COMMONWEALTH EDISON COMPANY

ZION NUCLEAR POWER STATION UNITS 1 AND 2

PLANT RESPONSE TREE NOTEBOOK

STEAM GENERATOR TUBE RUPTURE

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STEAM GENERATOR TUBE RUPTURE PLANT RESPONSE TREE NOTEBOOK

1.0 DEFINITION

A steam generator tube rupture (SGTR) event is the rupture of a single steam generator tube. For Zion, the rupture is considered to be a double-ended break of a single tube which results in a break area of 0.003276 sq. ft. This break area corresponds to the Zion Model 51 steam generator tube inside diameter of 0.775 inches and is assumed to exist at the top of the tube sheet on the cold leg side of the steam generator. Following the SGTR event, automatic reactor trip, safety injection and auxiliary feedwater help to maintain primary inventory and a secondary heat sink. However, appropriate operator actions are required to equalize RCS pressure with the ruptured steam generator pressure and to terminate safety injection in order to ultimately stop the primary to secondary break flow.

2.0 ACCIDENT PROGRESSION

At the time of initiation of a SGTR, the reactor is assumed to be in an equilibrium condition at power; the heat generated in the core is being removed via the secondary system. The SGTR is initiated by a random or consequential failure of a single tube leading to a double-ended break of that tube. The SGTR results in a breach of the primary coolant boundary between the primary coolant and the secondary coolant within the steam generator. Although the Chemical Volume and Control System (CVCS) attempts to compensate for the inventory loss by increasing the net charging flow, the break flow rate of a double ended break is greater that the charging pump capacity in normal charging mode, so the Reactor Coolant System (RCS) depressurization/pressurizer level decrease continues. Eventually, reactor trip will occur on either low pressurizer level or overtemperature delta-T.

The reactor trip signal will generate a turbine trip and the resulting generator trip will cause main feedwater trip. Safety injection (SI) actuation would occur soon thereafter due to low pressurizer pressure. The SI signal would automatically actuate the Auxiliary Feedwater (AFW) pumps (if they haven't already started on lo-lo SG level), which take suction from the Condensate Storage Tank (CST), to deliver water to all steam generators. Operator action is required to control AFW to maintain water level in the steam generators. The SI signal also starts the Emergency Core Cooling System (ECCS) pumps. The charging and SI pumps take suction from the Refueling Water Storage Tank (RWST) and inject borated water into the RCS. The Residual Heat Removal (RHR) pumps are also started by the SI signal, but cannot inject water since the RCS pressure is above the shutoff head of the RHR pumps. The RHR pumps continue to operate on mini-flow recirculation during the event sequences or the operators may switch these pumps 'off'. Finally, the SI signal switches the Reactor Containment Fan Coolers (RCFCs) to low speed and initiates Phase A containment isolation.

Following reactor trip and initiation of safety injection, the RCS temperature will be controlled to no-load conditions via steam dump from the steam generators to the condenser, or if the condenser is unavailable via steam dump to the atmosphere through the Atmospheric Relief Valves (ARVs). The RCS pressure equilibrates at the point where incoming SI flow approximately equals the outgoing primary to secondary break flow. The operator must perform several important actions to terminate this primary to secondary break flow. These actions are prescribed in the Zion Emergency Operating Procedures (E-3, 'Steam Generator Tube Rupture,' Reference 1.1) and are summarized as follows:

1. Identify and Isolate the Ruptured SG,
2. Perform an initial cooldown using the intact SGs,
3. Depressurize the RCS,
4. Terminate ECCS Flow.

The ruptured SG can be identified by the pre- or post-trip SG level response and also by steamline or SG blowdown radiation indications. Isolation of the ruptured SG requires closure of the Main Steam Isolation Valve (MSIV) on the ruptured SG plus any other potential leak paths (i.e., the steam supply line to the turbine driven AFW pump). If the MSIV on the ruptured SG can not be closed, the ruptured SG is isolated from the others by closing the MSIVs on the intact SGs. Additionally, as part of the isolation of the ruptured SG, auxiliary feedwater flow to this SG must be terminated to minimize the accumulation of water in this SG.

Following isolation of the ruptured SG, the operator dumps steam from the intact SGs in order to cool the RCS to a temperature of approximately 515°F (the pressure in the ruptured SG is used to determine the exact temperature to be achieved during this initial cooldown). The intent of this initial cooldown is to establish or maintain a temperature difference between the RCS and the intact SGs for decay heat removal and also to keep the RCS subcooled following the subsequent RCS depressurization. The condenser will be used for steam dump, if available, assuming that the intact SGs are not isolated. Otherwise, the SG atmospheric relief valves will be used to perform this RCS cooldown.

Next, the RCS is depressurized to minimize the primary to secondary break flow and to refill the pressurizer. Ideally, the depressurization will be stopped when the RCS pressure is less than the ruptured SG pressure. The depressurization is also stopped due to loss of subcooling or high pressurizer level. If the Reactor Coolant Pumps (RCPs) are in operation, normal pressurizer spray can be used to perform the RCS depressurization. If normal pressurizer spray is unavailable, then either one pressurizer Power Operated Relief Valve (PORV) or auxiliary spray will be used to perform the RCS depressurization.

Once the RCS depressurization is complete, the high pressure ECCS flow is terminated to prevent cr limit the RCS repressurization (and reinitiation of the primary to secondary break flow). After all ECCS flow is terminated, the RCS pressure will be approximately the same as the ruptured SG pressure and the primary to secondary leakage will be stopped (or minimal); thus a safe, stable state is achieved. Normal inventory and pressure controls will be established and a post-SGTR procedure will be used to cooldown and depressurize the plant to cold shutdown conditions.

3.0 PLANT RESPONSE TREE NODES

To construct the SGTR plant response tree, the nodes necessary to fulfill the functions of RCS inventory control, containment heat removal and containment integrity are modeled. The combination of plant systems and operator actions, as laid out in the Zion Emergency Operating Procedures or EOPs (Reference 1), required to prevent core damage and containment failure determine the success sequences or plant response tree success states.

The following subsections present a brief description of each of the nodes, success criteria for the nodes and the operator actions modeled on the plant response tree.

The following assumptions for the modeling of the plant response trees are noted here:

- Reactor trip is not modeled in the SGTR plant response tree. The Anticipated Transient Without Scram (ATWS) plant response tree notebook (Reference 2) provides a discussion of SGTR with failure of reactor trip.

- The accumulators are not modeled in the plant response tree for the SGTR since there are no sequences in which they are required to prevent core damage.

- RCP trip is not explicitly modeled in the SGTR plant response tree. For sequences with AFW available, a SGTR will not result in the criteria for RCP trip; however RCP trip is considered in the operator action to perform RCS depressurization since RCP operation is necessary to use normal pressurizer spray. For sequences with AFW unavailable, RCP trip is considered in the operator action to establish bleed and feed cooling.

- For event sequences with the failure of charging pumps and auxiliary feedwater but success of at least one safety injection pump, bleed and feed cooling is initiated by opening both pressurizer PORVs. The reclosure of the pressurizer PORVs following successful restoration of feedwater to the steam generators (via the main feedwater pumps) is not modeled on the SGTR plant response tree. FR-H.1, 'Loss of Heat Sink,' (Reference 1.2) permits termination of bleed and feed cooling if a source of feedwater is restored; this could lead to a success path involving normal RHR cooling. The exclusion of this path from the SGTR plant response tree is not expected to significantly impact the overall results.

- For event sequences in which bleed and feed is required by FR-H.1, but cannot be established, the alignment of service water to the steam generators is not modeled. It is assumed that this action will not significantly improve the probability of success for SGTR sequences.

- Operator actions to cooldown and depressurize the RCS using the steam generators, per FR-C.2, 'Response to Degraded Core Cooling,' (Reference

1.3) and FR-C.1, 'Response to Inadequate Core Cooling,' (Reference 1.4) are not modeled. For a SGTR event, the indication to begin a RCS cooldown with the steam generators is very early in the EOPs. Since there is a long time to accomplish these actions prior to the time at which degraded or inadequate core cooling indications are received, the probability of accomplishing this action is sufficiently high that consideration of RCS cooldown via FR-C.2 or FR-C.1 can be ignored.

- Containment spray via the RHR pumps during recirculation as instructed by ES-1.3, 'Transfer to Cold Leg Recirculation,' (Reference 1.5) or FR-Z.1, 'Response to High Containment Pressure,' (Reference 1.6) is not included on the plant response tree. This mode of operation is not required for containment heat removal during the initial 24 hours of the accident.

- For event sequences which lead to core damage, operator actions per FR-C.1 to open the pressurizer PORVs in order to achieve a low RCS pressure at the time of reactor vessel failure is not modeled in the SGTR plant response tree. Based on the results presented in Reference 18, the accident progression and consequences are not affected by the RCS pressure at vessel failure.

- For event sequences in which RCS cooldown via any intact SG cannot be performed, it is assumed that RCS cooldown via the ruptured SG will also fail. Although the EOPs direct the operators to use the ruptured SG for the scenario in which the intact SGs are unavailable for RCS cooldown, the loss of steam dumping capability from all three intact SGs (either to condenser or atmosphere) is assumed to be a result of a common cause failure such that the ruptured SG would also be unavailable for RCS cooldown.

- Steam generator overfill is assumed to exist when the secondary side of the ruptured SG is filled with water up to and including the vertical run of steam pipe above the steam generator. This encompasses a volume of 5780 ft^3 (43,235 gallons).

- For all event sequences which lead to steam generator overfill, it is assumed that water relief through the relief or safety valves results in the consequential failure of a valve to reseat. Since the precise behavior of the atmospheric relief valves and safety valves after water relief is not known, this simplifying assumption can be made.

  It is noted that water relief through the ARVs or safety valves for a few cycles is not expected to cause valve failures; however the SG overfill sequences of greatest interest in the SGTR PRT involve continuous cycling of the relief valves for an extended period of time. This would result in continuous RCS inventory loss analogous to that of a stuck open relief valve. Accordingly, it can be assumed that SG overfill results in the failure of a relief valve to reseat.

  The specific assumption for SG overfill sequences is that since the failure of an atmospheric relief valve can be mitigated by closure of the block valve, the consequential failure due to SG overfill is assumed to be a failure of one safety valve to reseat. As a result, the continued release from the ruptured steam generator results in a continual primary to secondary pressure differential such that the primary to secondary break flow continues. Continued ECCS injection depletes the RWST; since ECCS recirculation is not possible, the ECCS flow must be reduced or RWST refill must be accomplished. For further discussion of SG overfill, see also References 3 and 19.

- As a result of the consequential failure of the safety valve to reseat, all SG overfill cases which lead to core damage are considered containment bypass sequences.

- The response to a SGTR may result in a return to criticality for two specific scenarios:

  1. One of the initial operator actions during the response to a SGTR event is a RCS cooldown via steam relief from the intact SGs at maximum rate (per Step 14 of E-3). This RCS cooldown is continued at maximum rate until a 'target temperature' is attained; this 'target temperature' is based on the pressure in the ruptured SG. The intent of this RCS cooldown is to establish a pressure/temperature differential between the ruptured and intact SGs.

     A return to criticality could occur during this relatively fast RCS cooldown (recall: maximum steam relief) under certain circumstances. Specifically, the RCS cooldown must be on the order of >150°F, and the initial core conditions must correspond to minimum shutdown margin plus the most negative Moderator Temperature Coefficient (MTC). These conditions may occur if the ruptured SG continues to depressurize due to an unisolated steam path resulting in a reduced 'target temperature' and if the SGTR event occurs at end-of-life core conditions. Assuming that these conditions exist, it may be postulated that the positive reactivity insertion due to the RCS cooldown (i.e., negative MTC) in conjunction with the lack of negative reactivity insertion (recall that

Zion no longer utilizes highly borated water in the Boron Injection Tank (BIT))may result in return to criticality.

2. A return to criticality has been postulated in Reference 14 for the scenario in which 'backfill' from the ruptured SG to the RCS is being utilized for RCS depressurization (per ES-3.1, 'Post-SGTR Cooldown Using Backfill,' Reference 1.7 or ES-3.3, 'Post-SGTR Cooldown Using Steam Dump,' Reference 1.8). In this situation, the RCS pressure is less than the ruptured SG pressure and relatively unborated secondary water is flowing back into the RCS. If a slug of this unborated water should be introduced to a region of the core (i.e., such as during RCP restart in the loop with the ruptured SG), then return to criticality could occur. Prerequisites to such a scenario include RCP trip for an extended time such that flow stagnation occurs in the ruptured loop and an accumulation of unborated water in the RCS piping of this loop.

It is noted that in either case, any return to criticality would be at low power, that which would be 'supported' by the AFW flow and secondary steam relief.

To address these potential scenarios of return to criticality, the following assumptions are made. For Case 1 above, it is noted that the probability of the conditions needed to return to criticality are sufficiently small as to preclude consideration of return to criticality. However, in the event that such circumstances occur, the consequences have been determined in an analysis which addresses return to criticality for steamline breaks (Reference 13). This analysis uses conservative assumptions to address return to criticality following a steamline break including the assumption of the most reactive control rod fully withdrawn (clearly a non-conservative assumption for a realistic PRA). The results of the analysis conclude that no fuel failures would occur. Since the results of this analysis would encompass the SGTR scenario described for Case 1 above, it is corcluded that return to criticality for a SGTR event will not result in any fu l failures. Therefore, return to criticality is not addressed in the SGTR pla it response trees.

