0	3.1	6.693e-07	5.994e-07	7.420e-07
	50.0	3.2	9.571e-07	8.714e-07	1.137e-06
	60.0	3.1	1.476e-06	1.305e-06	1.694e-06
	70.0	2.9	2.272e-06	1.949e-06	2.634e-06
	75.0	2.7	3.085e-06	2.538e-06	3.574e-06
	80.0	2.5	4.043e-06	3.561e-06	4.528e-06
	90.0	1.9	7.800e-06	6.074e-06	1.018e-05
	95.0	1.4	1.478e-05	1.174e-05	1.884e-05
	97.5	1.0	2.417e-05	1.893e-05	3.671e-05
	99.0	0.7	4.578e-05	3.130e-05	5.963e-05
	99.5	0.5	5.813e-05	4.578e-05	1.485e-04
TH-119 [U33-(TH-086)]	0.5	0.5	3.081e-08	2.181e-08	5.087e-08
	1.0	0.7	5.087e-08	2.713e-08	7.146e-08
	2.5	1.0	9.187e-08	6.902e-08	1.059e-07
	5.0	1.4	1.257e-07	1.084e-07	1.421e-07
	10.0	1.9	1.843e-07	1.629e-07	2.006e-07
	20.0	2.5	2.719e-07	2.462e-07	2.860e-07
	25.0	2.7	3.106e-07	2.846e-07	3.304e-07
	30.0	2.9	3.452e-07	3.248e-07	3.807e-07
	40.0	3.1	4.448e-07	4.195e-07	4.689e-07
	50.0	3.2	5.610e-07	5.131e-07	5.843e-07
	60.0	3.1	6.722e-07	6.341e-07	7.156e-07
	70.0	2.9	7.999e-07	7.674e-07	8.624e-07
	75.0	2.7	9.118e-07	8.522e-07	9.640e-07
	80.0	2.5	1.022e-06	9.623e-07	1.070e-06
	90.0	1.9	1.322e-06	1.252e-06	1.446e-06
	95.0	1.4	1.730e-06	1.578e-06	1.891e-06
	97.5	1.0	1.995e-06	1.895e-06	2.368e-06
	99.0	0.7	2.693e-06	2.309e-06	3.314e-06
	99.5	0.5	3.185e-06	2.693e-06	4.200e-06

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
TH-120 [U34-(TH-087)]	0.5	0.5	3.082e-08	1.727e-08	5.290e-08
	1.0	0.7	5.290e-08	2.958e-08	6.921e-08
	2.5	1.0	8.803e-08	6.690e-08	1.023e-07
	5.0	1.4	1.302e-07	1.053e-07	1.462e-07
	10.0	1.9	1.937e-07	1.663e-07	2.188e-07
	20.0	2.5	3.357e-07	2.877e-07	3.590e-07
	25.0	2.7	3.896e-07	3.590e-07	4.256e-07
	30.0	2.9	4.563e-07	4.221e-07	4.919e-07
	40.0	3.1	5.780e-07	5.321e-07	6.294e-07
	50.0	3.2	7.511e-07	6.904e-07	8.063e-07
	60.0	3.1	9.336e-07	8.758e-07	1.007e-06
	70.0	2.9	1.199e-06	1.117e-06	1.278e-06
	75.0	2.7	1.368e-06	1.265e-06	1.449e-06
	80.0	2.5	1.516e-06	1.449e-06	1.604e-06
	90.0	1.9	2.110e-06	2.010e-06	2.297e-06
	95.0	1.4	2.744e-06	2.532e-06	2.992e-06
	97.5	1.0	3.392e-06	3.086e-06	3.815e-06
	99.0	0.7	4.231e-06	3.767e-06	4.885e-06
	99.5	0.5	4.486e-06	4.231e-06	6.062e-06
TH-121 [U36-(TH088)]	0.5	0.5	6.083e-09	1.840e-09	9.517e-09
	1.0	0.7	9.517e-09	5.725e-09	1.197e-08
	2.5	1.0	1.515e-08	1.163e-08	1.799e-08
	5.0	1.4	2.269e-08	1.900e-08	2.429e-08
	10.0	1.9	2.971e-08	2.701e-08	3.413e-08
	20.0	2.5	4.763e-08	4.341e-08	5.213e-08
	25.0	2.7	5.578e-08	5.171e-08	5.884e-08
	30.0	2.9	6.309e-08	5.836e-08	6.847e-08
	40.0	3.1	7.924e-08	7.480e-08	8.424e-08
	50.0	3.2	9.959e-08	9.251e-08	1.069e-07
	60.0	3.1	1.262e-07	1.179e-07	1.344e-07
	70.0	2.9	1.519e-07	1.445e-07	1.623e-07
	75.0	2.7	1.720e-07	1.599e-07	1.814e-07
	80.0	2.5	1.976e-07	1.807e-07	2.081e-07
	90.0	1.9	2.808e-07	2.618e-07	3.103e-07
	95.0	1.4	3.575e-07	3.389e-07	3.967e-07
	97.5	1.0	4.375e-07	4.019e-07	4.873e-07
	99.0	0.7	5.592e-07	4.843e-07	6.434e-07
	99.5	0.5	6.422e-07	5.592e-07	8.553e-07

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
TH-122 [U39-(TH089)]	0.5	0.5	6.083e-09	1.840e-09	9.517e-09
	1.0	0.7	9.517e-09	5.725e-09	1.197e-08
	2.5	1.0	1.515e-08	1.163e-08	1.799e-08
	5.0	1.4	2.269e-08	1.900e-08	2.429e-08
	10.0	1.9	2.971e-08	2.701e-08	3.413e-08
	20.0	2.5	4.763e-08	4.341e-08	5.213e-08
	25.0	2.7	5.578e-08	5.171e-08	5.884e-08
	30.0	2.9	6.309e-08	5.836e-08	6.847e-08
	40.0	3.1	7.924e-08	7.480e-08	8.424e-08
	50.0	3.2	9.959e-08	9.251e-08	1.069e-07
	60.0	3.1	1.262e-07	1.179e-07	1.344e-07
	70.0	2.9	1.519e-07	1.445e-07	1.623e-07
	75.0	2.7	1.720e-07	1.599e-07	1.814e-07
	80.0	2.5	1.976e-07	1.807e-07	2.081e-07
	90.0	1.9	2.808e-07	2.618e-07	3.103e-07
	95.0	1.4	3.575e-07	3.389e-07	3.967e-07
	97.5	1.0	4.375e-07	4.019e-07	4.873e-07
	99.0	0.7	5.592e-07	4.843e-07	6.434e-07
	99.5	0.5	6.422e-07	5.592e-07	8.553e-07
TH-123 [U37-(TH090)]	0.5	0.5	4.652e-09	3.105e-09	5.988e-09
	1.0	0.7	5.988e-09	4.434e-09	9.752e-09
	2.5	1.0	1.443e-08	9.385e-09	1.611e-08
	5.0	1.4	1.900e-08	1.696e-08	2.177e-08
	10.0	1.9	2.917e-08	2.595e-08	3.122e-08
	20.0	2.5	4.664e-08	4.246e-08	5.289e-08
	25.0	2.7	5.929e-08	5.236e-08	6.326e-08
	30.0	2.9	6.757e-08	6.241e-08	7.469e-08
	40.0	3.1	9.095e-08	8.300e-08	9.750e-08
	50.0	3.2	1.161e-07	1.082e-07	1.236e-07
	60.0	3.1	1.498e-07	1.399e-07	1.589e-07
	70.0	2.9	1.874e-07	1.773e-07	1.984e-07
	75.0	2.7	2.153e-07	1.969e-07	2.306e-07
	80.0	2.5	2.473e-07	2.300e-07	2.605e-07
	90.0	1.9	3.499e-07	3.216e-07	3.901e-07
	95.0	1.4	4.749e-07	4.252e-07	5.308e-07
	97.5	1.0	6.506e-07	5.450e-07	7.495e-07
	99.0	0.7	9.041e-07	7.406e-07	9.939e-07
	99.5	0.5	9.933e-07	9.041e-07	1.416e-06

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
TH-124 [U40-(TH091)]	0.5	0.5	4.652e-09	3.105e-09	5.988e-09
	1.0	0.7	5.988e-09	4.434e-09	9.752e-09
	2.5	1.0	1.443e-08	9.385e-09	1.611e-08
	5.0	1.4	1.900e-08	1.696e-08	2.177e-08
	10.0	1.9	2.917e-08	2.595e-08	3.122e-08
	20.0	2.5	4.664e-08	4.246e-08	5.289e-08
	25.0	2.7	5.929e-08	5.236e-08	6.326e-08
	30.0	2.9	6.757e-08	6.241e-08	7.469e-08
	40.0	3.1	9.095e-08	8.300e-08	9.750e-08
	50.0	3.2	1.161e-07	1.082e-07	1.236e-07
	60.0	3.1	1.498e-07	1.399e-07	1.589e-07
	70.0	2.9	1.874e-07	1.773e-07	1.984e-07
	75.0	2.7	2.153e-07	1.969e-07	2.306e-07
	80.0	2.5	2.473e-07	2.300e-07	2.605e-07
	90.0	1.9	3.499e-07	3.216e-07	3.901e-07
	95.0	1.4	4.749e-07	4.252e-07	5.308e-07
	97.5	1.0	6.506e-07	5.450e-07	7.495e-07
	99.0	0.7	9.041e-07	7.406e-07	9.939e-07
	99.5	0.5	9.933e-07	9.041e-07	1.416e-06
U16-(TH-092)	0.5	0.5	1.141e-08	3.022e-09	1.445e-08
	1.0	0.7	1.445e-08	6.446e-09	1.843e-08
	2.5	1.0	2.096e-08	1.738e-08	2.453e-08
	5.0	1.4	3.063e-08	2.479e-08	3.577e-08
	10.0	1.9	4.749e-08	4.075e-08	5.238e-08
	20.0	2.5	7.269e-08	6.547e-08	7.745e-08
	25.0	2.7	8.247e-08	7.725e-08	8.977e-08
	30.0	2.9	9.369e-08	8.810e-08	1.026e-07
	40.0	3.1	1.217e-07	1.133e-07	1.301e-07
	50.0	3.2	1.532e-07	1.454e-07	1.627e-07
	60.0	3.1	1.893e-07	1.782e-07	2.024e-07
	70.0	2.9	2.341e-07	2.189e-07	2.514e-07
	75.0	2.7	2.661e-07	2.482e-07	2.845e-07
	80.0	2.5	3.049e-07	2.834e-07	3.258e-07
	90.0	1.9	4.473e-07	4.241e-07	4.903e-07
	95.0	1.4	6.266e-07	5.402e-07	6.650e-07
	97.5	1.0	7.452e-07	6.823e-07	8.740e-07
	99.0	0.7	9.427e-07	8.604e-07	1.538e-06
	99.5	0.5	1.189e-06	9.427e-07	2.629e-06