For Case 2, the Westinghouse Owners Group Operations Subcommittee reviewed the Reference 14 report and concurred that although the scenario has a low probability of occurrence, the issue of a return to criticality due to boron dilution during a SGTR event should be addressed. Therefore, all affected plants (including Zion) were notified of this concern and although the relevant procedures direct the operator to verify and maintain adequate shutdown margin during 'backfill', the Emergency Response Guidelines were modified to include a caution to restart the RCP(s) in the non-ruptured loop(s) first in order to provide boron mixing in the ruptured loop (Reference 15). On this basis, return to criticality via the scenario in Case 2 is not considered in the SGTR plant response trees.

- For those SGTR scenarios in which pressurizer pressure control is lost, RCS depressurization to cold shutdown via either backfill, blowdown or steam dump from the ruptured SG as instructed in ECA-3.3, 'SGTR Without Pressurizer Pressure Control,' (Reference 1.9), Step 31 is not considered. The scenario of a loss of all pressurizer pressure control (normal spray, PORVs and auxiliary spray per E-3 and ECCS termination per ECA-3.3) is assumed to be sufficiently small that the plant response tree need not include these paths.

- For those SGTR scenarios in which the operator action to reduce ECCS injection via E-3 or ECA-3.3 cannot be accomplished prior to SG overfill, it is assumed that subsequent steps in ECA-3.1, 'SGTR with Loss of Reactor Coolant-Subcooled Recovery,' (Reference 1.10) or ECA-3.2, 'SGTR with Loss of Reactor Coolant-Saturated Recovery,' (Reference 1.11) to establish RCS inventory control also fail.

- For SGTR sequences in which the RHR pumps are required for ECC recirculation (i.e., loss of heat sink), it is assumed that component cooling water (CCW) flow to the RHR heat exchanger (OHX/RHX) for the purpose of pump cooling during miniflow recirculation is not needed. Per Reference 8, the longest time the RHR pumps can operate with no miniflow recirculation is 9 hours. Since the switchover to ECC recirculation will take place prior to this time for most SGTR sequences in which the RHR pumps are required (Reference 16), establishing CCW to the RHR heat exchangers is not modeled.

- For SGTR sequences which result in SG overfill due to the failure to isolate the ruptured SG (failure of OAI/MSI or OAF/AFI), a SAM end state may be achieved upon success of RCS cooldown (ODS/DS) and ECCS reduction (OIR). It is assumed that the success criteria for ODS, DS and OIR will not be redefined for the SG overfill sequences and will thus utilize the criteria developed for the SGTR sequences in which ruptured SG isolation succeeds (Reference 16).

- Consideration of RCS depressurization for SGTR sequences only includes RCS depressurization via the pressurizer PORVs (Reference 7).

3.1 Description of Nodes

A brief description of each of the nodes of the SGTR plant response tree is given in the following paragraphs. The plant response tree model and a discussion of the nodal dependencies are given in Section 6.0.

A. Initiator SGTR1

This node is the SGTR initiator and represents a double-ended break of one (1) steam generator tube.

B. Auxiliary Feedwater (AFW)

This node is auxiliary feedwater delivery to the steam generators with either the motor driven or turbine driven auxiliary feedwater pumps. The auxiliary feedwater system provides water to the steam generators to maintain steam generator level in order to ensure that heat removal via the steam generators is effective. Auxiliary feedwater is also required to: 1) cooldown and depressurize the RCS and 2) prevent the EOPs from requiring the operators to initiate RCS bleed and feed cooling. The auto-opening of a safety valve is also included in this node. A detailed description of AFW is provided in the Auxiliary Feedwater System Notebook (Reference 4).

C. Refueling Water Storage Tank (TK)

This node is the RWST. The RWST provides the source of borated water necessary for safety injection (and containment spray, if necessary) following a SGTR event. It is shown as a separate node because it is shared by several systems. Separate suction lines from the RWST supply water to the following sets of pumps: two centrifugal charging pumps, two safety injection pumps, two RHR pumps and three containment spray pumps. If the RWST fails, all ECCS injection fails and containment spray injection fails.

D. Centrifugal Charging Pumps (CCP)

This node is high pressure safety injection via the centrifugal charging pumps. The SI signal would immediately start the two centrifugal charging pumps and align them to take suction from the RWST and deliver water to the RCS via the ECCS cold leg injection pipes. The charging pumps can also be used to inject subcooled, borated water to the RCS during ECCS high-pressure recirculation. During recirculation, the charging pumps take suction from the discharge of the RHR pumps. The charging pumps can also be used to continue injection of water from the RWST if the RWST is refilled. In terms of subsequent nodes, for event sequences in which auxiliary feedwater has failed and at least one charging pump is operational, restoration of an alternate feedwater source to the steam generators takes precedence over initiation of bleed and feed cooling. Finally, at least one charging pump is required to be operational in order to implement the shutdown cooling mode of the RHR system for continued cooldown to cold shutdown conditions. A detailed description of CCP is provided in the ECCS notebook (Reference 5).

E. Safety Injection Pumps (SIP)

This node is high pressure safety injection via the safety injection pumps. The SI signal would immediately start the two safety injection pumps which would deliver water to the RCS via the ECCS cold leg injection pipes. The safety injection pumps can also be used to inject subcooled, borated water to the RCS during ECCS high-pressure recirculation. During recirculation, the safety injection pumps take suction from the discharge of the RHR pumps. The safety injection pumps can also be used to continue injection of water from the RWST if the RWST is refilled. The safety injection pumps are not required for ECCS injection if the charging pumps are successful. In terms of subsequent nodes, for event sequences which include the failure of auxiliary feedwater and the charging pumps, at least one safety injection pump must be operational to initiate bleed and feed cooling. A detailed description of SIP is provided in the ECCS notebook (Reference 5).

F. Operator Action to Establish Alternate Feedwater (ORF)

This node is the operator action to establish an alternate source of feedwater to the steam generators in the event that auxiliary feedwater is not available. This node represents the operator action to establish alternate feedwater per Step 9 of FR-H.1.

Sources of alternate feedwater from Step 9 include the main feedwater pumps and the condensate booster pumps. However, as a simplifying assumption, this node only considers the operator action to establish alternate feedwater with the main feedwater pumps. The rapid SG depressurization needed for condensate booster pump injection is not modeled here. Note that operation of the condensate booster pumps is necessary for successful injection with the main feedwater pumps. The alignment for injection with the main feedwater pumps to the steam generator(s) includes opening the feedwater isolation Motor Operated

Valves (MOVs), the feedwater regulating bypass valve manual isolation valves and throttling the feedwater regulating bypass valves.

The detailed evaluation of the operator action ORF is given in the Human Reliability Analysis Notebook (Reference 6).

G. Alternate Feedwater (ALT)

This node is alternate feedwater delivery to the steam generators with the main feedwater pumps. If auxiliary feedwater is not available, an alternate feedwater source is required to cooldown and depressurize the RCS. For the SGTR scenario, the main feedwater pump(s) can provide sufficient water to the steam generators in order to ensure steam generator heat removal capability.

For injection with the main feedwater pump(s), this node represents the successful start and continued operation of the main feedwater pump(s) along with the operation of the associated valves required to realign the main feedwater pump(s) for injection to the steam generator(s). The main feedwater pump will be fed by the condensate booster pump(s); therefore successful injection with the main feedwater pump(s) also includes the successful start and continued operation of the condensate booster pumps along with the operation of the associated valves required for the condensate booster pumps to feed the main feedwater pump(s). However, no steam generator depressurization is necessary for injection with the main feedwater pump(s).

A detailed description of ALT is provided in the Miscellaneous Systems Notebook (Reference 7).

H. Operator Action to Initiate RCS Bleed (OBL)

This node is the operator action to initiate 'bleed and feed' via the opening of at least one pressurizer PORV. The actions considered at this node are dependent upon the event sequence path, as follows:

a) for all event sequences in which at least one charging pump is available but no feedwater injection to the steam generators is available (auxiliary feedwater or alternate supplies), this node models the operator actions to initiate bleed and feed cooling, per FR-H.1, Step 16 when the steam generator level reaches 24% of wide range indication and,

b) for all event sequences in which at least one SI pump is available but no charging pump and no auxiliary feedwater injection to the steam generators is available, this node models the operator actions to immediately initiate bleed and feed cooling per FR-H.1, Steps 4 and 16.

Note that for scenario (a) above, the operators may initially transfer out of FR-H.1, but based on logic presented in Section 8 (and Appendix B), the operators will return to FR-H.1 to initiate bleed and feed cooling due to loss of level in all SGs and lack of AFW flow.

The detailed evaluation of the operator actions OBL is given in the Human Reliability Analysis Notebook (Reference 6).

I. RCS Bleed via Pressurizer PORV(s) (BL)

This node is the action of at least one pressurizer PORV to open and remain open upon demand. As part of this equipment, the associated block valve must also open (if not already) and remain open. A detailed description of BL is provided in the Miscellaneous Systems Notebook (Reference 7).

J. Operator Action to Isolate Steam Flow from the Ruptured Steam Generator (OAI)

This node represents the operator action to diagnose a SGTR event, identify the steam generator with the ruptured tube, and to take the necessary steps to isolate this steam generator from the 3 intact steam generators. Indications of a SGTR event include pre- or post-trip SG level response as well as steamline and blowdown radiation indications. Isolation of the ruptured steam generator provides a pressure/temperature differential between this ruptured steam generator and the intact steam generators; such a differential is important in the subsequent actions during a SGTR event. Isolation requires closure of the ruptured SG MSIV and other potential leak paths (i.e., the steam supply line to the turbine driven AFW pump). If the MSIV for the ruptured SG can not be closed, the ruptured SG is isolated from the others by closure of the MSIVs on the intact SGs. Operator guidance for steam generator isolation is given in Zion EOP E-3, Step 4.

The detailed evaluation of operator action OAI is given in the Human Reliability Analysis Notebook (Reference 6).

K. Isolation of Steam Flow from Ruptured SG (MSI)

This node includes the equipment to isolate steam flow from the ruptured SG. Specifically, this includes the MSIV on the ruptured steam generator. Isolation of the ruptured steam generator also includes isolation of other steam flow paths such as the turbine driven AFW pump steam supply line, etc.

Success of this node may also be achieved by closing the MSIVs on the intact steam generators. This action effectively isolates the ruptured SG from the intact SGs since the steam dumps should stay closed. A detailed description of MSI is given in the Miscellaneous Systems Notebook (Reference 7).

L. Operator Action to Isolate Feedwater Flow to the Ruptured SG (OAF)

This node represents the operator action to terminate all feedwater flow to the ruptured steam generator. This action is necessary to prolong the time available to stop the primary to secondary break flow through the ruptured tube before steam generator overfill occurs. Operator guidance for feedwater isolation is given in Zion EOP E-3, Step 6.

The detailed evaluation of operator action OAF is given in the Human Reliability Analysis Notebook (Reference 6).

M. Isolation of Feedwater Flow to Ruptured SG (AFI)

This node includes the equipment to isolate feedwater flow to the ruptured SG. Specifically, this equipment includes the AFW flow regulating valves on the motor driven AFW pump line (FW0051, FW0053, FW0055, FW0057) and on the turbine driven AFW pump line (FW0050, FW0052, FW0054, FW0056). For feedwater to the SGs via the main feedwater pumps, the equipment includes the main feedwater flow regulating valve on each line (LCV-FW510, LCV-FW520, LCV-FW530, LCV-FW540) as well as the main feedwater bypass line flow regulating valve on each line (LCV-FW510A, LCV-FW520A, LCV-FW530A, LCV-FW540A). An evaluation of node AFI is given in the Auxiliary Feedwater Systems Notebook (Reference 4) for auxiliary feedwater control and the Miscellaneous Systems Notebook (Reference 7) for alternate feedwater control.

N. Operator Action to Perform RCS Cooldown via Steam Dump from Intact Steam Generators (ODS)

This node represents the operator action to initiate RCS cooldown via steam dump from the intact steam generators in order to attain a desirable level of subcooling in the RCS. The operator instructions for this action comes from Zion EOP E-3, Step 14: the operators are instructed to dump steam from the intact SGs via the condenser or atmospheric relief valves at maximum rate in order to attain a desirable level of subcooling in the RCS prior to the subsequent RCS depressurization step. Operator instruction for RCS cooldown is also provided in Zion EOP ECA-3.1, Step 8 for the cases in which isolation of steam flow from the ruptured SG fails and RCS cooldown is needed to achieve subcooling for the subsequent

ECCS reduction step. The detailed evaluation of operator action ODS is given in the Human Reliability Analysis Notebook (Reference 6).

O. Steam Dump from Intact SGs to Condenser or Atmosphere (DS)

This node is the action of the condenser steam dump valves or the atmospheric relief valves on the intact steam generators to function upon demand. The opening of either the condenser steam dump valves or the atmospheric relief valves permits depressurization of the steam generators and removes heat from the reactor coolant system. Success of AFW or alternate feedwater is necessary to permit SG depressurization (this equipment is covered by separate nodes). A detailed description of DS is provided in the Miscellaneous Systems Notebook (Reference 7).

P. Operator Action to Depressurize the RCS (ODP)

This node represents the operator action to depressurize the RCS via normal pressurizer spray (if the RCPs have not been tripped), one PORV or auxiliary spray. The purpose of this RCS depressurization is to equilibrate the primary and secondary pressures in order to terminate the primary to secondary break flow, and to recover level in the pressurizer for easier inventory control. Operator guidance for the RCS depressurization is given in Zion EOP E-3, Step 14f (if concurrent RCS cooldown and depressurization) or Step 18 (if separate RCS cooldown and depressurization).

The detailed evaluation of operator action ODP is given in the Human Reliability Analysis Notebook (Reference 6).

Q. RCS Depressurization with Pressurizer PORV (DP)

This node is the operation of one pressurizer PORV for RCS depressurization. As noted in Section 3.0, this RCS depressurization step does not consider normal pressurizer spray or auxiliary spray.

An evaluation of node DP, as defined above, is provided in the Miscellaneous Systems Notebook (Reference 7).

R. Operator Action to Reduce ECCS Injection (OIR)

This node represents the operator action to reduce the ECCS injection to no greater than one (1) high pressure injection pump (either 1 charging pump or 1 SI pump). For sequences in which the recovery actions of identification, isolation and RCS cooldown have been successful, the ECCS flow must be reduced as a necessary precursor to establishing normal charging. Normal charging (discussed later) is necessary for RCS inventory control and subsequent termination of the primary to secondary break flow (i.e., success end state). For sequences in which the charging pumps are not available or in which SG overfill occurs prior to ECCS reduction, the ECCS flow must be reduced to extend the time that the RWST will be available (i.e., SAM end state). [Recall that SG overfill is assumed to result in the consequential failure of a secondary safety valve to reclose, thereby necessitating continued ECCS injection.] Operator guidance to perform this ECCS reduction is provided in different procedures depending upon the specific path considered:

a) Zion EOP E-3, Steps 22 and 26 - ECCS flow is reduced to 1 charging pump following RCS cooldown and depressurization as a precursor to establishing RCS inventory control. Also, for cases in which charging pumps are not available or in which SG overfill has occurred, the ECCS pumps (typically 1 charging pump or 1 SI pump, as applicable) are restarted as necessary to maintain adequate RCS subcooling and pressurizer level.

b) Zion EOP ECA-3.3, Steps 11 and 14 - For the sequence in which there is no pressurizer pressure control (i.e., failure of ODP/DP), ECCS flow is reduced to 1 charging pump following RCS cooldown as a precursor to establishing RCS inventory control. Also, for cases in which charging pumps are not available or in which SG overfill has occurred, the ECCS pumps (typically 1 charging pump or 1 SI pump, as applicable) are restarted as necessary to maintain adequate RCS subcooling.

c) Zion EOP ECA-3.1, Steps 16, 20 and 21 - For the sequence in which steam flow from the ruptured SG cannot be isolated (i.e., failure of OAI/MSI), ECCS flow is reduced to 1 charging pump following RCS cooldown and depressurization as a precursor to establishing RCS inventory control. Also, for cases in which charging pumps are not available or in which SG overfill has occurred, the ECCS pumps (typically 1 charging pump or 1 SI pump, as applicable) are restarted as necessary to maintain adequate subcooling and pressurizer level.

d) Zion EOP ECA-3.2, Steps 11, 15 and 16 - For the sequence in which steam flow from the ruptured SG cannot be isolated (i.e., failure of OAI/MSI) in conjunction with high SG wide-range level or low RWST level, ECCS flow is reduced to 1 charging pump following RCS cooldown and depressurization as a precursor to establishing RCS inventory control. Also, for cases in which charging pumps are not available or in which SG overfill has occurred, the ECCS pumps (typically 1 charging pump or 1 SI pump, as applicable) are restarted as necessary to maintain adequate subcooling and pressurizer level.

The detailed evaluation of operator action OIR is provided in the Human Reliability Analysis Notebook (Reference 6).

S. Operator Action to Establish Normal Charging (ONC)

This node represents the operator action to initiate normal charging with the remaining charging pump. This action is undertaken following the successful operator action to reduce ECC injection to 1 charging pump. The operator must realign the charging pumps to their normal flow control alignment in order to permit RCS inventory control via throttling of flow; flow throttling capability is not possible with the charging pump aligned in the injection mode. The action to establish normal charging flow is necessary because continued ECC injection will result in the repressurization of the RCS and reinitiation of the primary to secondary break flow.

Note that letdown is not modeled in this node since the operator can control RCS inventory (pressurizer level) with only the normal charging throttling capability. Operator guidance for establishing normal charging is provided in several different procedures depending upon the specific path considered:

a) Zion EOP E-3, Step 24 - Normal charging flow is established as a necessary precursor to establishing RCS inventory control and eventually terminating the primary to secondary break flow.

b) Zion EOP ECA-3.3, Step 13 - For the sequence in which there is no pressurizer pressure control (i.e., failure of ODP/DP), normal charging flow is established as a necessary precursor to establishing RCS inventory control and eventually terminating the primary to secondary break flow.

The detailed evaluation of operator action ONC is provided in the Human Reliability Analysis Notebook (Reference 6).

T. Establish Normal Charging (NC)

This node represents the equipment necessary to realign normal charging flow. Refer to Zion EOP E-3 for normal charging components.

An evaluation of node NC is given in the ECCS Notebook (Reference 5).

U. Reactor Containment Fan Coolers (FC)

This node is the RCFCs which provide cooling for the containment atmosphere and can prevent automatic spray actuation for the scenario in which the pressurizer PORVs are opened for bleed and feed cooling. This node is included in the plant response tree since it can impact the time at which ECCS recirculation is required (i.e., whether operation of the RCFCs can prevent automatic containment spray injection). Also, the number of operating Fan Coolers will impact the containment pressure response for core damage sequences.

The Reactor Containment Fan Coolers Notebook provides a detailed description of this system (Reference 9).

V. Containment Spray Injection (CSI)

This node is Containment Spray during the ECC injection mode. CSI, when delivering water from the RWST, rapidly reduces the pressure in the containment atmosphere. CSI also scrubs the atmosphere of radionuclides, reducing the severity of the release if CSI is operating after core damage occurs. CSI will not prevent core damage or containment failure. Operation of the containment spray system after core damage can also provide for draining the RWST water inventory to the containment.

A detailed description of this system is provided in the Containment Spray Notebook (Reference 10).

W. Operator Action to Establish RHR Heat Exchanger Cooling (OHX)

This node represents the operator action to establish cooling to the RHR heat exchangers by opening the Component Cooling Water (CCW) valves from the RHR heat exchangers. This node is addressed for those plant response tree paths where the RHR heat exchangers are needed for heat removal during ECCS recirculation (bleed and feed). Operator guidance for establishing CCW to the RHR heat exchangers is provided in several procedures:

a) Zion EOP E-0, 'Reactor Trip or Safety Injections,' (Reference 1.12) Step 8 - The operators are instructed to provide CCW to the RHR heat exchangers if the RCS pressure is above the shutoff head of the RHR pumps,

b) Zion EOP ES-1.3, Step 4 - The operators are instructed to verify that CCW flow is directed to the RHR heat exchangers,

c) Zion EOP FR-H.1, Step 19 - The operators are instructed to provide CCW to the RHR heat exchangers after bleed and feed has been initiated.

The detailed evaluation of operator action OHX is given in the Human Reliability Analysis Notebook (Reference 6).

X. RHR Heat Exchanger (RHX)

This node is the equipment for RHR heat exchanger cooling and includes the CCW isolation valves to the RHR heat exchanger. A detailed description of RHX is given in the ECCS notebook (Reference 5).

Y. Operation Action to Establish ECC Recirculation (ORC)

This node is the operator action to establish high-pressure recirculation. This node is addressed for the FR-H.1 bleed and feed scenario since the operators will eventually be instructed to transfer to ES-1.3 due to low RWST level. This action includes aligning the ECCS system for low pressure recirculation and starting and stopping the RHR pumps, as directed by ES-1.3. Since high pressure recirculation is required for this event, this node also includes the operator actions to isolate the high pressure pump suction (charging pumps and/or SI pumps) from the RWST and align the RHR pump discharge to the high pressure pump suction.

The detailed evaluation of the operator action ORC is given in the Human Reliability Analysis Notebook (Reference 6).

Z. High Pressure Recirculation (HPR)

This node is the equipment for high pressure recirculation with either the charging pumps or the safety injection pumps, aligned to take suction from the RHR pumps. This node includes the components required to operate in the high pressure recirculation mode associated with the operator action ORC, including sump valves open, RWST suction valves to RHR pumps and high head pumps closed, RHR pumps restarted, and valves opening and closing to align the high pressure pumps to the RHR pumps. Note that operation of the low pressure injection (RHR) pumps is also necessary for success of HPR since it is the RHR pumps which take suction from the sump. HPR is required to maintain the plant in a long term stable condition during bleed and feed cooling.

A detailed description of HPR is given in the ECCS notebook (Reference 5).

AA. Operator Action to Refill the RWST (ORT)

This node represents the operator action to refill the RWST. If high pressure recirculation fails during bleed and feed cooling, the operators are instructed to transfer to ECA-1.1, 'Loss of Emergency Coolant

Recirculation,' (Reference 1.13) where RWST refill would be initiated. RWST refill will also be addressed for those event sequences in which the operators are instructed to begin bleed and feed, but the pressurizer PORVs will not open. In this case, low RWST level will result in operator transition to RWST refill since there would be no water in containment for recirculation. Finally, RWST refill is addressed for those paths in which SG overfill occurs and RWST refill is necessary to maintain RCS inventory.

The detailed evaluation of the operator action ORT is given in the Human Reliability Analysis Notebook (Reference 6).

BB. Refilling the RWST (RTK)

This node includes the components required to refill the RWST and continue ECCS injection associated with the operator action ORT. If the flow to refill the RWST is sufficient to match the injection flow from one of the ECCS pumps, then the reactor core would remain covered and core damage would be averted for a prolonged time.

A detailed description of the components required for node RTK is given in the ECCS notebook (Reference 5).

CC. Containment Isolation (CI)

This node is containment isolation. CI is not required for success of either core or containment cooling. Failure of CI, given core damage, will result in a release of fission products to the environment.

A detailed description of node CI is given in the Containment Isolation notebook (Reference 11).

3.2 Success Criteria

The Success Criteria Notebook (Reference 16) details the best estimate analyses and bases used to determine the combination of frontline systems necessary to define the success sequences on the plant response tree and the mission times required for each of the systems. A summary of the success criteria as detailed in the Success Criteria Notebook is provided in Table 1.

3.3 Operation Actions

The Zion Emergency Operating Procedures (Reference 1) provide the bases used to determine the operator actions that are included on the plant response tree model. The reactor trip and SI signal cause the operators to enter the EOPs at E-0, "Reactor Trip or Safety Injection". The operators would continue in E-0 and diagnose the event as a SGTR. Step 15 of E-0 would instruct the operators to transfer to E-3, "Steam Generator Tube Rupture". Upon exiting from E-0, the operators would then begin to monitor the Critical Safety Function Status Trees (CSFSTs). These status trees indicate degraded plant conditions that would require the operators to transfer to specific emergency procedures to implement further actions.

Six other EOPs are of interest for the SGTR event:

a. ECA-3.1, SGTR with Loss of Reactor Coolant - Subcooled Recovery;
b. ECA-3.2, SGTR with Loss of Reactor Coolant - Saturated Recovery;
c. ECA-3.3, SGTR without Pressurizer Pressure Control;
d. FR-H.1, Response to Loss of Secondary Heat Sink;

e. ES-1.3, Transfer to Cold Leg Recirculation;

f. ECA-1.1, Loss of Emergency Coolant Recirculation.

The ECA-3.1 procedure is implemented for a number of circumstances from E-3 including if a ruptured SG can not be isolated from the intact SGs, if the intact SGs can not be used for RCS cooldown, if a pressurizer PORV can not be closed, and loss of RCS subcooling. The ECA-3.2 procedure is typically implemented from ECA-3.1 due to low RWST level or high level in the ruptured SG. The ECA-3.3 procedure is implemented if pressurizer pressure control can not be established in E-3. If no auxiliary feedwater is available, then FR-H.1 is implemented; ES-1.3 would be implemented from FR-H.1 on low RWST level. Finally, the ECA-1.1 procedure would be implemented upon entry into ECA-3.2 or if ECCS recirculation can not be established in ES-1.3.

To a lesser extent, Zion EOPs FR-C.1 and FR-Z.1 were reviewed for the scenarios which lead to core damage and containment failure, respectively.

Based on a review of these EOPs (detailed in Appendix B), the following operator actions are identified and included on the plant response tree:

- The operators diagnose, identify and isolate the ruptured steam generator by stopping steam flow from, and feedwater flow to, this generator (OAI & OAF/E-3).

- The operators initiate an RCS cooldown by dumping steam from the intact steam generators in order to achieve a desirable level of subcooling in the RCS (ODS/E-3 or ECA-3.1).

- The operators initiate an RCS depressurization via normal pressurizer spray, one pressurizer PORV or auxiliary pressurizer spray in order to stop or reduce the primary to secondary break flow and to recover pressurizer level (ODP/E-3).

- The operators reduce ECCS injection to no greater than one high pressure injection pump (either 1 charging pump or 1 SI pump) as either a precursor to establishing normal charging flow or to extend the ECCS injection time (OIR/E-3, ECA-3.3, ECA-3.1 or ECA-3.2).

- The operators establish normal charging flow with the remaining charging pump for RCS inventory control; this will prevent repressurization of the RCS and reinitiation of the primary to secondary break flow (ONC/E 3 or ECA-3.3).