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U16-(TH-093)	0.5	0.5	1.141e-08	3.022e-09	1.445e-08
	1.0	0.7	1.445e-08	6.446e-09	1.843e-08
	2.5	1.0	2.096e-08	1.738e-08	2.453e-08
	5.0	1.4	3.063e-08	2.479e-08	3.577e-08
	10.0	1.9	4.749e-08	4.075e-08	5.238e-08
	20.0	2.5	7.269e-08	6.547e-08	7.745e-08
	25.0	2.7	8.247e-08	7.725e-08	8.977e-08
	30.0	2.9	9.369e-08	8.810e-08	1.026e-07
	40.0	3.1	1.217e-07	1.133e-07	1.301e-07
	50.0	3.2	1.532e-07	1.454e-07	1.627e-07
	60.0	3.1	1.893e-07	1.782e-07	2.024e-07
	70.0	2.9	2.341e-07	2.189e-07	2.514e-07
	75.0	2.7	2.661e-07	2.482e-07	2.845e-07
	80.0	2.5	3.049e-07	2.834e-07	3.258e-07
	90.0	1.9	4.473e-07	4.241e-07	4.903e-07
	95.0	1.4	6.266e-07	5.402e-07	6.650e-07
	97.5	1.0	7.452e-07	6.823e-07	8.740e-07
	99.0	0.7	9.427e-07	8.604e-07	1.538e-06
	99.5	0.5	1.189e-06	9.427e-07	2.629e-06
U14-(TH-094)	0.5	0.5	2.319e-06	7.566e-07	2.985e-06
	1.0	0.7	2.985e-06	1.473e-06	3.603e-06
	2.5	1.0	4.279e-06	3.545e-06	4.967e-06
	5.0	1.4	5.533e-06	5.032e-06	6.359e-06
	10.0	1.9	8.558e-06	7.411e-06	9.454e-06
	20.0	2.5	1.355e-05	1.225e-05	1.488e-05
	25.0	2.7	1.596e-05	1.485e-05	1.723e-05
	30.0	2.9	1.872e-05	1.685e-05	2.006e-05
	40.0	3.1	2.411e-05	2.240e-05	2.544e-05
	50.0	3.2	3.007e-05	2.841e-05	3.168e-05
	60.0	3.1	3.664e-05	3.459e-05	3.886e-05
	70.0	2.9	4.556e-05	4.281e-05	4.927e-05
	75.0	2.7	5.210e-05	4.850e-05	5.588e-05
	80.0	2.5	5.894e-05	5.544e-05	6.284e-05
	90.0	1.9	8.543e-05	7.997e-05	9.435e-05
	95.0	1.4	1.156e-04	1.068e-04	1.373e-04
	97.5	1.0	1.536e-04	1.401e-04	1.744e-04
	99.0	0.7	1.870e-04	1.736e-04	2.273e-04
	99.5	0.5	2.090e-04	1.870e-04	3.944e-04

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
TH-125 [U21-(TH-095)]	0.5	0.5	8.937e-06	6.243e-06	1.158e-05
	1.0	0.7	1.158e-05	8.086e-06	1.365e-05
	2.5	1.0	1.872e-05	1.336e-05	2.091e-05
	5.0	1.4	2.447e-05	2.111e-05	2.830e-05
	10.0	1.9	3.655e-05	3.322e-05	4.005e-05
	20.0	2.5	5.455e-05	5.052e-05	5.932e-05
	25.0	2.7	6.388e-05	5.849e-05	6.836e-05
	30.0	2.9	7.179e-05	6.709e-05	7.660e-05
	40.0	3.1	8.889e-05	8.408e-05	9.429e-05
	50.0	3.2	1.073e-04	1.010e-04	1.132e-04
	60.0	3.1	1.298e-04	1.225e-04	1.381e-04
	70.0	2.9	1.610e-04	1.517e-04	1.693e-04
	75.0	2.7	1.781e-04	1.685e-04	1.878e-04
	80.0	2.5	1.976e-04	1.878e-04	2.143e-04
	90.0	1.9	2.637e-04	2.444e-04	2.778e-04
	95.0	1.4	3.256e-04	3.055e-04	3.635e-04
	97.5	1.0	4.076e-04	3.680e-04	4.554e-04
	99.0	0.7	4.953e-04	4.552e-04	5.656e-04
	99.5	0.5	5.589e-04	4.953e-04	7.607e-04
TH-126 [U22-(TH-096)]	0.5	0.5	8.424e-06	3.024e-06	1.372e-05
	1.0	0.7	1.372e-05	7.666e-06	1.625e-05
	2.5	1.0	2.164e-05	1.540e-05	2.359e-05
	5.0	1.4	2.821e-05	2.438e-05	3.117e-05
	10.0	1.9	4.289e-05	3.743e-05	4.687e-05
	20.0	2.5	6.685e-05	6.126e-05	7.254e-05
	25.0	2.7	7.860e-05	7.234e-05	8.408e-05
	30.0	2.9	8.935e-05	8.293e-05	9.762e-05
	40.0	3.1	1.189e-04	1.095e-04	1.251e-04
	50.0	3.2	1.474e-04	1.396e-04	1.620e-04
	60.0	3.1	1.823e-04	1.739e-04	1.913e-04
	70.0	2.9	2.287e-04	2.079e-04	2.432e-04
	75.0	2.7	2.582e-04	2.401e-04	2.742e-04
	80.0	2.5	2.883e-04	2.739e-04	3.045e-04
	90.0	1.9	3.735e-04	3.552e-04	4.032e-04
	95.0	1.4	4.912e-04	4.532e-04	5.258e-04
	97.5	1.0	5.613e-04	5.260e-04	6.658e-04
	99.0	0.7	6.956e-04	6.461e-04	8.538e-04
	99.5	0.5	7.944e-04	6.956e-04	1.063e-03

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U26-(TH-097)	0.5	0.5	3.970e-08	2.275e-08	8.398e-08
	1.0	0.7	8.398e-08	3.784e-08	1.221e-07
	2.5	1.0	1.332e-07	1.135e-07	1.503e-07
	5.0	1.4	1.923e-07	1.524e-07	2.237e-07
	10.0	1.9	3.098e-07	2.663e-07	3.525e-07
	20.0	2.5	5.570e-07	4.843e-07	6.458e-07
	25.0	2.7	7.378e-07	6.416e-07	8.061e-07
	30.0	2.9	9.209e-07	7.950e-07	1.030e-06
	40.0	3.1	1.355e-06	1.212e-06	1.493e-06
	50.0	3.2	1.808e-06	1.682e-06	1.988e-06
	60.0	3.1	2.491e-06	2.249e-06	2.848e-06
	70.0	2.9	3.546e-06	3.230e-06	3.903e-06
	75.0	2.7	4.256e-06	3.809e-06	4.817e-06
	80.0	2.5	5.298e-06	4.763e-06	5.853e-06
	90.0	1.9	8.529e-06	7.715e-06	9.750e-06
	95.0	1.4	1.291e-05	1.109e-05	1.628e-05
	97.5	1.0	1.963e-05	1.650e-05	2.612e-05
	99.0	0.7	2.895e-05	2.472e-05	3.638e-05
	99.5	0.5	3.558e-05	2.895e-05	8.618e-05
TH-127 [U27-(TH-098)]	0.5	0.5	1.930e-06	8.892e-07	2.217e-06
	1.0	0.7	2.217e-06	1.888e-06	2.558e-06
	2.5	1.0	3.217e-06	2.445e-06	3.683e-06
	5.0	1.4	4.273e-06	3.717e-06	4.675e-06
	10.0	1.9	6.453e-06	5.232e-06	6.788e-06
	20.0	2.5	9.486e-06	8.497e-06	1.060e-05
	25.0	2.7	1.141e-05	1.050e-05	1.238e-05
	30.0	2.9	1.296e-05	1.225e-05	1.399e-05
	40.0	3.1	1.606e-05	1.512e-05	1.727e-05
	50.0	3.2	1.961e-05	1.852e-05	2.059e-05
	60.0	3.1	2.394e-05	2.262e-05	2.554e-05
	70.0	2.9	3.006e-05	2.840e-05	3.259e-05
	75.0	2.7	3.457e-05	3.235e-05	3.669e-05
	80.0	2.5	3.892e-05	3.651e-05	4.089e-05
	90.0	1.9	5.300e-05	4.964e-05	5.871e-05
	95.0	1.4	7.068e-05	6.533e-05	7.514e-05
	97.5	1.0	8.071e-05	7.553e-05	9.252e-05
	99.0	0.7	9.968e-05	9.046e-05	1.502e-04
	99.5	0.5	1.272e-04	9.968e-05	1.894e-04

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
TH-128 [U24-(TH-099)]	0.5	0.5	1.930e-06	8.892e-07	2.217e-06
	1.0	0.7	2.217e-06	1.888e-06	2.558e-06
	2.5	1.0	3.217e-06	2.445e-06	3.683e-06
	5.0	1.4	4.273e-06	3.717e-06	4.675e-06
	10.0	1.9	6.453e-06	5.232e-06	6.788e-06
	20.0	2.5	9.486e-06	8.497e-06	1.060e-05
	25.0	2.7	1.141e-05	1.050e-05	1.238e-05
	30.0	2.9	1.296e-05	1.225e-05	1.399e-05
	40.0	3.1	1.606e-05	1.512e-05	1.727e-05
	50.0	3.2	1.961e-05	1.852e-05	2.059e-05
	60.0	3.1	2.394e-05	2.262e-05	2.554e-05
	70.0	2.9	3.006e-05	2.840e-05	3.259e-05
	75.0	2.7	3.457e-05	3.235e-05	3.669e-05
	80.0	2.5	3.892e-05	3.651e-05	4.089e-05
	90.0	1.9	5.300e-05	4.964e-05	5.871e-05
	95.0	1.4	7.068e-05	6.533e-05	7.514e-05
	97.5	1.0	8.071e-05	7.553e-05	9.252e-05
	99.0	0.7	9.968e-05	9.046e-05	1.502e-04
	99.5	0.5	1.272e-04	9.968e-05	1.894e-04
TH-129 [U28-(TH-100)]	0.5	0.5	1.288e-06	2.370e-07	1.663e-06
	1.0	0.7	1.663e-06	6.454e-07	2.223e-06
	2.5	1.0	2.970e-06	2.152e-06	3.537e-06
	5.0	1.4	4.167e-06	3.571e-06	5.187e-06
	10.0	1.9	6.868e-06	6.294e-06	7.285e-06
	20.0	2.5	1.011e-05	9.310e-06	1.130e-05
	25.0	2.7	1.221e-05	1.116e-05	1.289e-05
	30.0	2.9	1.383e-05	1.278e-05	1.492e-05
	40.0	3.1	1.796e-05	1.684e-05	1.958e-05
	50.0	3.2	2.203e-05	2.108e-05	2.397e-05
	60.0	3.1	2.817e-05	2.644e-05	2.971e-05
	70.0	2.9	3.595e-05	3.313e-05	3.876e-05
	75.0	2.7	4.084e-05	3.847e-05	4.315e-05
	80.0	2.5	4.606e-05	4.298e-05	4.996e-05
	90.0	1.9	6.628e-05	6.147e-05	7.224e-05
	95.0	1.4	8.274e-05	7.674e-05	9.449e-05
	97.5	1.0	1.071e-04	9.492e-05	1.309e-04
	99.0	0.7	1.441e-04	1.251e-04	1.691e-04
	99.5	0.5	1.675e-04	1.441e-04	2.264e-04

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
TH-130 [U25-(TH-101)]	0.5	0.5	1.288e-06	2.370e-07	1.663e-06
	1.0	0.7	1.663e-06	6.454e-07	2.223e-06
	2.5	1.0	2.970e-06	2.152e-06	3.537e-06
	5.0	1.4	4.167e-06	3.571e-06	5.187e-06
	10.0	1.9	6.868e-06	6.294e-06	7.285e-06
	20.0	2.5	1.011e-05	9.310e-06	1.130e-05
	25.0	2.7	1.221e-05	1.116e-05	1.289e-05
	30.0	2.9	1.383e-05	1.278e-05	1.492e-05
	40.0	3.1	1.796e-05	1.684e-05	1.958e-05
	50.0	3.2	2.203e-05	2.108e-05	2.397e-05
	60.0	3.1	2.817e-05	2.644e-05	2.971e-05
	70.0	2.9	3.595e-05	3.313e-05	3.876e-05
	75.0	2.7	4.084e-05	3.847e-05	4.315e-05
	80.0	2.5	4.606e-05	4.298e-05	4.996e-05
	90.0	1.9	6.628e-05	6.147e-05	7.224e-05
	95.0	1.4	8.274e-05	7.674e-05	9.449e-05
	97.5	1.0	1.071e-04	9.492e-05	1.309e-04
	99.0	0.7	1.441e-04	1.251e-04	1.691e-04
	99.5	0.5	1.675e-04	1.441e-04	2.264e-04
TH-102	0.5	0.5	5.042e-07	2.778e-07	6.585e-07
	1.0	0.7	6.585e-07	4.446e-07	1.473e-06
	2.5	1.0	2.124e-06	1.446e-06	2.680e-06
	5.0	1.4	3.821e-06	2.766e-06	4.739e-06
	10.0	1.9	6.854e-06	5.840e-06	7.661e-06
	20.0	2.5	1.274e-05	1.165e-05	1.406e-05
	25.0	2.7	1.542e-05	1.403e-05	1.794e-05
	30.0	2.9	2.064e-05	1.767e-05	2.446e-05
	40.0	3.1	3.077e-05	2.776e-05	3.421e-05
	50.0	3.2	4.028e-05	3.803e-05	4.670e-05
	60.0	3.1	6.573e-05	5.668e-05	7.226e-05
	70.0	2.9	9.112e-05	8.502e-05	9.955e-05
	75.0	2.7	1.072e-04	9.748e-05	1.248e-04
	80.0	2.5	1.483e-04	1.232e-04	1.663e-04
	90.0	1.9	2.385e-04	2.116e-04	2.999e-04
	95.0	1.4	4.811e-04	4.056e-04	5.615e-04
	97.5	1.0	5.998e-04	5.657e-04	6.866e-04
	99.0	0.7	7.357e-04	6.856e-04	9.028e-04
	99.5	0.5	8.610e-04	7.357e-04	9.937e-04

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
TH-103	0.5	0.5	1.214e-06	3.303e-07	1.582e-06
	1.0	0.7	1.582e-06	1.080e-06	1.954e-06
	2.5	1.0	2.217e-06	1.867e-06	2.353e-06
	5.0	1.4	2.608e-06	2.388e-06	2.819e-06
	10.0	1.9	3.348e-06	3.137e-06	3.643e-06
	20.0	2.5	4.850e-06	4.450e-06	5.059e-06
	25.0	2.7	5.549e-06	5.054e-06	5.894e-06
	30.0	2.9	6.191e-06	5.840e-06	6.606e-06
	40.0	3.1	7.857e-06	7.504e-06	8.357e-06
	50.0	3.2	9.471e-06	8.968e-06	9.769e-06
	60.0	3.1	1.112e-05	1.049e-05	1.162e-05
	70.0	2.9	1.304e-05	1.240e-05	1.367e-05
	75.0	2.7	1.426e-05	1.352e-05	1.508e-05
	80.0	2.5	1.574e-05	1.502e-05	1.658e-05
	90.0	1.9	1.989e-05	1.855e-05	2.090e-05
	95.0	1.4	2.324e-05	2.221e-05	2.583e-05
	97.5	1.0	2.802e-05	2.624e-05	3.062e-05
	99.0	0.7	3.226e-05	3.026e-05	3.719e-05
	99.5	0.5	3.632e-05	3.226e-05	4.511e-05
TH-104	0.5	0.5	3.119e-07	5.202e-08	5.770e-07
	1.0	0.7	5.770e-07	2.314e-07	7.928e-07
	2.5	1.0	1.204e-06	7.611e-07	1.569e-06
	5.0	1.4	2.496e-06	1.809e-06	3.236e-06
	10.0	1.9	4.489e-06	3.771e-06	5.070e-06
	20.0	2.5	9.967e-06	8.753e-06	1.125e-05
	25.0	2.7	1.250e-05	1.120e-05	1.396e-05
	30.0	2.9	1.578e-05	1.361e-05	1.782e-05
	40.0	3.1	2.601e-05	2.175e-05	2.822e-05
	50.0	3.2	3.727e-05	3.348e-05	4.231e-05
	60.0	3.1	5.526e-05	5.001e-05	6.290e-05
	70.0	2.9	8.374e-05	7.385e-05	9.682e-05
	75.0	2.7	1.064e-04	9.375e-05	1.219e-04
	80.0	2.5	1.346e-04	1.211e-04	1.522e-04
	90.0	1.9	2.710e-04	2.357e-04	3.284e-04
	95.0	1.4	4.956e-04	4.078e-04	6.276e-04
	97.5	1.0	8.129e-04	6.421e-04	9.843e-04
	99.0	0.7	1.053e-03	9.108e-04	1.271e-03
	99.5	0.5	1.198e-03	1.053e-03	1.641e-03

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
TH-105	0.5	0.5	6.615e-07	2.376e-07	7.441e-07
	1.0	0.7	7.441e-07	5.476e-07	8.872e-07
	2.5	1.0	1.121e-06	8.843e-07	1.292e-06
	5.0	1.4	1.555e-06	1.327e-06	1.788e-06
	10.0	1.9	2.405e-06	2.035e-06	2.557e-06
	20.0	2.5	3.433e-06	3.194e-06	3.777e-06
	25.0	2.7	4.108e-06	3.770e-06	4.362e-06
	30.0	2.9	4.724e-06	4.324e-06	5.026e-06
	40.0	3.1	5.966e-06	5.668e-06	6.569e-06
	50.0	3.2	7.771e-06	7.170e-06	8.213e-06
	60.0	3.1	9.790e-06	9.099e-06	1.061e-05
	70.0	2.9	1.305e-05	1.220e-05	1.411e-05
	75.0	2.7	1.471e-05	1.397e-05	1.602e-05
	80.0	2.5	1.723e-05	1.593e-05	1.838e-05
	90.0	1.9	2.347e-05	2.206e-05	2.563e-05
	95.0	1.4	2.863e-05	2.649e-05	3.125e-05
	97.5	1.0	3.574e-05	3.235e-05	3.880e-05
	99.0	0.7	4.314e-05	3.853e-05	5.152e-05
	99.5	0.5	5.146e-05	4.314e-05	5.416e-05
TH-106	0.5	0.5	2.927e-08	1.307e-08	4.399e-08
	1.0	0.7	4.399e-08	2.746e-08	7.155e-08
	2.5	1.0	8.787e-08	6.865e-08	1.034e-07
	5.0	1.4	1.260e-07	1.065e-07	1.432e-07
	10.0	1.9	1.862e-07	1.652e-07	2.129e-07
	20.0	2.5	3.281e-07	2.923e-07	3.626e-07
	25.0	2.7	4.011e-07	3.621e-07	4.514e-07
	30.0	2.9	5.045e-07	4.424e-07	5.458e-07
	40.0	3.1	6.741e-07	6.288e-07	7.108e-07
	50.0	3.2	9.089e-07	8.044e-07	9.902e-07
	60.0	3.1	1.254e-06	1.118e-06	1.382e-06
	70.0	2.9	1.746e-06	1.552e-06	1.954e-06
	75.0	2.7	2.101e-06	1.884e-06	2.341e-06
	80.0	2.5	2.622e-06	2.333e-06	2.941e-06
	90.0	1.9	4.672e-06	4.172e-06	5.564e-06
	95.0	1.4	8.088e-06	6.651e-06	9.682e-06
	97.5	1.0	1.212e-05	9.903e-06	1.671e-05
	99.0	0.7	2.178e-05	1.547e-05	3.129e-05
	99.5	0.5	2.948e-05	2.178e-05	1.440e-04