- For the scenario in which AFW is not available, the operators attempt to initiate alternate feedwater via the main feedwater pumps (ORF/FR-H.1).

- For the scenario in which AFW is not available, the operators initiate bleed and feed cooling by opening at least one pressurizer PORV (OBL/FR-H.1). Note that although FR-H.1 instructs the operators to open both pressurizer PORVs, MAAP analyses (Reference 16) indicate that 1 out of 2 pressurizer PORVs will be sufficient for bleed and feed.

- The operators align component cooling water to the RHR heat exchangers for decay heat removal during ECCS recirculation (OHX/E-0, FR-H.1 or ES-1.3).

- If cold leg recirculation is required, the operators align the ECCS systems for recirculation to provide long term RCS inventor control and decay heat removal (ORC/ES-1.3).

- If needed, the operators refill the RWST to provide a continued source of water for ECCS injection (ORT/ECA-1.1).

The times available to accomplish each of these operator actions are documented in the Success Criteria notebook. These times are listed in Table 2.

TABLE 1 (Page 1 of 4)

STEAM GENERATOR TUBE RUPTURE SUCCESS CRITERIA

PLANT RESP. TREE NODE	NODAL DEPENDENCIES	SUCCESS CRITERIA	OPERATOR ACTIONS	MISSION TIME
Auxiliary Feed-water Injection (AFW)	None	1 out of 3 pumps injecting to 4 out of 4 SGs -OR- 1 out of 3 pumps injecting to 3 out of 4 SGs with operator action to open throttle valves[1]	Verification	6 hours
Refueling Water Storage Tank (TK)	None	≥ 224,890 gallons; ≥ 1700 ppm boron	Verification	24 hours
Charging Pump Injection (CCP)	AFW-Failed TK-Success	1 out of 2 pumps injecting to 2 out of 4 cold legs	Verification	6 hours
SI Pump Injection (SIP)	AFW-Failed TK-Success CCP-Failed	1 out of 2 pumps injecting to 2 out of 4 cold legs	Verification	6 hours

Note 1: Operator Action to open throttle valves modeled in AFW fault tree (Reference 4).

STEAM GENERATOR TUBE RUPTURE SUCCESS CRITERIA

PLANT RESP. TREE NODE	NODAL DEPENDENCIES	SUCCESS CRITERIA	OPERATOR ACTIONS	MISSION TIME
Alternate Feed-water Injection (ALT)	AFW-Failed ORF-Success	1 out of 3 MFW pumps injecting to 1 out of 4 SGs	Align MFW and CB pumps (ORF); Stop RCPs	6 hours
RCS Bleed with Pressurizer PORVs (BL)	AFW-Failed ORF/ALT-Failed CCP or SIP-Success OBL-Success	1 out of 2 Pressurizer PORVs	Depressurize RCS for Bleed & Feed (OBL)	24 hours
Isolation of Steam Flow from Ruptured Steam Generator (MSI)	OAI-Success	1 out of 1 MSIVs on ruptured SG; or 3 out of 3 MSIVs on intact SGs	Close MSIV(s) (OAI)	24 hours
Isolation of Feed Flow to Ruptured Steam Generator (AFI)	OAF-Success	1 out of 1 AFW flow reg valve from MD pump and 1 out of 1 AFW flow reg valve from TD pump to ruptured SG; or 1 out of 1 MFW flow reg valve to ruptured SG	Close AFW reg valves to ruptured SG; or close MFW reg valve to ruptured SG (OAF)	24 hours
RCS Cooldown (DS)	AFW-Success or ORF/ALT-Success; ODS-Success	2 out of 3 intact SG ARVs or 2 out of 3 steam dump valves	Depressurize SGs to achieve ~40°F RCS cooldown (ODS)	6 hours
RCS Depressurization (DP)	None	Normal pressurizer spray; or 1 out of 2 pressurizer PORVs; or auxiliary pressurizer spray	Depressurize RCS to terminate break flow (ODP)	24 hours (see BL)

STEAM GENERATOR TUBE RUPTURE SUCCESS CRITERIA

PLANT RESP. TREE NODE	NODAL DEPENDENCIES	SUCCESS CRITERIA	OPERATOR ACTIONS	MISSION TIME
Normal Charging (NC)	OIR-Success TK-Success CCP-Success	1 of 2 charging pumps aligned for normal charging	Reduce ECCS pumps (OIR), Establish Normal charging (ONC)	18 hours
Reactor Containment Fan Coolers to Prevent CSI (FC)	AFW-Failed OBL/BL-Success	2 out of 5 fan coolers	Verification	24 hours
Reactor Containment Fan Coolers to Remove Decay Heat (FC)	AFW-Failed OBL/BL-Success OHX/RHX-Failed ORC/HPR-Success	1 out of 5 fan coolers	Verification	24 hours
Reactor Containment Fan Coolers to Prevent Containment Failure (FC)	None	1 out of 5 fan coolers	Verification	24 hours
Containment Spray Injection (CSI)	<2 FCs	1 out of 2 MD pumps; or 1 out of 1 diesel pump	Verification	2.4 hours
RHR Heat Exchanger to prevent core damage (RHX)	AFW-Failed OBL/BL-Success 0 FCs OHX-Success ORC/HPR-Success	1 out of 2 RHR Hx in train with an operating RHR pump	Align CCW to RHR Hx (OHX)	18 hours

STEAM GENERATOR TUBE RUPTURE SUCCESS CRITERIA

PLANT RESP. TREE NODE	NODAL DEPENDENCIES	SUCCESS CRITERIA	OPERATOR ACTIONS	MISSION TIME
High Pressure Recirculation (HPR)	AFW-Failed OBL/BL-Success ORC-Success	1 out of 2 SI pumps or 1 out of 2 charging pumps to 2 out of 4 cold legs	Align SI/Charging pump for suction from RHR; align RHR pump to sump (ORC)	18 hours
Refilling the RWST (RTK)	ORT-Success	Refill flow ≥ 400 gpm w/ bleed and feed; ≥ 500 gpm if no bleed and feed	Align charging pump to refill RWST	18 hours
Containment Isolation (CI)	None	All lines > 2 inches isolated	Verification	24 hours

TABLE 2 (Page 1 of 4)

OPERATOR ACTION TIMES

OPERATOR ACTION	TIME AVAILABLE	CONDITIONS	GOAL
Align Alternate Feedwater (ORF)	25 minutes	AFW-Failed All ECCS	Return to E-3, terminate breakflow prior to SG overfill
	2 hours	AFW-Failed No ECCS	
Align Alternate Feedwater (ORF)	2 hours	AFW-Failed All ECCS	Avoid bleed & feed cooling per FR-H.1
	1.5 hours	AFW-Failed 1 CCP	
Depressurize RCS for Bleed and Feed (OBL)	10 hours	AFW-Failed ORF/ALT-Failed CCP-Success or AFW-Failed CCP-Failed SIP-Success	Bleed and Feed Cooling
Isolate Steam Flow from Ruptured SG (OAI)	20 minutes	AFW-Success or ORF/ALT-Success; CCP-Success	Pressure/Temperature differential between ruptured & intact SGs
Isolate Steam Flow from Ruptured SG (OAI)	10 hours	AFW-Success or ORF/ALT-Success; CCP-Failure SIP-Failure	Equilibrate RCS pressure with ruptured SG pressure

TABLE 2 (Page 2 of 4)
OPERATOR ACTION TIMES

OPERATOR ACTION	TIME AVAILABLE	CONDITIONS	GOAL
Isolate Feed Flow to Ruptured SG (OAF)	20 minutes	AFW-Success or ORF/ALT-Success; CCP-Success OAI/MSI-Success	Limit addition of mass to ruptured SG thereby prolong time to SG overfill
Cooldown RCS (ODS)	25 minutes	AFW-Success or ORF/ALT-Success; CCP-Success OAI/MSI-Success OAF/AFI-Success	Establish adequate RCS subcooling for ECCS Reduction prior to SG overfill
Cooldown RCS (ODS)	≤ 1 hour	AFW-Success or ORF/ALT-Success; CCP-Failure, SIP-Success - OR - AFW-Success or ORF/ALT-Success; CCP-Success OAI/MSI-Failed or OAF/AFI-Failed	Establish adequate RCS subcooling for ECCS Reduction after SG overfill
Depressurize RCS (ODP)	40 minutes	AFW-Success or ORF/ALT-Success; CCP-Success OAI/MSI-Success OAF/AFI-Success ODS/DS-Success	Terminate break flow; Establish przr level
Reduce ECCS Injection (OIR)	52 minutes	AFW-Success or ORF/ALT-Success; CCP-Success OAI/MSI-Success OAF/AFI-Success ODS/DS-Success ODP/DP-Success	Prevent RCS repressurization and reinitiation of breakflow
	45 minutes	AFW-Success or ORF/ALT-Success; CCP-Success OAI/MSI-Success OAF/AFI-Success ODS/DS-Success ODP/DP-Failed	

OPERATOR ACTION TIMES

OPERATOR ACTION	TIME AVAILABLE	CONDITIONS	GOAL
Reduce ECCS Injection (OIR)	≤ 1 Hour	AFW-Success or ORF/ALT-Success; CCP-Success ODS/DS-Success OAI/MSI-Failed or OAF/AFI-Failed -OR- AFW-Success or ORF/ALT-Success; CCP-Failed SIP-Success ODS/DS-Success	Extend time of RWST availability for ECCS Injection following SG Overfill
Establish Normal Charging (ONC)	52 minutes	AFW-Success or ORF/ALT-Success; CCP-Success OAI/MSI-Success OAF/AFI-Success ODS/DS-Success ODP/DP-Success	Control of RCS inventory (i.e., pressurizer level) as precursor to to terminating primary to secondary break flow
	45 minutes	AFW-Success or ORF/ALT-Success; CCP-Success OAI/MSI-Success OAF/AFI-Success ODS/DS-Success ODP/DP-Failed	
Align RHR Heat Exchangers (OHX)	15 hours	AFW-Failed ORF/ALT-Failed CCP or SIP-Success OBL/BL-Success 0 FCs	Decay Heat removal during ECCS recirculation

TABLE 2 (Page 4 of 4)

OPERATOR ACTION TIMES

OPERATOR ACTION	TIME AVAILABLE	CONDITIONS	GOAL
Align for High Pressure Recirculation (ORC)	3 hours	AFW-Failed ORF/ALT-Failed CCP or SIP-Success OBL/BL-Success CSI-Success	Continue core cooling via high pressure recirculation
	7 hours	AFW-Failed ORF/ALT-Failed CCP or SIP-Success OBL/BL-Success CSI-Failed	
Initiate RWST Refill (ORT)	14 hours	OBL/BL-NA or Failed	Continue core cooling via RWST refill
	3 hours	OBL/BL-Success CSI-Success	
	7 hours	OBL/BL-Success CSI-failed	

4.0 FUNCTIONAL REQUIREMENTS

The nodes modeled on the SGTR plant response tree address the following functional requirements:

1. Initial Inventory Control

    - Refueling Water Storage Tank (TK)
    - High Pressure Injection (CCP & SIP)
    - Operator Actions to Terminate Break Flow Before SG Overfill

        - Isolate Ruptured SG (OAI/MSI, OAF/AFI)
        - RCS Cooldown (ODS/DS)
        - RCS Depressurization (ODP/DP)
        - ECCS Reduction (OIR)
        - Establish Normal Charging (ONC/NC)

2. Long Term Inventory Control

    - ECCS Reduction (OIR)
    - High Pressure Recirculation (ORC/HPR)
    - RWST Refill (ORT/RTK)

3. Core Heat Removal

    - Auxiliary Feedwater (AFW)
    - Alternate Feedwater (ORF/ALT)
    - Bleed and Feed (OBL/BL)

4. Containment Heat Removal

- RHR Heat Exchanger Cooling (OHX/RHX) during High Pressure Recirculation
- Reactor Containment Fan Coolers (FC)

5. Containment Integrity

- Containment Isolation

It is noted that the containment spray node is modeled in order to address the timing of RWST depletion plus fission product scrubbing following core damage. Containment spray also provides a means of ex-vessel debris cooling following core damage.

5.0 SEQUENCE IDENTIFIERS

An identifier is assigned to each plant response tree sequence. If the end state results in a safe, stable plant configuration as defined in the success criteria notebook with no additional long term operator actions or system actuations required, the sequence is labeled as success (SCS). If additional activities (accident management) are required beyond 24 hours, the sequence is labeled as success with accident management (SAM). Core damage sequences are further identified to describe the unique core and containment response characteristics determined by the combinations of success and/or failure of the nodes. These core damage identifiers are used as an intermediate step so that the source term/release categories can be assigned. The plant state sequence identifiers are described with four designators as follows:

First designator: initiating event behavior

Second designator: core damage timing

Third designator: functional failures resulting in core melt and disposition of the RWST inventory

Fourth designator: source term including containment failure definition.

These designators are discussed in more detail in the following paragraphs.

1. The first designator identifies the type of initiating event behavior:

   R = Steam Generator Tube Rupture

2. The second designator identifies the estimated time that core damage occurs.

   E = Early core damage (i.e., occurs within 0 - 2 hours of initiation of event).

   The timing for 'early' core damage of less than 2 hours was chosen primarily for accident management purposes. Specifically, it is felt that any sequences in which core damage occurs within the first two hours of the event would not benefit by any accident management strategies. Any improvements for these type of sequences would need to be reflected in updated procedures or operating training, for example. Additionally, it is noted that there would be relatively little fission product decay during this time period, thus resulting in a large source term release.