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
TH-107	0.5	0.5	5.024e-09	1.542e-09	6.213e-09
	1.0	0.7	6.213e-09	4.044e-09	7.408e-09
	2.5	1.0	1.014e-08	7.377e-09	1.205e-08
	5.0	1.4	1.671e-08	1.262e-08	1.886e-08
	10.0	1.9	2.720e-08	2.211e-08	3.177e-08
	20.0	2.5	4.868e-08	4.270e-08	5.536e-08
	25.0	2.7	6.228e-08	5.525e-08	7.053e-08
	30.0	2.9	7.790e-08	6.907e-08	8.426e-08
	40.0	3.1	1.129e-07	9.888e-08	1.282e-07
	50.0	3.2	1.625e-07	1.447e-07	1.826e-07
	60.0	3.1	2.306e-07	2.029e-07	2.601e-07
	70.0	2.9	3.298e-07	2.966e-07	3.792e-07
	75.0	2.7	4.226e-07	3.748e-07	4.888e-07
	80.0	2.5	5.276e-07	4.884e-07	5.998e-07
	90.0	1.9	8.942e-07	8.374e-07	1.071e-06
	95.0	1.4	1.573e-06	1.299e-06	1.950e-06
	97.5	1.0	2.898e-06	2.144e-06	3.865e-06
	99.0	0.7	5.130e-06	3.781e-06	7.491e-06
	99.5	0.5	7.272e-06	5.130e-06	1.128e-05
TH-108	0.5	0.5	3.209e-06	1.768e-06	4.191e-06
	1.0	0.7	4.191e-06	2.830e-06	9.372e-06
	2.5	1.0	1.352e-05	9.199e-06	1.706e-05
	5.0	1.4	2.432e-05	1.760e-05	3.016e-05
	10.0	1.9	4.362e-05	3.717e-05	4.875e-05
	20.0	2.5	8.109e-05	7.413e-05	8.948e-05
	25.0	2.7	9.811e-05	8.927e-05	1.142e-04
	30.0	2.9	1.313e-04	1.124e-04	1.556e-04
	40.0	3.1	1.958e-04	1.767e-04	2.177e-04
	50.0	3.2	2.563e-04	2.420e-04	2.972e-04
	60.0	3.1	4.183e-04	3.607e-04	4.599e-04
	70.0	2.9	5.799e-04	5.410e-04	6.335e-04
	75.0	2.7	6.821e-04	6.203e-04	7.945e-04
	80.0	2.5	9.436e-04	7.838e-04	1.058e-03
	90.0	1.9	1.518e-03	1.347e-03	1.909e-03
	95.0	1.4	3.062e-03	2.581e-03	3.573e-03
	97.5	1.0	3.817e-03	3.600e-03	4.369e-03
	99.0	0.7	4.682e-03	4.363e-03	5.745e-03
	99.5	0.5	5.479e-03	4.682e-03	6.324e-03

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
TH-109	0.5	0.5	7.727e-06	2.102e-06	1.007e-05
	1.0	0.7	1.007e-05	6.873e-06	1.244e-05
	2.5	1.0	1.411e-05	1.188e-05	1.497e-05
	5.0	1.4	1.660e-05	1.520e-05	1.794e-05
	10.0	1.9	2.130e-05	1.996e-05	2.318e-05
	20.0	2.5	3.086e-05	2.832e-05	3.219e-05
	25.0	2.7	3.531e-05	3.216e-05	3.751e-05
	30.0	2.9	3.939e-05	3.716e-05	4.204e-05
	40.0	3.1	5.000e-05	4.775e-05	5.318e-05
	50.0	3.2	6.027e-05	5.707e-05	6.217e-05
	60.0	3.1	7.075e-05	6.677e-05	7.397e-05
	70.0	2.9	8.300e-05	7.891e-05	8.701e-05
	75.0	2.7	9.076e-05	8.602e-05	9.599e-05
	80.0	2.5	1.001e-04	9.561e-05	1.055e-04
	90.0	1.9	1.265e-04	1.181e-04	1.330e-04
	95.0	1.4	1.479e-04	1.413e-04	1.644e-04
	97.5	1.0	1.783e-04	1.670e-04	1.949e-04
	99.0	0.7	2.053e-04	1.926e-04	2.367e-04
	99.5	0.5	2.311e-04	2.053e-04	2.871e-04
TH-110	0.5	0.5	1.985e-06	3.310e-07	3.672e-06
	1.0	0.7	3.672e-06	1.473e-06	5.045e-06
	2.5	1.0	7.659e-06	4.843e-06	9.981e-06
	5.0	1.4	1.588e-05	1.151e-05	2.059e-05
	10.0	1.9	2.857e-05	2.400e-05	3.226e-05
	20.0	2.5	6.343e-05	5.570e-05	7.161e-05
	25.0	2.7	7.955e-05	7.129e-05	8.884e-05
	30.0	2.9	1.004e-04	8.661e-05	1.134e-04
	40.0	3.1	1.655e-04	1.384e-04	1.796e-04
	50.0	3.2	2.372e-04	2.131e-04	2.692e-04
	60.0	3.1	3.516e-04	3.183e-04	4.003e-04
	70.0	2.9	5.329e-04	4.699e-04	6.161e-04
	75.0	2.7	6.768e-04	5.966e-04	7.754e-04
	80.0	2.5	8.568e-04	7.707e-04	9.687e-04
	90.0	1.9	1.725e-03	1.500e-03	2.090e-03
	95.0	1.4	3.154e-03	2.595e-03	3.994e-03
	97.5	1.0	5.173e-03	4.086e-03	6.263e-03
	99.0	0.7	6.699e-03	5.796e-03	8.087e-03
	99.5	0.5	7.622e-03	6.699e-03	1.045e-02

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
TH-111	0.5	0.5	4.209e-06	1.512e-06	4.735e-06
	1.0	0.7	4.735e-06	3.484e-06	5.646e-06
	2.5	1.0	7.131e-06	5.627e-06	8.219e-06
	5.0	1.4	9.895e-06	8.445e-06	1.138e-05
	10.0	1.9	1.531e-05	1.295e-05	1.627e-05
	20.0	2.5	2.185e-05	2.033e-05	2.403e-05
	25.0	2.7	2.614e-05	2.399e-05	2.776e-05
	30.0	2.9	3.006e-05	2.751e-05	3.199e-05
	40.0	3.1	3.797e-05	3.607e-05	4.180e-05
	50.0	3.2	4.945e-05	4.563e-05	5.226e-05
	60.0	3.1	6.230e-05	5.790e-05	6.753e-05
	70.0	2.9	8.303e-05	7.764e-05	8.979e-05
	75.0	2.7	9.357e-05	8.891e-05	1.020e-04
	80.0	2.5	1.097e-04	1.014e-04	1.170e-04
	90.0	1.9	1.494e-04	1.404e-04	1.631e-04
	95.0	1.4	1.822e-04	1.685e-04	1.989e-04
	97.5	1.0	2.274e-04	2.059e-04	2.469e-04
	99.0	0.7	2.745e-04	2.452e-04	3.279e-04
	99.5	0.5	3.275e-04	2.745e-04	3.447e-04
TH-112	0.5	0.5	1.863e-07	8.315e-08	2.800e-07
	1.0	0.7	2.800e-07	1.747e-07	4.553e-07
	2.5	1.0	5.592e-07	4.368e-07	6.579e-07
	5.0	1.4	8.021e-07	6.778e-07	9.114e-07
	10.0	1.9	1.185e-06	1.051e-06	1.355e-06
	20.0	2.5	2.088e-06	1.860e-06	2.307e-06
	25.0	2.7	2.553e-06	2.304e-06	2.873e-06
	30.0	2.9	3.210e-06	2.815e-06	3.473e-06
	40.0	3.1	4.290e-06	4.001e-06	4.523e-06
	50.0	3.2	5.784e-06	5.119e-06	6.302e-06
	60.0	3.1	7.980e-06	7.116e-06	8.793e-06
	70.0	2.9	1.111e-05	9.875e-06	1.244e-05
	75.0	2.7	1.337e-05	1.199e-05	1.490e-05
	80.0	2.5	1.669e-05	1.485e-05	1.871e-05
	90.0	1.9	2.973e-05	2.655e-05	3.541e-05
	95.0	1.4	5.147e-05	4.233e-05	6.162e-05
	97.5	1.0	7.710e-05	6.302e-05	1.064e-04
	99.0	0.7	1.386e-04	9.842e-05	1.991e-04
	99.5	0.5	1.876e-04	1.386e-04	9.163e-04

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
TH-113	0.5	0.5	3.197e-08	9.815e-09	3.954e-08
	1.0	0.7	3.954e-08	2.574e-08	4.714e-08
	2.5	1.0	6.454e-08	4.695e-08	7.665e-08
	5.0	1.4	1.063e-07	8.028e-08	1.200e-07
	10.0	1.9	1.731e-07	1.407e-07	2.022e-07
	20.0	2.5	3.098e-07	2.717e-07	3.523e-07
	25.0	2.7	3.963e-07	3.516e-07	4.488e-07
	30.0	2.9	4.957e-07	4.396e-07	5.362e-07
	40.0	3.1	7.186e-07	6.292e-07	8.161e-07
	50.0	3.2	1.034e-06	9.206e-07	1.162e-06
	60.0	3.1	1.467e-06	1.291e-06	1.655e-06
	70.0	2.9	2.098e-06	1.888e-06	2.413e-06
	75.0	2.7	2.689e-06	2.385e-06	3.110e-06
	80.0	2.5	3.357e-06	3.108e-06	3.817e-06
	90.0	1.9	5.690e-06	5.329e-06	6.817e-06
	95.0	1.4	1.001e-05	8.264e-06	1.241e-05
	97.5	1.0	1.844e-05	1.364e-05	2.460e-05
	99.0	0.7	3.265e-05	2.406e-05	4.767e-05
	99.5	0.5	4.627e-05	3.265e-05	7.177e-05
U02-(TH-114)	0.5	0.5	1.352e-05	9.705e-06	1.555e-05
	1.0	0.7	1.555e-05	1.293e-05	1.857e-05
	2.5	1.0	2.132e-05	1.766e-05	2.257e-05
	5.0	1.4	2.614e-05	2.283e-05	2.807e-05
	10.0	1.9	3.373e-05	3.051e-05	3.568e-05
	20.0	2.5	4.445e-05	4.235e-05	4.695e-05
	25.0	2.7	4.904e-05	4.687e-05	5.188e-05
	30.0	2.9	5.483e-05	5.138e-05	5.752e-05
	40.0	3.1	6.625e-05	6.188e-05	6.893e-05
	50.0	3.2	7.853e-05	7.455e-05	8.332e-05
	60.0	3.1	9.312e-05	8.730e-05	9.773e-05
	70.0	2.9	1.118e-04	1.055e-04	1.183e-04
	75.0	2.7	1.226e-04	1.170e-04	1.300e-04
	80.0	2.5	1.366e-04	1.299e-04	1.470e-04
	90.0	1.9	1.850e-04	1.706e-04	1.986e-04
	95.0	1.4	2.360e-04	2.150e-04	2.577e-04
	97.5	1.0	2.846e-04	2.644e-04	3.154e-04
	99.0	0.7	3.611e-04	3.123e-04	4.875e-04
	99.5	0.5	4.784e-04	3.611e-04	9.619e-04

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U04-(TH-115)	0.5	0.5	1.352e-05	9.705e-06	1.555e-05
	1.0	0.7	1.555e-05	1.293e-05	1.857e-05
	2.5	1.0	2.132e-05	1.766e-05	2.257e-05
	5.0	1.4	2.614e-05	2.283e-05	2.807e-05
	10.0	1.9	3.373e-05	3.051e-05	3.568e-05
	20.0	2.5	4.445e-05	4.235e-05	4.695e-05
	25.0	2.7	4.904e-05	4.687e-05	5.188e-05
	30.0	2.9	5.483e-05	5.138e-05	5.752e-05
	40.0	3.1	6.625e-05	6.188e-05	6.893e-05
	50.0	3.2	7.853e-05	7.455e-05	8.332e-05
	60.0	3.1	9.312e-05	8.730e-05	9.773e-05
	70.0	2.9	1.118e-04	1.055e-04	1.183e-04
	75.0	2.7	1.226e-04	1.170e-04	1.300e-04
	80.0	2.5	1.366e-04	1.299e-04	1.470e-04
	90.0	1.9	1.850e-04	1.706e-04	1.986e-04
	95.0	1.4	2.360e-04	2.150e-04	2.577e-04
	97.5	1.0	2.846e-04	2.644e-04	3.154e-04
	99.0	0.7	3.611e-04	3.123e-04	4.875e-04
	99.5	0.5	4.784e-04	3.611e-04	9.619e-04
U07-(TH-116)	0.5	0.5	1.806e-07	8.025e-08	2.580e-07
	1.0	0.7	2.580e-07	1.637e-07	3.443e-07
	2.5	1.0	4.450e-07	3.301e-07	5.335e-07
	5.0	1.4	6.792e-07	5.483e-07	7.993e-07
	10.0	1.9	1.128e-06	9.549e-07	1.295e-06
	20.0	2.5	2.081e-06	1.832e-06	2.340e-06
	25.0	2.7	2.638e-06	2.330e-06	2.947e-06
	30.0	2.9	3.244e-06	2.890e-06	3.626e-06
	40.0	3.1	4.754e-06	4.237e-06	5.281e-06
	50.0	3.2	6.767e-06	6.070e-06	7.510e-06
	60.0	3.1	9.637e-06	8.624e-06	1.079e-05
	70.0	2.9	1.408e-05	1.258e-05	1.584e-05
	75.0	2.7	1.741e-05	1.551e-05	1.958e-05
	80.0	2.5	2.203e-05	1.950e-05	2.491e-05
	90.0	1.9	4.063e-05	3.530e-05	4.765e-05
	95.0	1.4	6.707e-05	5.754e-05	8.306e-05
	97.5	1.0	1.065e-04	8.680e-05	1.397e-04
	99.0	0.7	1.819e-04	1.339e-04	3.011e-04
	99.5	0.5	2.646e-04	1.819e-04	8.711e-04

Table 9.2. Detailed quantile information for final Beaver Valley TH bins.

End State	Distribution Quantile (%)	95% Confidence Interval in %	Quantile Values	Lower Bound 95% Confidence Interval	Upper Bound 95% Confidence Interval
U08-(TH-117)	0.5	0.5	2.107e-07	9.363e-08	3.010e-07
	1.0	0.7	3.010e-07	1.910e-07	4.017e-07
	2.5	1.0	5.191e-07	3.851e-07	6.224e-07
	5.0	1.4	7.924e-07	6.397e-07	9.325e-07
	10.0	1.9	1.316e-06	1.114e-06	1.511e-06
	20.0	2.5	2.428e-06	2.138e-06	2.730e-06
	25.0	2.7	3.077e-06	2.719e-06	3.438e-06
	30.0	2.9	3.785e-06	3.372e-06	4.231e-06
	40.0	3.1	5.547e-06	4.943e-06	6.161e-06
	50.0	3.2	7.895e-06	7.082e-06	8.762e-06
	60.0	3.1	1.124e-05	1.006e-05	1.259e-05
	70.0	2.9	1.642e-05	1.468e-05	1.847e-05
	75.0	2.7	2.031e-05	1.810e-05	2.284e-05
	80.0	2.5	2.570e-05	2.275e-05	2.906e-05
	90.0	1.9	4.740e-05	4.118e-05	5.560e-05
	95.0	1.4	7.824e-05	6.713e-05	9.690e-05
	97.5	1.0	1.242e-04	1.013e-04	1.630e-04
	99.0	0.7	2.122e-04	1.562e-04	3.513e-04
	99.5	0.5	3.087e-04	2.122e-04	1.016e-03
TH-118	0.5	0.5	8.438e-08	3.323e-08	1.171e-07
	1.0	0.7	1.171e-07	7.777e-08	1.341e-07
	2.5	1.0	1.471e-07	1.318e-07	1.595e-07
	5.0	1.4	2.224e-07	1.639e-07	2.598e-07
	10.0	1.9	3.622e-07	3.201e-07	4.129e-07
	20.0	2.5	6.197e-07	5.479e-07	7.162e-07
	25.0	2.7	8.083e-07	7.144e-07	9.145e-07
	30.0	2.9	9.997e-07	8.914e-07	1.118e-06
	40.0	3.1	1.405e-06	1.271e-06	1.560e-06
	50.0	3.2	1.970e-06	1.778e-06	2.225e-06
	60.0	3.1	2.896e-06	2.594e-06	3.246e-06
	70.0	2.9	4.325e-06	3.817e-06	5.056e-06
	75.0	2.7	5.697e-06	4.932e-06	6.583e-06
	80.0	2.5	7.325e-06	6.526e-06	8.837e-06
	90.0	1.9	1.611e-05	1.303e-05	1.892e-05
	95.0	1.4	3.193e-05	2.489e-05	4.482e-05
	97.5	1.0	5.885e-05	4.666e-05	8.611e-05
	99.0	0.7	1.182e-04	8.491e-05	2.237e-04
	99.5	0.5	2.143e-04	1.182e-04	1.176e-03

9.3 Important T-H Bin Cut Set Information

To aid reader understanding, Tables 9.3 through 9.14 provide summaries of the most significant cut sets (i.e., initiators, equipment and operator failures, and modeled successes) and explanatory text for the most important T-H bins because these bins ended up contributing the most to the estimated through wall crack frequency (TWCF) for Beaver Valley Unit 1.

Table 9.3. Contribution of cut sets to T-H bin (end state) 7.

T-H Description for End State 7
Initiating Event: LOCA
Primary Side Failure: 20.32 cm. (8 inch) surge line break
Secondary Side Failure: None
Operator Action: None
Power Level: Power

Cut Set #	% Total	Cut Set %	Frequency	Inputs
1	100.0	100.0	2.1E-005	IE->MLOCA, DUMMY-1, FRAC-MLOCA-1

End state 7 involves a reactor trip from full power initiated by a medium size primary system LOCA, modeled as a 8 inch diameter surge line break. All other systems perform as intended including the operator response that is primarily only a monitoring function since full injection occurs and needs to be maintained during the time of interest in order to make up for the rapid and significant loss of RCS inventory.

Due to the very simple but adequate modeling of the medium LOCA for PTS since all other systems and actions are assumed successful (this provides significant cold water injection into the reactor vessel downcomer region), there is only one cut set in this bin. 100% of the T-H bin frequency involves cut set 1 which includes the medium LOCA initiating event assigned a frequency when the plant is at full power and a “DUMMY-1” event set at a probability of 1.0 simply as a necessary modeling event in order for the computer code to recognize this as a cut set. The FRAC-MLOCA-1 event is an assigned probability (0.35) from the uncertainty analysis that accounts for this discrete bin being representative of that portion of the total range of medium LOCA results (considering ranges of break sizes, flow rates, injection water temperatures, etc.) obtained for all the medium LOCA analyses. Cut set 1 exactly matches the modeled end state, a medium LOCA from full power conditions.

Table 9.4. Contribution of cut sets to T-H bin (end state) 9.

T-H Description for End State 9
Initiating Event: LOCA
Primary Side Failure: 40.64 cm. (16 inch) hot leg break
Secondary Side Failure: None
Operator Action: None
Power Level: Power

Cut Set #	% Total	Cut Set %	Frequency	Inputs
1	100.0	100.0	7.0E-006	IE->LLOCA, DUMMY-1

End state 9 involves a reactor trip from full power initiated by a large size primary system LOCA,

modeled as a 16 inch diameter hot leg break. All other systems perform as intended including the operator response that is primarily only a monitoring function since full injection occurs and needs to be maintained during the time of interest in order to make up for the rapid and significant loss of RCS inventory.