I = Intermediate core damage (i.e., occurs within 2 - 6 hours of initiation of event).

The timing for 'intermediate' core damage was chosen primarily for accident management purposes. For the 2-6 hour interval in which core damage would occur, it is felt that some limited accident management strategies would be beneficial and should be investigated; however no offsite support could be credited. An example of this would include local operator actions for event mitigation. Additionally, although some fission product decay would occur during the time period considered, the source term would still remain relatively high.

L = Late core damage (i.e., occurs within 6 - 24 hours of initiation of event).

The timing for 'late' core damage was chosen primarily for accident management purposes. For times greater than 6 hours, there is a high probability that the offsite support groups would be available and accident management strategies could be effectively implemented. Examples include directives from TSC, operator actions for ex-vessel debris cooling, etc.

3. The third designator is a number that identifies the failure of key functions. The key functions are those whose failure causes the core melt and/or affects the disposition of RWST water. The identification of the functional failure that caused the core melt is important in determining which systems merit attention for accident management development. The identification of the disposition of RWST water is important in

determining whether vessel failure after core melt can be prevented via external vessel flooding. If the vessel does fail, the disposition of RWST water is important in determining the extent of core debris cooling and fission product scrubbing via sprays or via a water layer over the debris.

Given the success of certain functions, the status of other functions are not important and therefore, are not indicated. For example, if high pressure injection is successful, the status of low pressure injection is not important (for injection) because it is not needed to keep the core from melting and it is not needed to inject the RWST water into the containment. The case of high pressure injection successful and low pressure injection failed will be identified as the failure of recirculation.

If high pressure injection fails, then the status of low pressure injection is important. Therefore, the ECCS injection failures are broken down into high pressure injection fails and all injection fails.

1 = Reactivity control fails
(CSI is successful)

The failure of reactivity control causes the core melt (failure of reactivity control is defined as the failure of the control rods to insert to trip the reactor and/or the failure of the control rods and other systems to maintain the core in a subcritical condition following reactor trip). The CSI system injects the RWST inventory into the containment for debris cooling, and fission product scrubbing. The status of the ECCS injection system is not important since the RWST inventory is injected via the containment sprays.

2 = Reactivity control fails, CSI fails
(ECCS injection is successful)

The failure of reactivity control causes the core melt. The failure of the CSI system means that ECCS injection is required to inject the RWST inventory into the containment for debris cooling and fission product scrubbing (the fission product scrubbing will be different then if the sprays had actuated). There is no need to delineate between high pressure injection and low pressure injection since the RCS pressure will be close to containment pressure following vessel failure. The different rates of injection between HPI and LPI do not significantly affect the results.

3 = Reactivity control fails, all ECCS injection fails, CSI fails

The failure of reactivity control causes the core melt. The failures of all ECCS and containment spray injection means that there will be no RWST inventory injected to the containment. The water inventory available for debris cooling and fission product scrubbing will be limited to the reactor coolant system inventory (including the accumulator inventories if injected) that gets to containment through the failed vessel.

4 = High Pressure ECCS injection fails
(CSI is successful)

The failure of the high pressure injection system to inject water to the RCS causes the core melt. The failure is due either to a system failure or to the RCS pressure limiting the amount of injection to less than that required to prevent core melt. The CSI system injects the RWST inventory into the containment for debris cooling and fission product scrubbing. The status of the ECCS injection systems is not important since the RWST inventory is injected via the containment sprays.

5 = High pressure ECCS injection fails and CSI fails
(High pressure injection and/or Low pressure ECCS injection are/is successful after vessel failure)

This scenario is the same as '4' except that containment spray injection has also failed. After vessel failure the RCS pressure drops and either high pressure (if the system hasn't failed) or low pressure injection or both inject the RWST inventory into containment. Fission product scrubbing will be different than for case 4 since containment spray injection has failed.

6 = All ECCS injection fails
(CSI is successful)

In this instance, there is no ECCS injection and no recirculation (low pressure or high pressure). The operation of the containment sprays will inject the RWST contents into the containment and either prevent the vessel from failing or accomplish ex-vessel core debris cooling and fission product scrubbing following vessel failure.

7 = All ECCS injection fails and CSI fails

This scenario is the same as '6', except that the RWST would not be injected into the containment and thus the vessel will fail. The water inventory available for debris cooling and fission product scrubbing will be limited to the reactor coolant system inventory (including the accumulator inventories if injected) that gets to containment through the failed vessel.

8 = ECCS recirculation fails
(ECCS injection is successful, CSR is successful)

In this instance, there is ample injection early in the event to maintain core cooling; however, ECCS recirculation (either high pressure or low pressure or both) fails and core cooling is lost following RWST depletion. [NOT USED FOR ZION]

9 = ECCS recirculation fails, CSR fails

This scenario is the same as '8' except that containment spray recirculation fails which affects fission product scrubbing.

O = ECCS recirculation fails due to containment failure

Most of the cases where ECCS injection and recirculation have been successful will result in either a success (SCS) state or a success with accident management (SAM) state. However, if heat is not being removed from containment, late containment failure can occur followed by core damage. The mechanism for core damage after containment failure is the flashing of water in the RHR pump suction due to the sudden depressurization of containment. This flashing/voiding of injection water is assumed to result in failure of the RHR pumps thereby leading to loss of ECCS recirculation and subsequent core damage.

4. The fourth designator addresses the timing and magnitude of fission product releases for severe accident sequences. It also implicitly includes the containment heat removal function and containment failure modes as it incorporates impaired containment (bypass or isolation failure) as well as containment failures (early or late) due to severe accident containment loadings.

   The designator of 'A' implies that no containment failure is predicted within the 48 hour mission time used for sequence quantification but containment failure could occur if no recovery actions were taken. Accident management actions have failed to prevent core damage, but are successful to prevent containment failure.

   The combinations of containment failure timing and fission product release magnitudes are addressed by the following designators:

A - No containment failure within 48 hour mission time but failure could eventually occur without accident management action; noble gases and less than 1/10% volatiles released.

B - Containment bypassed with noble gases plus less than 1/10% of the volatiles released.

C - Containment bypassed with noble gases plus up to 1% of the volatiles released.

D - Containment bypassed with noble gases and up to 10% of the volatiles released.

E - Containment failure prior to vessel failure with the noble gases and less than 1/10% of the volatiles released (containment not bypassed; containment isolation impaired or isolation successful but late containment failure).

F - Containment failure prior to vessel failure with noble gases and up to 1% of the volatiles released (containment not bypassed; containment isolation impaired or isolation successful but late containment failure).

G - Containment failure prior to vessel failure with noble gases and up to 10% of the volatiles released (containment not bypassed; containment isolation impaired or isolation successful but late containment failure).

H - Early containment failure with the noble gases and less than 1/10% volatiles released (containment failure at or immediately after vessel failure; containment not bypassed; isolation successful).

I - Early containment failure with noble gases and up to 1% of the volatiles released (containment failure at or immediately after vessel failure; containment not bypassed; isolation successful).

J - Early containment failure with noble gases and up to 10% of the volatiles released (containment failure at or immediately after vessel failure; containment not bypassed; isolation successful).

K - Late containment failure with noble gases and less than 1/10% volatiles released (containment failure approximately 8 hours or longer after vessel failure; containment not bypassed; isolation successful).

L - Late containment failure with noble gases and up to 1% of the volatiles released (containment failure approximately 8 hours or longer after vessel failure; containment not bypassed; isolation successful).

M - Late containment failure with noble gases and up to 10% of the volatiles released (containment failure approximately 8 hours or longer after vessel failure; containment not bypassed; isolation successful).

N - Late containment failure with noble gases and up to 1% of the volatiles and up to 1/10% of the non-volatiles released (containment failure approximately 8 hours or longer after vessel failure; containment not bypassed; isolation successful).

S - No containment failure (leakage only, successful maintenance of containment integrity; containment not bypassed; isolation successful).

T - Containment bypassed with noble gases and up to 50% of the volatiles released.

6.0 PLANT RESPONSE TREE MODEL

The nodes for the plant response tree are:

SGTR1	SGTR Initiator
AFW	Auxiliary Feedwater
TK	Refueling Water Storage Tank
CCP	ECCS Injection Using the Centrifugal Charging Pump(s)
SIP	ECCS Injection Using the Safety Injection Pump(s)
ORF	Operator Action to Establish Alternate Feedwater
ALT	Alternate Feedwater to Steam Generators
OAL	Operator Action to Initiate Bleed and Feed
BL	RCS Bleed via Two Pressurizer PORVs
OAI	Operator Action to Isolate the Ruptured SG
MSI	Closure of Ruptured SG MSIV (and associated steam paths) OR Closure of Intact SGs MSIVs (and associated steam paths)
OAF	Operator Action to Isolate Feedwater Flow to Ruptured SG

AFI	Closure or Throttling of Feedwater Pump(s) Discharge Valve(s)
ODS	Operator Action to Initiate RCS Cooldown via Intact SGs
DS	RCS Cooldown via Steam Dump from Intact SGs (to condenser or atmosphere)
ODP	Operator Action to Depressurize the RCS
DP	RCS Depressurization via Normal Pressurizer Spray OR Pressurizer PORV OR Auxiliary Pressurizer Spray
OIR	Operator Action to Reduce ECCS Injection
ONC	Operator Action to Establish Normal Charging
NC	Realign Centrifugal Charging Pumps to VCT for Normal Charging
FC	Reactor Containment Fan Coolers
CSI	Containment Spray Injection
OHX	Operator Action to Establish RHR Heat Exchanger Cooling
RHX	RHR Heat Exchanger
ORC	Operator Action to Establish ECCS Recirculation
HPR	High Pressure Recirculation
ORT	Operator Action to Refill the RWST
RTK	RWST Refill
CI	Containment Isolation

TREE SGTR-1: INITIAL ACTIONS

TREE SGTR-1 shows the nodes for the initial response to the SGTR event.

Following reactor trip and/or safety injection, Zion EOP E-0 addresses the availability of auxiliary feedwater (AFW). If AFW succeeds, the following nodes address the availability of the RWST (TK) and subsequently high pressure injection via the centrifugal charging pumps (CCP) or the safety injection pumps (SIP). Although high pressure safety injection flow is desirable for a SGTR, the failure to inject any SI water (due to failure of TK, or CCP/SIP) may not result in a detrimental end state. This will be discussed subsequently.

Following the verification of AFW and high pressure safety injection the Zion EOPs instruct the operators to diagnose the cause of the reactor trip and/or safety injection. The presence of a SGTR may be identified by rising level in one SG, steamline radiation or blowdown radiation. Following the diagnosis of a SGTR event (included in OAI), the operators will transition to E-3 and perform a series of actions. Once the steam generator with the ruptured tube has been identified, the E-3 procedure instructs the operators to isolate steam flow from, and feedwater flow to, the ruptured SG (OAI and OAF, respectively). Steam flow from the ruptured SG is isolated by closing the MSIV on the ruptured SG or by closing the MSIVs on the intact SGs (MSI). Isolation of feedwater flow to the ruptured SG is accomplished by closing the auxiliary and main feed regulating valve(s) (AFI). Once steam flow from and feedwater flow to the ruptured SG have been isolated, the procedures instruct the operator to perform an RCS cooldown by dumping steam from the intact steam generators at maximum rate (ODS). The steam dump may be accomplished via the condenser steam dump valves or the atmospheric relief valves (DS). The RCS cooldown will provide a pressure and temperature differential between the ruptured and intact SGs as a necessary precursor to the next operator action. Following the RCS cooldown, the procedures next instruct the operators to depressurize the RCS in order to restore level to the pressurizer (i.e., inventory control) and if possible, equilibrate the primary and secondary pressures thereby terminating the break flow through the ruptured tube (ODP). This RCS depressurization may be performed with normal pressurizer spray (if RCPs are not tripped), pressurizer PORV or auxiliary spray (DP). Once the primary and secondary pressures have equilibrated (or nearly equilibrated), the next operator action is to reduce the ECCS flow to 1 charging pump (OIR). The injection flow must be reduced in order to limit any RCS re-pressurization (and reinitiation of primary to secondary break flow) and as a necessary precursor to termination of the break flow. The final operator action is to align the charging pump flow for normal charging so that throttling capability is available for RCS inventory control (ONC). The equipment for this step involves the valve alignment for normal charging flow (NC). If these steps can be completed and RCS inventory control established prior to overfill of the SG, then the end state is success.

For the scenario in which the operator actions to cooldown (ODS/DS) and depressurize (ODP/DP) the RCS are successful, ECCS reduction to 1 charging pump (OIR) is accomplished, but normal charging (ONC/NC) cannot be established prior to SG overfill, the end state is Success with Accident Management (SAM). The reduction of ECCS will extend the RWST availability following SG overfill (and the consequential failure to close of a safety valve) such that no core damage will occur for the first 24 hours (Reference 16).

For the sequence in which the operator action to cooldown (ODS/DS) and depressurize (ODP/DP) the RCS are successful but ECCS reduction (OIR) fails, SG overfill will occur and the path is transferred to TREE SGTR-2 (RWST REFILL). Recall that SG overfill results in the consequential failure of a safety valve to reseat; the continual primary to secondary pressure differential results in continued primary to secondary break flow through the ruptured tube. The inability to terminate the break flow and establish RCS inventory control dictates the necessity for continued ECCS injection to ensure core cooling. Since ECCS recirculation is not possible, the ECCS flow must be reduced or RWST refill must be accomplished (Section 3.0). Per definition of this particular sequence, ECCS reduction has failed; therefore RWST refill must be accomplished for continued core cooling. It is noted that although the operator would be directed to actions in ECA-3.1 or ECA-3.2 following SG overfill which provide instructions to sequentially terminate the ECCS pumps, it is assumed that since this action has already failed via E-3, the operators would not be able to succeed in ECA-3.1 or ECA-3.2 either (Section 3.0).

For the case in which pressurizer pressure control (ODP/DP) cannot be established, the operators will transition to ECA-3.3. Here, the operators will be instructed to reduce ECCS injection (OIR) and establish normal charging flow (ONC/NC) if the ruptured SG narrow range level exceed 70%. Success of establishing RCS inventory control in this instance will also result in a safe, stable state and a 'success' end state. Analogous to the path in which RCS depressurization succeeds, the path in which pressurizer pressure control fails, ECCS reduction succeeds but normal charging cannot be established, the end state is Success with Accident Management (SAM). Similarly, the path in which pressurizer pressure control fails and ECCS reduction fails, the path is transferred to TREE SGTR-2 (RWST REFILL).

For any scenario in which no intact SG is available for RCS cooldown (ODS/DS), the path is transferred to TREE SGTR-2 to address RWST refill. As noted in Section 3.0, RCS cooldown via the ruptured SG is not considered; the inability to perform an RCS cooldown results in SG overfill since a lack of subcooling will prevent reduction of ECCS flow. Additionally, the inability to reduce ECCS flow following SG overfill necessitates RWST refill for continued core cooling.

For those sequences in which feedwater to the ruptured SG cannot be stopped (OAF/AFI), SG overfill will occur. Regardless of feedwater isolation, the operators are instructed to perform an RCS cooldown (ODS/DS) and establish RCS inventory control via ECCS reduction (OIR) and establishing normal charging flow (ONC/NC). These instructions may be in E-3, or in ECA-3.1 or ECA-3.2 following SG overfill. Success of RCS cooldown and ECCS reduction will extend the RWST availability such that no core damage will occur for the first 24 hours; thus the end state for this path is Success with Accident Management (SAM). Failure of RCS cooldown or ECCS reduction results in path transfer to SGTR-2 (RWST REFILL) to address the capability to continue ECCS injection via refill of the RWST.

For the scenario in which the ruptured SG cannot be isolated from the intact SGs (OAI/MSI), the operators will be instructed to transition to ECA-3.1 to complete the actions. However, it is assumed that the additional timing involved in this sequence will result in the overfill of the ruptured SG. The ECA-3.1 procedure instructs the operators to perform an RCS cooldown (ODS/DS) and reduce ECCS (OIR). Success of RCS cooldown and ECCS reduction will extend the RWST availability such that no core damage will occur for the first 24 hours; thus the end state for this path is Success with Accident Management (SAM). Failure of RCS cooldown or ECCS reduction results in path transfer to SGTR-2 (RWST REFILL) to address the capability to continue ECCS injection via refill of the RWST.

For those scenarios in which high pressure injection is available with the SI pumps only (CCP fails, SIP success), a successful end state cannot be achieved since normal charging (ONC/NC) cannot be established. Therefore, RCS cooldown (ODS/DS) and ECCS reduction (OIR) are addressed. If RCS cooldown is successful and the ECCS flow reduced to 1 SI pump, the RWST availability is extended such that no core damage occurs for the first 24 hour; thus the end state for this path is Success with Accident Management (SAM). Failure of RCS cooldown or ECCS reduction results in core damage; in these cases an end state is assigned.

For the cases in which AFW is available but high pressure injection (CCP and SIP) fails, the RCS pressure will decrease to near the secondary pressure, ultimately resulting in the reduction of the primary to secondary break flow. If steam flow from the ruptured SG is stopped by isolating that SG (OAI/MSI), the RCS and ruptured SG pressure will equilibrate and the SGTR flow will be stopped. Provided that feedwater flow control is provided (OAF/AFI), primary to secondary heat removal is provided by the steam generators and the plant will be in an equilibrium condition (albeit saturated). Long term actions include RCS cooldown and depressurization to cold shutdown conditions. Since the break flow has been terminated and the steam generators are providing heat transfer capability, this scenario will be considered Success with Accident Management (SAM). If isolation of the ruptured SG cannot be completed, a small delta-P across the ruptured tube will exist thereby resulting in continued primary to secondary break flow. This break flow will eventually drain the RCS to the level of the ruptured tube (i.e., top of tube sheet), and the lack of water in the primary side of the steam generator tubes will result in degraded primary to secondary heat transfer and eventual core damage. In this case, the path is transferred to SGTR-4 (CORE DAMAGE) to address the availability of containment spray (CSI).

For the case in which AFW is available but the RWST (TK) fails, successful isolation of steam flow from (OAI/MSI) and feed flow to (OAF/AFI) the ruptured SG will result in an end state of Success with Accident Management. The logic is identical to that discussed in the proceeding paragraph. However, failure of either of these isolation steps will result in core damage; an end state is assigned on this tree since the failure of the RWST results in the failure of the containment sprays.

For those cases in which AFW flow cannot be verified via the instructions in E-0, the operators will be instructed to transition to FR-H.1, Loss of Secondary Heat Sink. Once in FR-H.1, the operators verify operability of at least one centrifugal charging pump (TK and CCP). If TK and CCP are successful, the procedures instruct the operator to establish an alternate feedwater source to the steam generators (ORF). As the event progresses, level will return to the ruptured SG due to the primary to secondary break flow regardless if alternate feedwater is established. Based on a level check in any SG, the operator will be instructed to transition back to E-0 due to level indication in the ruptured SG. However, since the intent of the 'level check' step(s) in FR-H.1 is to verify feedwater to the SGs, and since the level return is not due to the establishment of any auxiliary feedwater or alternate feedwater, the operator may remain in FR-H.1. Thus, the path would continue based on FR-H.1 procedures.

If the operator does transfer back to E-0, the operators will subsequently return to FR-H.1 due to monitoring of the Critical Safety Function Safety Trees, specifically loss of heat sink indication (no level in any SGs and no auxiliary/alternate feedwater flow). Consider the transfer back to E-0. Following identification of the SGTR in E-0, the operators will begin a series of actions in E-3 including RCS cooldown, as discussed above. However, the lack of AFW flow to the intact SGs will limit the cooldown via the intact SGs and force the operators to transition to ECA-3.1 or result in the operators using the ruptured SG for RCS cooldown since it is the only available heat sink, based on level indication. The primary to secondary break flow is not sufficient to keep up with the steam production in the ruptured SG during RCS cooldown and the level subsequently decreases in the ruptured SG. Once level is lost in all SGs, the operators will return to FR-H.1 via the CSFSTs. Thus, in either case the operators continue via FR-H.1.

As noted, the next major action in FR-H.1 for the scenario in which AFW has failed, but CCP is available, is the attempt to establish an alternate source of feedwater (ORF/ALT). Success of alternate feedwater results in transition back to E-0 and subsequent transition to E-3 since there is now feedwater available for a RCS cooldown. If a source of alternate feedwater cannot be established, the operators are instructed to initiate bleed and feed cooling by opening both pressurizer PORVs (OBL/BL). Success of this node results in initiation of bleed and feed cooling, and since no heat sink exists, the operators will continue bleed and feed cooling until RWST depletion forces transition to ES-1.3, Transfer to Cold Leg Recirculation. This results in a path transfer from TREE SGTR-1 to TREE SGTR-3 (BLEED & FEED). Failure of OBL/BL results in path transfer to TREE SGTR-2 (RWST REFILL) since there would be no water in containment available for recirculation and RWST refill would be the only means of continuing decay heat removal.

Should the charging pumps be unavailable once the operators are in FR-H.1, the operators will be instructed to verify that at least one safety injection pump (SIP) is available, and if so to immediately begin 'bleed and feed' cooling by opening both pressurizer PORVs (OBL/BL). This RCS depressurization enables ECCS water to be injected to the RCS via the safety injection pumps; it is further noted that the rapid RCS depressurization caused by the opening of the PORVs results in RCS/secondary pressure equilibration and break flow termination. Since further efforts to establish alternate feedwater are not modeled (Section 3.0), the operators will remain in FR-H.1 and continue bleed and feed cooling until depletion of the RWST results in transition to ES-1.3, Transfer to Cold Leg Recirculation. This scenario is modeled as a path transfer from TREE SGTR-1 to TREE SGTR-3 (BLEED & FEED). Failure of OBL/BL results in core damage for these sequences since RWST refill is not possible without the charging pumps; core damage end states are assigned to these sequences.

Failure of all high pressure injection (TK success, CCP fails and SIP fails) in conjunction with failure of auxiliary feedwater (AFW) results in the operators attempting to establish alternate feedwater (ORF/ALT) to maintain the SGs as a heat sink. Success of ORF/ALT for this scenario results in a subsequent end state of Success with Accident Management (SAM) provided that steam flow from (OAI/MSI) and alternate feedwater to (OAF/AFI) the ruptured SG can be isolated (as discussed above for the case with no high pressure injection). Failure to isolate steam flow or feed flow following the success of alternate feedwater will result in core damage and path transfer to TREE SGTR-4 (CORE DAMAGE). Additionally, failure to establish alternate feedwater in conjunction with failure of high pressure injection and auxiliary feedwater results in core damage and path transfer to TREE SGTR-4 (CORE DAMAGE).

For those paths in which both auxiliary feedwater (AFW) and the RWST (TK) fail, the operator attempts to establish alternate feedwater (ORF/ALT) in order to maintain the SGs as a heat sink. Success of ORF/ALT for this scenario results in a subsequent end state of Success with Accident Management (SAM) provided that steam flow from (OAI/MSI) and alternate feedwater to (OAF/AFI) the ruptured SG can be isolated (as discussed above for the case with no RWST). Failure to isolate steam flow or feed flow following the success of alternate feedwater will result in core damage; the end states are assigned here since containment sprays would not be available. Additionally, failure to establish alternate feedwater in conjunction with failure of the RWST and auxiliary feedwater results in core damage and path transfer to TREE SGTR-5 (CORE DAMAGE/NO RWST) in order to address containment heat removal with the fan coolers (FC) since this scenario is NOT a containment bypass (no SG overfill).

As noted in the previous discussion, the 'end states' or 'conditions' of TREE SGTR-1 are either accident sequences with success, success with accident management, core damage/containment bypass sequences with the end state defined, core damage sequences which require further consideration of containment survival, or accident sequences requiring further treatment of possible recovery paths. For each accident sequence path of TREE SGTR-1 not ending in success, an extended plant response tree is attached to provide the required considerations. These additional plant response trees represent RWST Refill (TREE SGTR-2), Bleed & Feed (TREE SGTR-3), Core Damage (TREE SGTR-4) and Core Damage/No RWST (TREE SGTR-5).

TREE SGTR-2: RWST REFILL

TREE SGTR-2 shows the remainder of the nodes for the plant response tree for all sequences from TREE SGTR-1 in which SG overfill occurs and a safe, stable end state is attainable via further action to refill the RWST.

Since SG overfill occurs, the sequence is a containment bypass sequence due to the consequential failure of the safety valve to reseat (Section 3.0). Accordingly, containment heat removal (FC) and containment isolation (CI) are not addressed. The only nodes addressed are those for RWST refill (ORT/RTK). Successful RWST refill results in Success with Accident Management (SAM). Failure of ORT or RTK results in a core damage/containment bypass sequence.

TREE SGTR-3: BLEED & FEED

TREE SGTR-3 shows the remainder of the nodes for the plant response tree for all sequences from TREE SGTR-1 in which bleed and feed cooling is initiated. Since it is assumed that no auxiliary or alternate feedwater can be established to any steam generator, bleed and feed cooling will continue until the RWST water is depleted and the operator is instructed to transfer to ES-1.3, Transfer to Cold Leg Recirculation. High pressure ECCS recirculation is required for long term decay heat removal and RCS inventory control.

The first node on TREE SGTR-3 addresses containment heat removal (FC). Two (2) fan coolers will prevent containment spray as well as prevent containment overpressurization failure. One (1) fan cooler will not prevent automatic actuation of containment spray but will prevent containment overpressurization failure. Additionally, ECCS recirculation with 1 fan cooler will prevent core damage. For the paths with 0 fan coolers, ECCS recirculation with success of the RHR heat exchangers is necessary to prevent core damage and containment failure.

For those paths in which less than 2 fan coolers are operational, the availability of the containment sprays (CSI) is addressed. If the containment sprays are available, the draining of the RWST occurs much more quickly and the time to switchover to ECCS recirculation is reduced for these accident sequences.

The next actions during bleed and feed cooling is providing CCW to the RHR heat exchangers (OHX/RHX) and establishing high pressure recirculation (ORC/HPR). In this instance, the RHR heat exchanger(s) will be used as a heat transfer mechanism during high pressure ECCS recirculation. For the case with 1 or greater fan coolers operating, there is no requirement for operation of the RHR heat exchangers during recirculation. For sequences with no (0) FC and success of high pressure recirculation, the operation of at least one RHR heat exchanger will prevent core damage. Failure of the RHR heat exchanger in this case will result in core damage after 24 hours.