Due to the very simple but adequate modeling of the large LOCA for PTS since all other systems and actions are assumed successful (this provides significant cold water injection into the reactor vessel downcomer region), there is only one cut set in this bin. 100% of the T-H bin frequency involves cut set 1 which includes the large LOCA initiating event assigned a frequency when the plant is at full power and a "DUMMY-1" event set at a probability of 1.0 simply as a necessary modeling event in order for the computer code to recognize this as a cut set. Cut set 1 exactly matches the modeled end state, a large LOCA from full power conditions.

Table 9.5. Contribution of cut sets to T-H bin (end state) 56.

T-H Description for End State 56
Initiating Event: LOCA
Primary Side Failure: 10.16 cm. (4 inch) surge line break
Secondary Side Failure: None
Operator Action: None
Power Level: Hot Zero Power (used to represent a large/cold end of the spectrum of possible small LOCAs at Power)

Cut Set #	% Total	Cut Set %	Frequency	Inputs
1	51.2	51.2	6.3E-005	IE->SLOCA, /AFW-FT, FRAC-SLOCA-1, /HHSI_INIT_F, /HHSI_SCREEN30MIN, /MFW-FT
2	~76	~25	3.1E-005	IE->SLOCA, /AFW-FT, FRAC-SLOCA-1, /HHSI_INIT_F, HHSI_SCREEN30MIN, /MFW-FT, RCP_RESTART_F
3	~100.0	~25	3.1E-005	IE->SLOCA, /AFW-FT, FRAC-SLOCA-1, /HHSI_INIT_F, HHSI_SCREEN30MIN, /MFW-FT, /RCP_RESTART_F

End state 56 involves a reactor trip from full power initiated by a small size primary system LOCA. However, as this bin is representative of a break that is among the largest sizes of the possible range in sizes of a small LOCA and for very cold injection water conditions as part of the uncertainty analysis, the bin is actually thermal-hydraulically modeled as a 4 inch diameter surge line break under hot zero power (HZP) conditions as a surrogate for the desired at power small LOCA event. A mixture of other system and operator successes and failures are included within this bin but these are variations that do not significantly alter the thermal-hydraulic response of the plant as far as the PTS challenge is concerned.

Approximately 51% of the T-H bin frequency involves cut set 1which involves the small LOCA, and success of injection including throttling of the injection by the operator (denoted by the /HHSI... events) when conditions are met (successful throttling conservatively puts this cut set into this bin, which is intended to be a bin involving failure of throttling, but this has little influence for this bin because the size of the break, the resulting rate of cooldown, and the expected timing of when vessel breach may occur make success or failure of throttling relatively inconsequential). Additionally, main feedwater properly trips as expected (denoted by the /MFW-FT event), the reactor coolant pumps are assumed to be tripped by the operator (no event shown in the cut sets) which is appropriate for a LOCA and tends to stagnate primary system flow (which is conservative for PTS), and auxiliary feedwater starts and is controlled to provide proper steam generator cooling (denoted by the /AFW-FT event). The possible addition of

secondary breaches simultaneously occurring was not specifically modeled since the size of this LOCA is sufficient to somewhat decouple the primary system from the secondary system thermal-hydraulically making any additional secondary fault inconsequential as far as the severity of the PTS challenge which is governed by the LOCA itself. Besides that, an additional secondary fault would make the cut sets considerably lower in frequency, to account for the probability of the secondary fault, which would make the bin far less important. The FRAC-SLOCA-1 event is an assigned probability (0.23) from the uncertainty analysis that accounts for this discrete bin being representative of that portion of the total range of small LOCA results (considering ranges of break sizes, flow rates, injection water temperatures, etc.) obtained for all the small LOCA analyses.

The remaining ~50% of the T-H bin frequency involves cut sets 2 and 3 that are just like the first cut set except that the operator does not throttle injection (denoted by the HHSI_SCREEN30MIN event) which is exactly the intent of this bin, although throttling (or not) has little influence as mentioned above. At the time of creation of the model, it was thought that with failure to throttle injection, the success or failure of restarting the reactor coolant pumps (denoted by /RCP_RESTART_F and RCP_RESTART_F respectively) when conditions allow may be important (running pumps provide forced flow and so mixing in the downcomer, while far less mixing occurs when the pumps are idle) as far as the ultimate severity of the PTS challenge. Subsequently the analyses showed that for any serious PTS challenge, the late timing of the possible restart of these pumps has no influence on the outcome of the PTS challenge (vessel failure is likely to occur, if at all, before the possible restart of the pumps) and so whether the pumps are restarted or not is unimportant. Hence it is acceptable to bin cut sets 2 and 3 together and with cut set 1 for this end state. Collectively, these three cut sets make up virtually all of the overall bin frequency.

Table 9.6. Contribution of cut sets to T-H bin (end state) 60.

T-H Description for End State 60
Initiating Event: Transient (various)
Primary Side Failure: Stuck-open pressurizer SRV that recloses at 6000 sec.
Secondary Side Failure: None
Operator Action: None
Power Level: Power

Cut Set #	% Total	Cut Set %	Frequency	Inputs
1	25.3	25.3	5.5E-006	IE->RTTT, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-10, /MFW-FT, /RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
2	50.5	25.3	5.5E-006	IE->RTTT, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-10, /MFW-FT, RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
3	64.6	14.1	3.0E-006	IE->RTTT, AFW_3_OF, AREA-FRAC-1, /FW_REC_FT-T-AB, /HHSI_INIT_F, HHSI_SCREEN30MIN, /MFW-FT, /RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
4	78.7	14.1	3.0E-006	IE->RTTT, AFW_3_OF, AREA-FRAC-1, /FW_REC_FT-T-AB, /HHSI_INIT_F, HHSI_SCREEN30MIN, /MFW-FT, RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
5	80.8	2.2	4.6E-007	IE->LOMF, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-10, RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
6	83.0	2.2	4.6E-007	IE->LOMF, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-10, /RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
7	85.1	2.1	4.6E-007	IE->LOMC, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-10, RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
8	87.2	2.1	4.6E-007	IE->LOMC, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-10, /RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO

9. Quantification

T-H Description for End State 60				
Initiating Event:	**Transient (various)**			
Primary Side Failure:	**Stuck-open pressurizer SRV that recloses at 6000 sec.**			
Secondary Side Failure:	**None**			
Operator Action:	**None**			
Power Level:	**Power**			
Cut Set #	**% Total**	**Cut Set %**	**Frequency**	**Inputs**
9	89.1	1.9	4.2E-007	IE->LOSP, /AFW-FT, AREA-FRAC-1, /DG_A, /DG_B, /HHSI_INIT_F, HHSI_TERM_0SRV-10, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
10	90.3	1.2	2.6E-007	IE->LOMF, AFW_3_OF, /AFW_REC_FT-T-AB, AREA-FRAC-1, /HHSI_INIT_F, HHSI_SCREEN30MIN, RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO

End state 60 involves a plant trip from full power initiated by a transient (various types) with a subsequent stuck-open pressurizer safety relief valve (SRV) that recloses 6000 seconds following the trip. The operator fails to throttle high head safety injection any time after the throttling criteria is met. A mixture of other system and operator successes and failures are included within this bin but these are variations that do not significantly alter the thermal-hydraulic response of the plant as far as the PTS challenge is concerned.

Approximately 50.5% of the T-H bin frequency involves cut sets 1and 2 that involve a reactor trip/turbine trip as the initiator while at power, success of injection (denoted by the /HHSI_INIT_F event), failure of the operator to throttle injection by even 10 minutes after the throttling criteria are met and therefore assumed that throttling never occurs (denoted by the HHSI_TERM_0SRV-10 event), main feedwater properly trips as expected (denoted by the /MFW-FT event), the reactor coolant pumps are assumed to be tripped by the operator (no event shown in the cut sets) which is appropriate for a LOCA and tends to stagnate primary system flow (which is conservative for PTS), auxiliary feedwater starts and is controlled to provide proper steam generator cooling (denoted by the /AFW-FT event), and a pressurizer safety relief valve (SRV) sticks open and subsequently recloses 6000 seconds after the trip (denoted by the SRV_SO and /SRV_ISO_F events respectively). The possible addition of secondary breaches simultaneously occurring was not specifically modeled since the size of this LOCA is sufficient to somewhat decouple the primary system from the secondary system thermal-hydraulically making any additional secondary fault inconsequential as far as the severity of the PTS challenge which is primarily governed by the stuck-open SRV itself. Besides that, an additional secondary fault would make the cut sets considerably lower in frequency, to account for the probability of the secondary fault, which would make the bin far less important. The AREA-FRAC-1 event accounts for the fraction of the area that a SRV may be stuck-open (e.g., it could be barely open, full open, or somewhere in-between) that is sufficiently large to cause enough of a cooldown to be a PTS challenge. The SRV-CLOSES-6000-SEC event accounts for the 50-50 probability assigned to whether the SRV recloses at 6000 seconds or 3000 seconds; for this bin the SRV recloses at 6000 seconds. The only difference in the first two cut sets is whether the operator subsequently restarts the reactor coolant pumps late in the scenario (denoted by the RCP_RESTART (failure to restart) and /RCP_RESTART (successfully restarts) events). This difference occurs so late in the scenario, it has no effect on the through wall crack frequency results and so these two cut sets are binned together into this T-H bin.

The remaining cut sets are variations of the first two cut sets involving different initiators some of which

cause the initial loss of main feedwater (e.g., loss of offsite power or loss of main condenser or loss of main feedwater), as well as different conditions for auxiliary feedwater. For instance, in cut sets 3 and 4, auxiliary feedwater initially starts but overfeeds all three steam generators (denoted by the AFW_3_OF event) but the operator subsequently regains steam generator cooling in a controlled fashion (denoted by the /FW_REC_FT-T-AB event). In these cut sets, the HHSI_SCREEN30MIN event is virtually the same as the HHSI_TERM_0SRV-10 event in that it means that the operator fails to throttle injection but the event uses a conservative high screening probability (which was not that important to re-evaluate more realistically since these two cut sets only contribute about 28% of the total bin frequency which is not a significant over-estimate of the overall bin frequency). The other cut sets vary only in the initiating event and whether or not the reactor coolant pumps are restarted late in the scenario. These variations are unimportant since the stuck-open SRV causes the primary system to be somewhat decoupled thermal-hydraulically from the secondary side of the plant and hence these variations of when main feedwater is lost (as the initiator or trips right after the initiator) and auxiliary feedwater response do not significantly alter the degree of the PTS challenge which is predominantly driven by the stuck-open SRV itself. For this reason, it is acceptable that these variable cut sets are binned together into this T-H bin. Collectively, the ten cut sets shown make up approximately 90% of the overall bin frequency. Other cut sets (not shown) continue to be unimportant variations for this bin (e.g., auxiliary feedwater initially overfeeds just one steam generator).