For those cases in which high pressure recirculation fails, the next nodes on the plant response tree address the possibility of refilling the RWST (ORT/RTK) and continuing ECCS injection in order to prevent core damage if high pressure recirculation can not be established. Nodes ORT and RTK are addressed for all event sequences in which there is failure to go to ECCS recirculation cooling. Successful refilling of the RWST will result in an end state of Success with Accident Management (SAM).

The final node of TREE SGTR-3 addresses containment isolation (CI) for core damage sequences.

TREE SGTR-4: CORE DAMAGE

TREE SGTR-4 shows the remainder of the nodes for the plant response tree for all sequences on TREE SGTR-1 which end in core damage.

The only nodes addressed on TREE SGTR-4 are those dealing with containment spray (CSI). By definition, the paths which lead to this tree have resulted in SG overfill. Therefore, this tree represents core damage/containment bypass sequences.

TREE SGTR-5: CORE DAMAGE / NO RWST

TREE SGTR-5 shows the remainder of the nodes for the plant response tree for all sequences on TREE SGTR-1 which end in core damage, and in which the RWST is not available.

Since the RWST is not available, there would be no ECCS injection and thus no SG overfill. Accordingly, containment heat removal (FC) and containment isolation (CI) are addressed on this tree. Containment spray is not addressed since the RWST is unavailable.

7.0 DIFFERENCES IN UNIT 1 AND UNIT 2

The emergency procedures are written for Unit 1 or Unit 2; no specific instructions are listed for the two units except:

> "Note: Unit 2 BIT inlet isolation valves 2MOV-SI8803A and B are OPEN De-ENERGIZED per TECH SPECS,"

> Service water valves to the auxiliary building coolers are listed specifically for each unit.

The control rooms are designed as duplicates (not mirror images) and the operators routinely switch shifts between the two units. Thus, there should be no increased chance of operator confusion in the control room due to differences in procedures or control room design.

The success criteria and best estimate analyses apply to both units. Therefore, the event tree model applies to both units.

8.0 IPE/ACCIDENT MANAGEMENT INSIGHTS

A number of insights have been identified during the analyses and evaluations leading to the construction of the SGTR plant response tree. These insights may be considered IPE insights and are noted here.

AFW Termination to Ruptured SG in ECA-3.1

For the scenario in which the ruptured SG can not be isolated from the intact SGs, Zion EOP E-3, Step 4 instructs the operators to complete Step 5 and then transition to ECA-3.1. Step 5 of E-3 instructs the operators to isolate [steam] flow from the ruptured SG. It is noted that Step 6 instructs the operators to isolate [feedwater] flow to the ruptured SG. Upon transition to ECA-3.1, there is no guidance to isolate [feedwater] flow to the ruptured SG. Therefore, for this scenario, the operators are not explicitly instructed to isolate [feedwater] flow to the ruptured SG. This would appear to be a 'loophole' in the procedures. It is suggested that E-3, Step 4 instruct the operators to complete Steps 5 AND 6 prior to transition to ECA-3.1 for the scenario in which the ruptured SG can not be isolated from the intact SG.

(This matter was also discussed with the Plant Operational Engineering group at Westinghouse; this group is responsible for updates to the Emergency Response Guidelines. Apparently this oversight was also recognized in late 1990 by Seabrook personnel. To correct this oversight, ERG maintenance item DWR DW-90-047 was approved February 1991).

Steaming SGs with no AFW

Consider the following two scenarios:

1. Due to the lack of AFW, the operators transition to FR-H.1. If the centrifugal charging pumps are unavailable, the procedure instructs the operators to begin bleed and feed (Step 16). Subsequent steps include establishing alternate feedwater to the SGs (Step 22), checking for SG level (Step 23a) and continuing in FR-H.1 if level returns to at least one SG. The very next step in FR-H.1 (Step 23b) instructs the operator to maintain the cooldown rate at less than 100°F/hr.

2. Due to the lack of AFW, the operators transition to FR-H.1. If the centrifugal charging pumps are available the procedure instructs the operators to establish alternate feedwater to the SGs (Steps 7-11), and if level returns in any SG return to E-0. From E-0, the operators would be expected to diagnose a SGTR event, transition to E-3 and begin the operator actions which include SG isolation and RCS cooldown.

For each case, it is probable that level would return in the ruptured SG due to the primary to secondary break flow. If the operator interprets this level indication as an available heat sink, then in either case he is instructed to begin a RCS cooldown. For case 1, the procedures do not explicitly tell the operators which SG(s) to use for the RCS cooldown; thus he may use only the SG with the available heat sink OR if he has wide range level indication, he may use all SGs. For case 2, E-3 instructs the operators to perform the RCS cooldown with the intact SGs. Thus he may use the intact SGs since there is wide range level and since he does not really want to dump steam from the ruptured SG. Nevertheless, the point is that there is no clear guidance to the operators as to what is the criteria for using a SG for a RCS cooldown.

Therefore, it is suggested that the availability of any SG for RCS cooldown be better defined in the EOPs to cover the scenarios in which AFW is not available.

On a semantics note, for the Case 1 scenario noted above, Step 23b of FR-H.1 instructs the operators to 'maintain' a 100°F/hr RCS cooldown. If no charging pumps are available, the operators skip over the step to depressurize the SGs for condensate booster pump injection. Thus no RCS cooldown has ever been initiated, so how can it be maintained?

Importance of the interpretation of a secondary heat sink

Again, consider the scenario in which AFW has failed, and the centrifugal charging pumps are available. The operators are in FR-H.1 attempting to establish alternate feedwater. During the SG level checks (4% narrow range) in Steps 10 and 12 of FR-H.1, there ultimately will be level return to the ruptured SG due to the primary to secondary break flow. It becomes important whether the operators interpret the level return as an available heat sink. This insight is divided into two 'sub-insights'.

A. If the operators decide that the ruptured SG does not represent an available heat sink and remains in FR-H.1, then he continues in his attempts to establish an alternate feedwater source to any SG. This would continue until wide range level in 3 of 4 SGs falls below 24%, at which time the operators are instructed to initiate bleed and feed by opening the two pressurizer PORVs. The rapid depressurization of the RCS effectively terminates the primary to secondary breakflow. However, during the time that the wide range level in the 3 intact SGs decreases to less than 24%, water is accumulating in the ruptured SG due to the primary to secondary break flow and it is likely that SG overfill will occur.

This is undesirable and may lead to the failure of a safety valve to reseat; this results in the necessity for further operator actions for recovery.

On the other hand, if the ruptured SG is considered an available heat sink, the operators will transfer back to E-0, diagnose a SGTR and transition to E-3 and ultimately begin operator actions. First, the operators will isolate the ruptured SG and then initiate a RCS cooldown by dumping steam. However, narrow range level in the intact SGs is offscale low; it is not clear as to which SG(s) the operators would use for RCS cooldown (See item above). If he uses the intact SGs, the RCS cooldown will deplete the inventory such that the RCS cooldown would only be effective for a short period of time; thus the operators would be forced to transfer to ECA-3.1 and use the ruptured SG for RCS cooldown. If the operators decide not to cooldown the intact SGs since the narrow range levels are offscale low, then he would transition to ECA-3.1 to use the ruptured SG. In either scenario, the ruptured SG will be used for RCS cooldown via ECA-3.1. The action to cooldown the RCS via the ruptured SG reverses the level increase due to the phase transition of water to steam (recall that the water in the ruptured SG is much warmer than the auxiliary feedwater would be). Continued steaming of the ruptured SG will result in a reduction of the narrow range level indication to below 4% such that the operators are forced to return to FR-H.1 due to the Critical Safety Function Status Trees (CSFSTs). Since there are no instructions in FR-H.1 to stop the RCS cooldown, the RCS cooldown continues via the ruptured SG, although the rate of cooldown decreases. The important point is that RCS cooldown with the ruptured SG results in additional time prior to SG overfill so that there is higher probability of recovering auxiliary or alternate feedwater.

B. Additionally, it is important to note that initiation of steam dump from the ruptured SG essentially terminates heat transfer to the remaining intact SGs thereby stabilizing the level. Once back in FR-H.1, the operators wait for less than 24% wide range level indication in 3/4 SGs. This will take a very long time due to the sequence of events described above. This also allows a long time to recover auxiliary or alternate feedwater, but also results in the operators being 'caught' in FR-H.1 waiting for level return in the ruptured SG or level reduction in the intact SGs. It may be wise to add a caution to FR-H.1 to discuss this scenario.

RWST Refill

In EOP ECA-3.1, the operators are instructed to transition to ECA-3.2 if the RWST level falls below 19.5 ft; the initial step in ECA-3.2 instructs the operators to initiate RWST refill and continue with the ECA-3.2 actions. This level indication corresponds to approximately half of the RWST volume. Considering the expected equilibrium break flow/SI flow, it is noted that the guidance to begin RWST refill is sufficiently early (i.e., before RWST empties) to ensure a high probability of success of preventing core damage.

Chance for Recovery

It is noted that for a SGTR event, there is a very long time to perform recovery actions prior to the onset of core damage. Additionally, the EOPs are structured for contingency actions during a SGTR (i.e., ECA-3.1, ECA-3.2 and ECA-3.3) such that there are many different paths to achieve ones' objective; namely termination of the primary to secondary break flow. Finally, although the incidents of steam generator tube ruptures indicate that this is a credible event, those plants which have experienced tube ruptures were able to use the resources available and shutdown the plant with no adverse circumstances. In short, the progression of a steam generator tube rupture to a core damage state is expected to be a remote possibility, while recovery from a steam generator tube rupture with no adverse effects is expected to be a high probability event.

No ECCS

It is interesting to note that analyses have indicated that lack of ECCS for a SGTR event does not automatically result in a core damage sequence (unlike the other LOCA events analyzed). In fact, lack of ECCS actually results in additional time for the operators to perform the necessary actions to prevent SG overfill. The only negative to such a scenario is that the RCS may become saturated, an undesirable but manageable situation. No procedure enhancements are noted here as a result of this insight, E-3 includes a note that ECCS flow must be terminated when the termination criteria are met. The only suggestion here is that this scenario be 'touched on' in training.

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    1.3 FR-C.2, Response to Degraded Core Cooling, Revision 7 through 10/1/89.

    1.4 FR-C.1, Response to Inadequate Core Cooling, Revision 7 through 10/1/89.

    1.5 ES-1.3, Transfer to Cold Leg Recirculation, Revision 5 through 12/10/88.

    1.6 FR-Z.1, Response to High Containment Pressure, Revision 2 through 9/8/89.

    1.7 ES-3.1, Post-SGTR Cooldown Using Backfill, Revision 2 through 4/4/89.

    1.8 ES-3.3, Post-SGTR Cooldown Using Steam Dump, Revision 4 through 4/4/89.

    1.9 ECA-3.3, SGTR Without Pressurizer Pressure Control, Revision 7 through 4/4/89.

    1.10 ECA-3.1, SGTR with Loss of Reactor Coolant - Subcooled Recovery, Revision 7 through 4/4/89.

    1.11 ECA-3.2, SGTR with Loss of Reactor Coolant - Saturated Recovery, Revision 7 through 4/4/89.

    1.12 E-0, Reactor Trip or Safety Injection, Revision 7 through 10/1/89.

    1.13 ECA-1.1, Loss of Emergency Coolant Recirculation, Revision 4 through 12/10/88.

1.14 FR-S.1, Response to Nuclear Power Generation/ATWS, Revision 4 through 10/1/89.

1.15 ES-1.1, SI Termination, Revision 5 through 4/4/89.

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8. CECo Letter of February 5, 1991 from Xavier Polanski (CECo) to Mike Loftus (Westinghouse) regarding RHR pump survivability with no CCW while on mini-flow recirculation.

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10. System Notebook for Containment Spray System, Zion Station Units 1 and 2, prepared by IPEP, February 1992.

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13. CECo Letter of June 9, 1988 from Glenn E. Trzyna (CECo) to Director of Nuclear Reactor Regulation regarding BIT Removal (includes Westinghouse Report "Boron Concentration Reduction/Boron Injection Tank Elimination for Zion Units 1 and 2," J. C. Bass, 1985.)

14. "Local Boron Dilution Transient in PWRs," S. Jacobson, Swedish State Power Board, 1989.

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16. SGTR Success Criteria Notebook, Zion Station Units 1 and 2, prepared by IPEP, March 1992.