Table 9.7. Contribution of cut sets to T-H bin (end state) 97.

T-H Description for End State 97
Initiating Event: Transient (various)
Primary Side Failure: Stuck-open pressurizer SRV that recloses at 3000 sec.
Secondary Side Failure: None
Operator Action: None
Power Level: Hot Zero Power

Cut Set #	% Total	Cut Set %	Frequency	Inputs
1	27.8	27.8	1.1E-006	IE->RTTT, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-10, HZP-MULTIPLIER, /MFW-FT, RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_1, SRV_SO
2	55.7	27.8	1.1E-006	IE->RTTT, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-10, HZP-MULTIPLIER, /MFW-FT, /RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_1, SRV_SO
3	71.0	15.4	6.0E-007	IE->RTTT, AFW_3_OF, AREA-FRAC-1, /FW_REC_FT-T-AB, /HHSI_INIT_F, HHSI_SCREEN30MIN, HZP-MULTIPLIER, /MFW-FT, RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_1, SRV_SO
4	86.4	15.4	6.0E-007	IE->RTTT, AFW_3_OF, AREA-FRAC-1, /FW_REC_FT-T-AB, /HHSI_INIT_F, HHSI_SCREEN30MIN, HZP-MULTIPLIER, /MFW-FT, /RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_1, SRV_SO
5	88.7	2.4	9.3E-008	IE->LOMF, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-10, HZP-MULTIPLIER, RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_1, SRV_SO
6	91.1	2.4	9.3E-008	IE->LOMF, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-10, HZP-MULTIPLIER, /RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_1, SRV_SO
7	93.1	2.0	8.0E-008	IE->RTTT, /AFW-FT, AREA-FRAC-1, HHSI_INIT_F, HHSI_REC_F, HZP-MULTIPLIER, /MFW-FT, SRV-CLOSES-3000-SEC, /SRV_ISO_F_1, SRV_SO
8	94.5	1.3	5.1E-008	IE->LOMF, AFW_3_OF, /AFW_REC_FT-T-AB, AREA-FRAC-1, /HHSI_INIT_F, HHSI_SCREEN30MIN, HZP-MULTIPLIER, RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_1, SRV_SO
9	95.8	1.3	5.1E-008	IE->LOMF, AFW_3_OF, /AFW_REC_FT-T-AB, AREA-FRAC-1, /HHSI_INIT_F, HHSI_SCREEN30MIN, HZP-MULTIPLIER, /RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_1, SRV_SO

End state 97 involves a plant trip from hot zero power (HZP) initiated by a transient (various types) with a subsequent stuck-open pressurizer safety relief valve (SRV) that recloses 3000 seconds following the trip. Like bin 60, the operator fails to throttle high head injection. A mixture of other system and operator successes and failures are included within this bin but these are variations that do not significantly alter the thermal-hydraulic response of the plant as far as the PTS challenge is concerned.

The cut sets and their variations are just like the cut sets shown for bin 60 above and can be binned together for the same reasons as noted in the bin 60 discussion. The primary differences are (a) that the bin is thermal-hydraulically modeled as the pressurizer safety relief valve reclosing at 3000 seconds after the plant trip (denoted by the SRV-CLOSES-3000-SEC event) rather than at 6000 seconds, and (b) the HZP-MULTIPLIER event accounts for the initiator occurring while at HZP conditions. The SRV reclosing at 3000 seconds rather than 6000 seconds tends to lessen the severity of the PTS challenge since the valve is not open as long to cool down the primary system. The initiator occurring at HZP tends to worsen the severity of the challenge than when the initiator occurs at full power because of the lower decay heat, however, the frequency is lower. The overall effect is that this bin is somewhat lessen important to through wall crack frequency than is bin 60.

Table 9.8. Contribution of cut sets to T-H bin (end state) 102.

T-H Description for End State 102
Initiating Event: Main Steam Line Break (assumed inside containment)
Primary Side Failure: None
Secondary Side Failure: Auxiliary feedwater continues to feed affected steam generator for 30 minutes
Operator Action: Throttles high head safety injection 30 minutes after criteria met
Power Level: Power

Cut Set #	% Total	Cut Set %	Frequency	Inputs
1	94.7	94.7	9.8E-005	IE->SLB2, AFW_ISO_FL10, /HHSI_INIT_F, /HHSI_TERM_MSLB-A, /MFW-FT-SLB, /RCP_INADV_TRIP
2	99.2	4.5	4.6E-006	IE->SLB2, AFW_ISO_FL10, /HHSI_INIT_F, /HHSI_TERM_MSLB-A, MFW_3_OF, MFW_REC_F, /RCP_INADV_TRIP

End state 102 involves a large steam line break initiator that cause a plant trip while at full power. This is modeled as a guillotine break of a main steam line. The operator successfully throttles high head injection by 30 minutes after allowed by the throttling criteria but fails to isolate the affected steam generator until 30 minutes into the event causing a greater cooldown than if the steam generator were isolated much sooner.

Approximately 94.7% of the T-H bin frequency involves cut set 1 which includes the large main steam line break initiating event assigned a frequency when the plant is at full power, success of injection including throttling of the injection by the operator (denoted by the /HHSI... events) by 30 minutes after appropriate conditions are met, main feedwater trips as expected (denoted by the /MFW-FT-SLB event), and the operator fails to isolate the auxiliary feedwater (which has started and is running) to the affected steam generator within 10 minutes but successfully does so by 30 minutes into the scenario (denoted by the AFW_ISO_FL10 event) which allows more cooling to occur longer than if the steam generator were isolated much sooner. While this and the next cut set both contain an event /RCP_INADV_TRIP denoting operator success to not inadvertently trip the reactor coolant pumps (which would be the correct response

if the break were outside containment), in this case, the break is assumed inside containment that will cause isolation of cooling water to the reactor coolant pumps and thus tripping the reactor coolant pumps is the correct thing to do (this worsens the PTS challenge since forced-flow conditions in the primary is lost so there is less mixing in the downcomer). Since the probability of /RCP_INADV_TRIP is 0.99, it is quantitatively the same as if the operator had successfully tripped the reactor coolant pumps (1.0 probability) like the operator should for an inside containment break and so the cut set essentially matches the exact conditions for the T-H bin.

Cut set 2 makes up an additional 4.5% of the T-H bin frequency and differs from cut set 1 in that main feedwater does not trip but overfeeds all three steam generators at first (denoted by the MFW_3_OF event) but control of the feed is regained within 10 minutes (e.g., due to a steam generator high level trip or via operator action) and auxiliary feedwater is subsequently operated. This perturbation is relatively unimportant since auxiliary feedwater continuing to feed the affected steam generator for 30 minutes (as involved in both cut sets) and the depressurization and cooldown effects of the main steam line break itself, dominate the severity of the PTS challenge. Hence it is acceptable that cut sets 1 and 2 are binned together into this T-H bin and collectively, the two cut sets make up over 99% of the overall bin frequency.

Table 9.9. Contribution of cut sets to T-H bin (end state) 103.

T-H Description for End State 103
Initiating Event: Main Steam Line Break (assumed inside containment)
Primary Side Failure: None
Secondary Side Failure: Auxiliary feedwater continues to feed affected steam generator for 30 minutes
Operator Action: Throttles high head safety injection 30 minutes after criteria met
Power Level: Hot Zero Power

Cut Set #	% Total	Cut Set %	Frequency	Inputs
1	90.8	90.8	9.7E-006	IE->SLB2, AFW_ISO_FL10, /HHSI_INIT_F, /HHSI_TERM_MSLB-A, HZP-FRACTION, /MFW-FT-SLB, /RCP_INADV_TRIP
2	95.0	4.2	4.5E-007	IE->SLB2, AFW_ISO_FL10, /HHSI_INIT_F, /HHSI_TERM_MSLB-A, HZP-FRACTION, MFW_3_OF, MFW_REC_F, /RCP_INADV_TRIP
3	97.4	2.4	2.6E-007	IE->SLB2, AFW_ISO_FL10, /HHSI_INIT_F, /HHSI_TERM_MSLB-A, HZP-FRACTION, /MFW-FT-SLB, RCP_INADV_TRIP, RCP_RESTART_F
4	99.8	2.4	2.6E-007	IE->SLB2, AFW_ISO_FL10, /HHSI_INIT_F, /HHSI_TERM_MSLB-A, HZP-FRACTION, /MFW-FT-SLB, RCP_INADV_TRIP, /RCP_RESTART_F

End state 103 involves a large steam line break initiator that cause a plant trip while at hot zero power (HZP). This is modeled as a guillotine break of a main steam line. The operator successfully throttles high head injection by 30 minutes after allowed by the throttling criteria but fails to isolate the affected steam generator until 30 minutes into the event causing a greater cooldown than if the steam generator were isolated much sooner.

The first two cut sets, making up about 95% of the total frequency, are just like those for bin 102 above with the exception that the HZP-FRACTION event is present to account for the initiator occurring while at HZP conditions. Cut sets 3 and 4 together make up the remaining 0.01 probability not accounted for by the 0.99 probability of the /RCP_INADV_TRIP event in cut set 1 (by virtue of the RCP_INADV_TRIP event in both cut sets) and thus all together, serve to account for the 1.0 probability of the reactor coolant pumps being tripped in this bin. As with bin 102, it is acceptable to bin these cut sets together and

collectively the four cut sets shown make up approximately 99.8% of the overall bin 103 frequency.

Table 9.10. Contribution of cut sets to T-H bin (end state) 104.

T-H Description for End State 104
Initiating Event: Main Steam Line Break (assumed inside containment)
Primary Side Failure: None
Secondary Side Failure: Auxiliary feedwater continues to feed affected steam generator for 30 minutes
Operator Action: Throttles high head safety injection 60 minutes after criteria met
Power Level: Power

Cut Set #	% Total	Cut Set %	Frequency	Inputs
1	94.8	94.8	9.7E-005	IE->SLB2, AFW_ISO_FL10, /HHSI_INIT_F, HHSI_TERM_MSLB-30A, /MFW-FT-SLB, /RCP_INADV_TRIP
2	99.3	4.5	4.6E-006	IE->SLB2, AFW_ISO_FL10, /HHSI_INIT_F, HHSI_TERM_MSLB-30A, MFW_3_OF, MFW_REC_F, /RCP_INADV_TRIP

End state 104 involves a large steam line break initiator that cause a plant trip while at full power. This is modeled as a guillotine break of a main steam line. The operator successfully throttles high head injection but not until 60 minutes after allowed by the throttling criteria. The operator fails to isolate the affected steam generator until 30 minutes into the event causing a greater cooldown than if the steam generator were isolated much sooner.

The cut sets for this bin are just like those for T-H bin 102 with the difference being that the HHSI_TERM_MSLB-30A event depicts the failure of the operator to throttle injection by 30 minutes but is successful by 60 minutes after meeting the throttling criteria. Otherwise the rationale for the acceptable binning of the cut sets shown is the same as described for bin 102. For bin 104, these first two cut sets collectively make up over 99% of the overall bin frequency.

Table 9.11. Contribution of cut sets to T-H bin (end state) 123.

T-H Description for End State 123
Initiating Event: Transient (various)
Primary Side Failure: Two stuck-open pressurizer SRVs that both reclose at 3000 sec.
Secondary Side Failure: None
Operator Action: Throttles high head safety injection 10 minutes after throttling criteria met
Power Level: Hot Zero Power

Cut Set #	% Total	Cut Set %	Frequency	Inputs
1	45.4	45.4	7.3E-008	IE->RTTT, /AFW-FT, AREA-FRAC-3, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-MULTIPLIER, /MFW-FT, /RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_0, SRV_SO_2
2	90.8	45.4	7.3E-008	IE->RTTT, /AFW-FT, AREA-FRAC-3, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-MULTIPLIER, /MFW-FT, RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_0, SRV_SO_2
3	94.6	3.9	6.2E-009	IE->LOMF, /AFW-FT, AREA-FRAC-3, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-MULTIPLIER, /RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_0, SRV_SO_2
4	98.5	3.9	6.2E-009	IE->LOMF, /AFW-FT, AREA-FRAC-3, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-MULTIPLIER, RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_0, SRV_SO_2

End state 123 involves a plant trip from hot zero power (HZP) initiated by a transient (various types) with

two stuck-open pressurizer safety relief valves (SRVs) that both reclose 3000 seconds following the trip. The operator fails to throttle high head injection within 1 minute after the throttling criteria are met but successfully throttles by 10 minutes after the criteria are met. A mixture of other system and operator successes and failures are included within this bin but these are variations that do not significantly alter the thermal-hydraulic response of the plant as far as the PTS challenge is concerned.

The cut sets for this bin are similar in form and make up as the cut sets for T-H bin 97 but with two stuck-open SRVs that subsequently reclose (denoted by the SRV_SO_2 and /SRV_ISO_F_O events respectively) rather than just one SRV. In this bin, the operator fails to throttle injection within 1 minute after the throttling criteria are met but is successful by 10 minutes after the criteria are met (denoted by the HHSI_TERM_0SRV-1 event), and the AREA-FRAC-3 event denotes that fraction of the possible area of two valves stuck-open that is significant from a cooldown perspective for PTS. Otherwise the nature of the cut sets and the rationale for the acceptable binning together of the cut sets shown is just like that already presented for T-H bins 97 and 60. In this case, the first four cut sets in bin 123 constitute nearly 99% of the overall bin frequency.

Table 9.12. Contribution of cut sets to T-H bin (end state) 126.

T-H Description for End State 126

Initiating Event: **Transient (various)**
Primary Side Failure: **Stuck-open pressurizer SRV that recloses at 6000 sec.**
Secondary Side Failure: **None**
Operator Action: **Throttles high head safety injection 10 minutes after throttling criteria met**
Power Level: **Power**

Cut Set #	% Total	Cut Set %	Frequency	Inputs
1	40.0	40.0	7.7E-005	IE->RTTT, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, /MFW-FT, /RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
2	80.0	40.0	7.7E-005	IE->RTTT, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, /MFW-FT, RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
3	83.4	3.4	6.5E-006	IE->LOMF, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
4	86.8	3.4	6.5E-006	IE->LOMF, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, /RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
5	90.2	3.4	6.4E-006	IE->LOMC, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
6	93.5	3.4	6.4E-006	IE->LOMC, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, /RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO

End state 126 involves a plant trip from full power initiated by a transient (various types) with a subsequent stuck-open pressurizer safety relief valve (SRV) that recloses 6000 seconds following the trip. The operator fails to throttle high head safety injection within 1 minute after the throttling criteria are met but does successfully throttle injection by 10 minutes after the criteria are met. A mixture of other system and operator successes and failures are included within this bin but these are variations that do not significantly alter the thermal-hydraulic response of the plant as far as the PTS challenge is concerned.

The cut sets are just like most of those in T-H bin 60 described earlier with the exception that injection throttling does not occur within 1 minute after the throttling criteria are met but does occur by 10 minutes after the throttling criteria are met (denoted by the HHSI_TERM_0SRV-1 event). Thus the nature and

rationale for the acceptable binning together of these cut sets is the same as already described for bin 60. While the successful throttling by 10 minutes would tend to decrease the severity of any PTS challenge over that from bin 60 which has no throttling (since primary pressure would be decreased when throttling occurs), the combination of the higher likelihood of successful throttling over failing to throttle, and the little change in the severity of the PTS challenge with throttling at 10 minutes after the throttling criteria are met (i.e., the throttling essentially occurs too late to be a significant deterrent to the likelihood of vessel failure), this bin actually ends up slightly more important to through wall crack frequency than does bin 60.

Table 9.13. Contribution of cut sets to T-H bin (end state) 129.

T-H Description for End State 129
Initiating Event: Transient (various)
Primary Side Failure: Stuck-open pressurizer SRV that recloses at 6000 sec.
Secondary Side Failure: None
Operator Action: Throttles high head safety injection 10 minutes after throttling criteria met
Power Level: Hot Zero Power

Cut Set #	% Total	Cut Set %	Frequency	Inputs
1	45.2	45.2	1.4E-005	IE->RTTT, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-MULTIPLIER, /MFW-FT, RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
2	90.4	45.2	1.4E-005	IE->RTTT, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-MULTIPLIER, /MFW-FT, /RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
3	94.2	3.8	1.2E-006	IE->LOMF, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-MULTIPLIER, RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
4	98.1	3.8	1.2E-006	IE->LOMF, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-MULTIPLIER, /RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
5	98.5	0.4	1.2E-007	IE->LOMC, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-FRACTION, RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO
6	98.9	0.4	1.2E-007	IE->LOMC, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-FRACTION, /RCP_RESTART_F, SRV-CLOSES-6000-SEC, /SRV_ISO_F_1, SRV_SO

End state 129 involves a plant trip from hot zero power (HZP) initiated by a transient (various types) with a subsequent stuck-open pressurizer safety relief valve (SRV) that recloses 6000 seconds following the trip. The operator fails to throttle high head safety injection within 1 minute after the throttling criteria are met but does successfully throttle injection by 10 minutes after the criteria are met. A mixture of other system and operator successes and failures are included within this bin but these are variations that do not significantly alter the thermal-hydraulic response of the plant as far as the PTS challenge is concerned.

The cut sets are just like those in T-H bin 126 above with the exception that the events HZP-MULTIPLIER and HZP-FRACTION are included in the cut sets to account for the trip occurring while at HZP conditions. Thus the nature and rationale for the acceptable binning together of these cut sets is the same as already described for bin 126. For bin 129, the first six cut sets shown here constitute approximately 99% of the overall bin frequency.

Table 9.14. Contribution of cut sets to T-H bin (end state) 130.

T-H Description for End State 130

Initiating Event: **Transient (various)**
Primary Side Failure: **Stuck-open pressurizer SRV that recloses at 3000 sec.**
Secondary Side Failure: **None**
Operator Action: **Throttles high head safety injection 10 minutes after throttling criteria met**
Power Level: **Hot Zero Power**

Cut Set #	% Total	Cut Set %	Frequency	Inputs
1	45.2	45.2	1.4E-005	IE->RTTT, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-MULTIPLIER, /MFW-FT, /RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_1, SRV_SO
2	90.4	45.2	1.4E-005	IE->RTTT, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-MULTIPLIER, /MFW-FT, RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_1, SRV_SO
3	94.2	3.8	1.2E-006	IE->LOMF, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-MULTIPLIER, /RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_1, SRV_SO
4	98.1	3.8	1.2E-006	IE->LOMF, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-MULTIPLIER, RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_1, SRV_SO
5	98.5	0.4	1.2E-007	IE->LOMC, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-FRACTION, /RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_1, SRV_SO
6	98.9	0.4	1.2E-007	IE->LOMC, /AFW-FT, AREA-FRAC-1, /HHSI_INIT_F, HHSI_TERM_0SRV-1, HZP-FRACTION, RCP_RESTART_F, SRV-CLOSES-3000-SEC, /SRV_ISO_F_1, SRV_SO

End state 130 involves a plant trip from hot zero power (HZP) initiated by a transient (various types) with a subsequent stuck-open pressurizer safety relief valve (SRV) that recloses 3000 seconds following the trip. The operator fails to throttle high head safety injection within 1 minute after the throttling criteria are met but does successfully throttle injection by 10 minutes after the criteria are met. A mixture of other system and operator successes and failures are included within this bin but these are variations that do not significantly alter the thermal-hydraulic response of the plant as far as the PTS challenge is concerned.

The cut sets are just like those in T-H bin 129 above with the exception that the event SRV-CLOSES-3000-SEC is in the cut sets denoting the SRV reclosure occurs at 3000 seconds rather than at 6000 seconds into the scenario. Thus the nature and rationale for the acceptable binning together of these cut sets is the same as already described for bin 129. Just like for bin 129, for bin 130, the first six cut sets shown here constitute approximately 99% of the overall bin frequency as the cut sets are quantitatively exactly the same as for bin 129.

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