17. Equipment Survivability Notebook for Zion Station Units 1 and 2, prepared by IPEP, Revision 0, March 1992.

18. Source Term Notebook for Zion Station Units 1 and 2, prepared by IPEP, April 1992.

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APPENDIX A

STEAM GENERATOR TUBE RUPTURE
PLANT RESPONSE TREES

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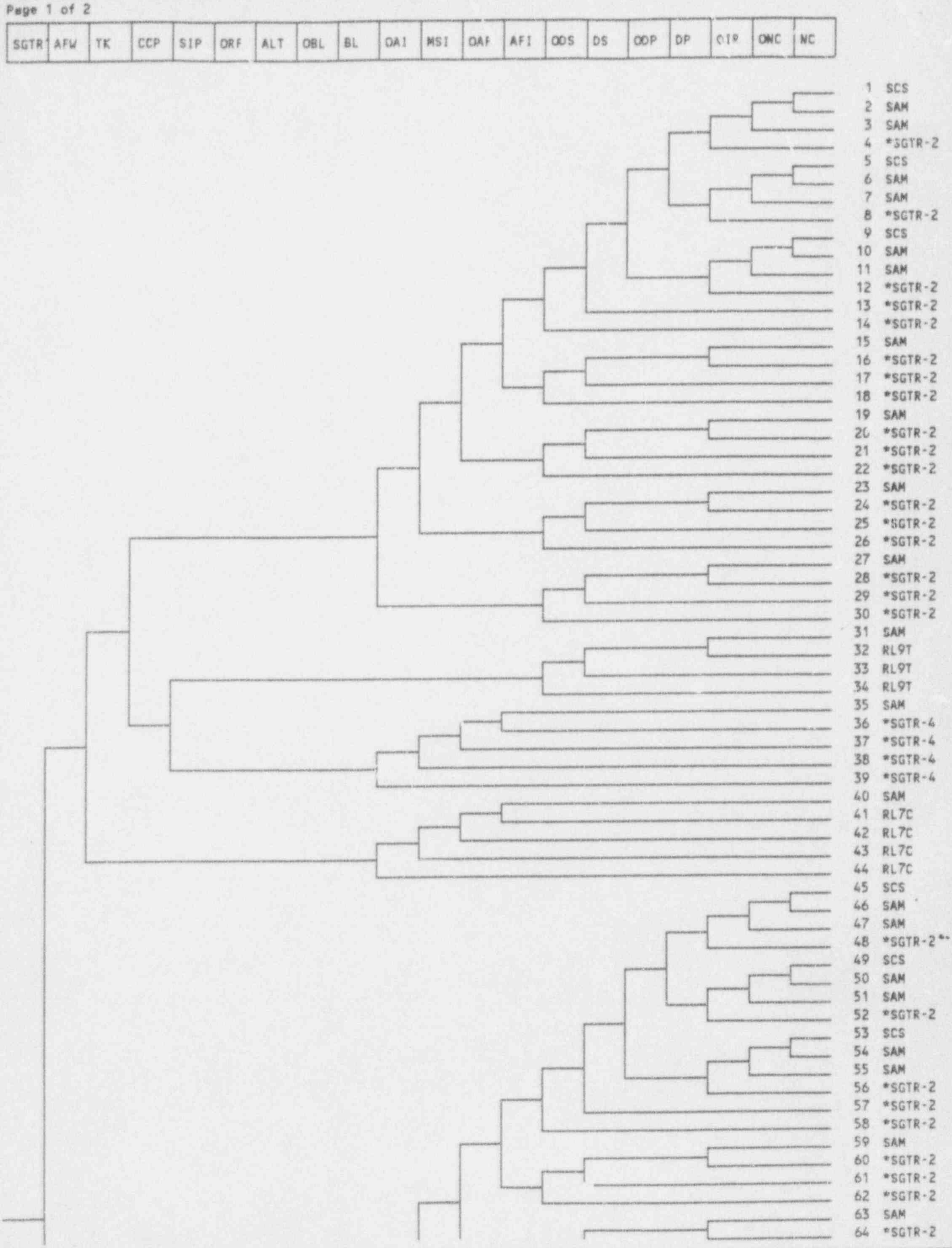

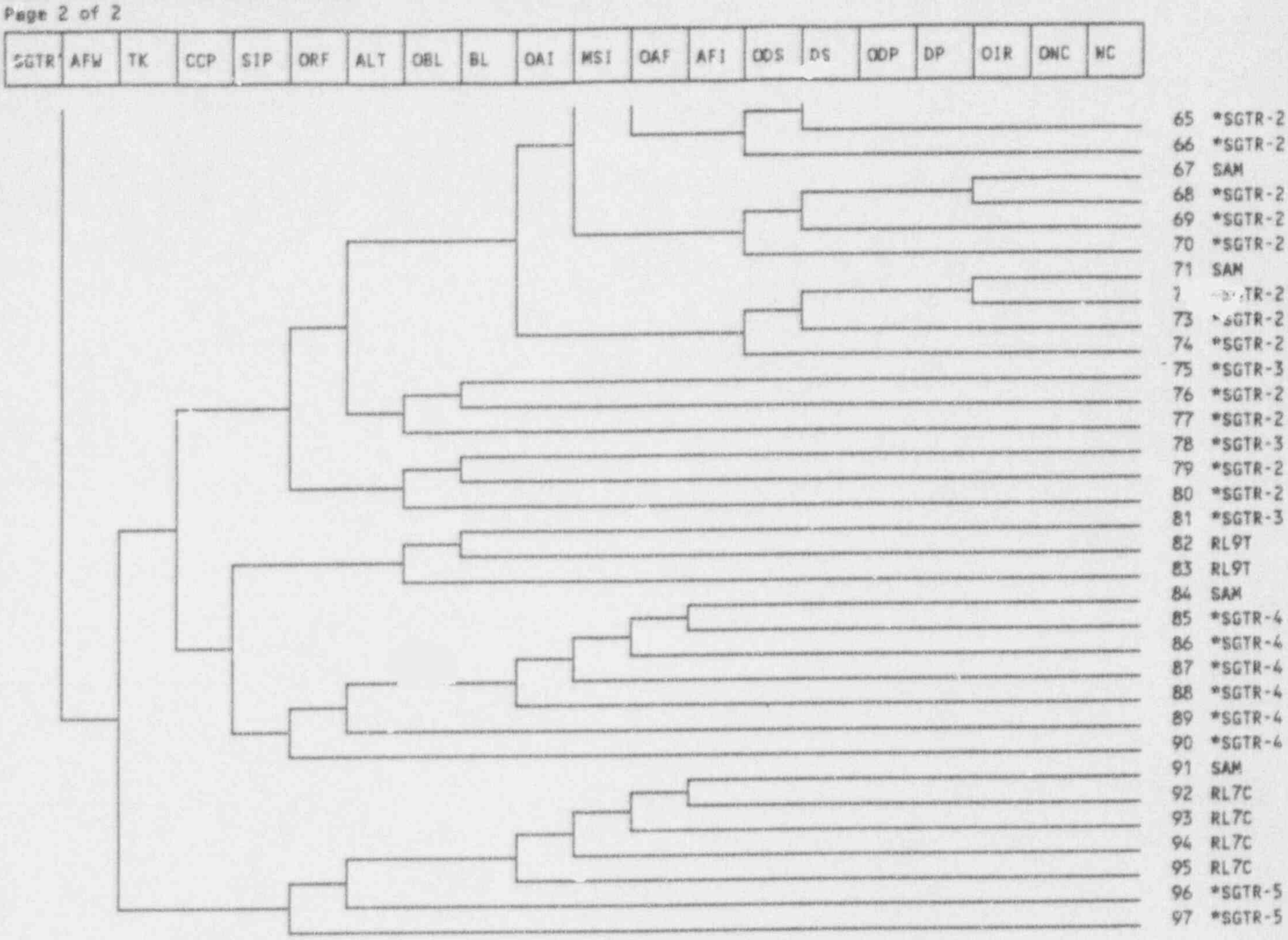
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CCP
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ONC
NC
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90 *SGTR-4
91 SAM
92 RL7C
93 RL7C
94 RL7C
95 RL7C
96 *SGTR-5
97 *SGTR-5

SGTR PRT ENTRY CONDITION SUMMARY

	EQUIPMENT								
SGTR TREE	TK	CCP	SIP	AFW OR ORF/ALT	OBL/BL	OAI/MSI + OAF/AFI (ISOLATE)	ODS/DS	ODP/DP	OIR
TREE SGTR-2 (1) (RWST REFILL)	S	S		S		S	S	S or F	F
TREE SGTR-2 (2) (RWST REFILL)	S	S		S		S	F		
TREE SGTR-2 (3) (RWST REFILL)	S	S		S		F	S		F
TREE SGTR-2 (4) (RWST REFILL)	S	S		S		F	F		
TREE SGTR-2 (5) (RWST REFILL)	S	S		F	F				
TREE SGTR-3 (1) (BLEED & FEED)	S	S		F	S				
TREE SGTR-3 (2) (BLEED & FEED)	S	F	S	F	S				
TREE SGTR-4 (1) (CORE DAMAGE)	S	F	F	S		F			
TREE SGTR-4 (2) (CORE DAMAGE)	S	F	F	F					
TREE SGTR-5 (CORE DAMAGE, NO RWST)	F			F					

S - SUCCESS
F - FAILURE
Alpha-numeric designates number of operational components
Blank denotes "Not Applicable".

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STEAM GENERATOR TUBE RUPTURE TREE 2 - RWST REFILL

SGTR2	FC	CSI	OHX	RHX	ORC	HPR	ORT	RTK	CI

SGTR PRT ENTRY CONDITION SUMMARY

SGTR TREE	EQUIPMENT								
	TK	CCP	SIP	AFW OR ORF/ALT	OBL/BL	OAI/MSI + OAF/AFI (ISOLATE)	ODS/DS	ODP/DP	OIR
TREE SGTR-2 (1) (RWST REFILL)	S	S		S		S	S	S or F	F
TREE SGTR-2 (2) (RWST REFILL)	S	S		S		S	F		
TREE SGTR-2 (3) (RWST REFILL)	S	S		S		F	S		F
TREE SGTR-2 (4) (RWST REFILL)	S	S		S		F	F		
TREE SGTR-2 (5) (RWST REFILL)	S	S		F	F				
TREE SGTR-3 (1) (BLEED & FEED)	S	S		F	S				
TREE SGTR-3 ([illegible]) (BLEED & FEED)	S	F	S	F	S				
TREE SGTR-4 (1) (CORE DAMAGE)	S	F	F	S		F			
TREE SGTR-4 (2) (CORE DAMAGE)	S	F	F	F					
TREE SGTR-5 (CORE DAMAGE, NO RWST)	F			F					

S - SUCCESS
F - FAILURE
Alpha-numeric designates number of operational components
Blank denotes "Not Applicable".

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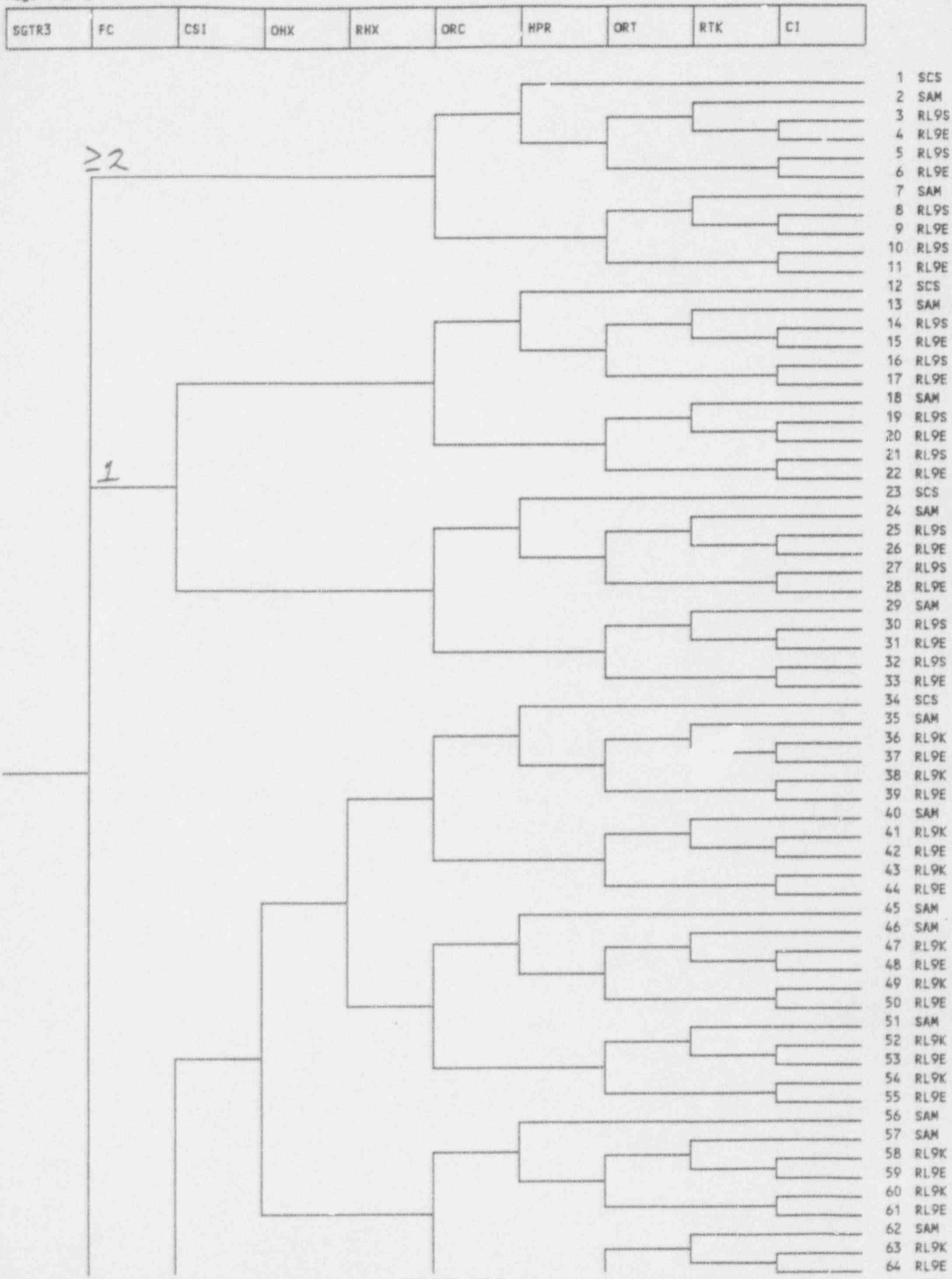
Page 1 of 2



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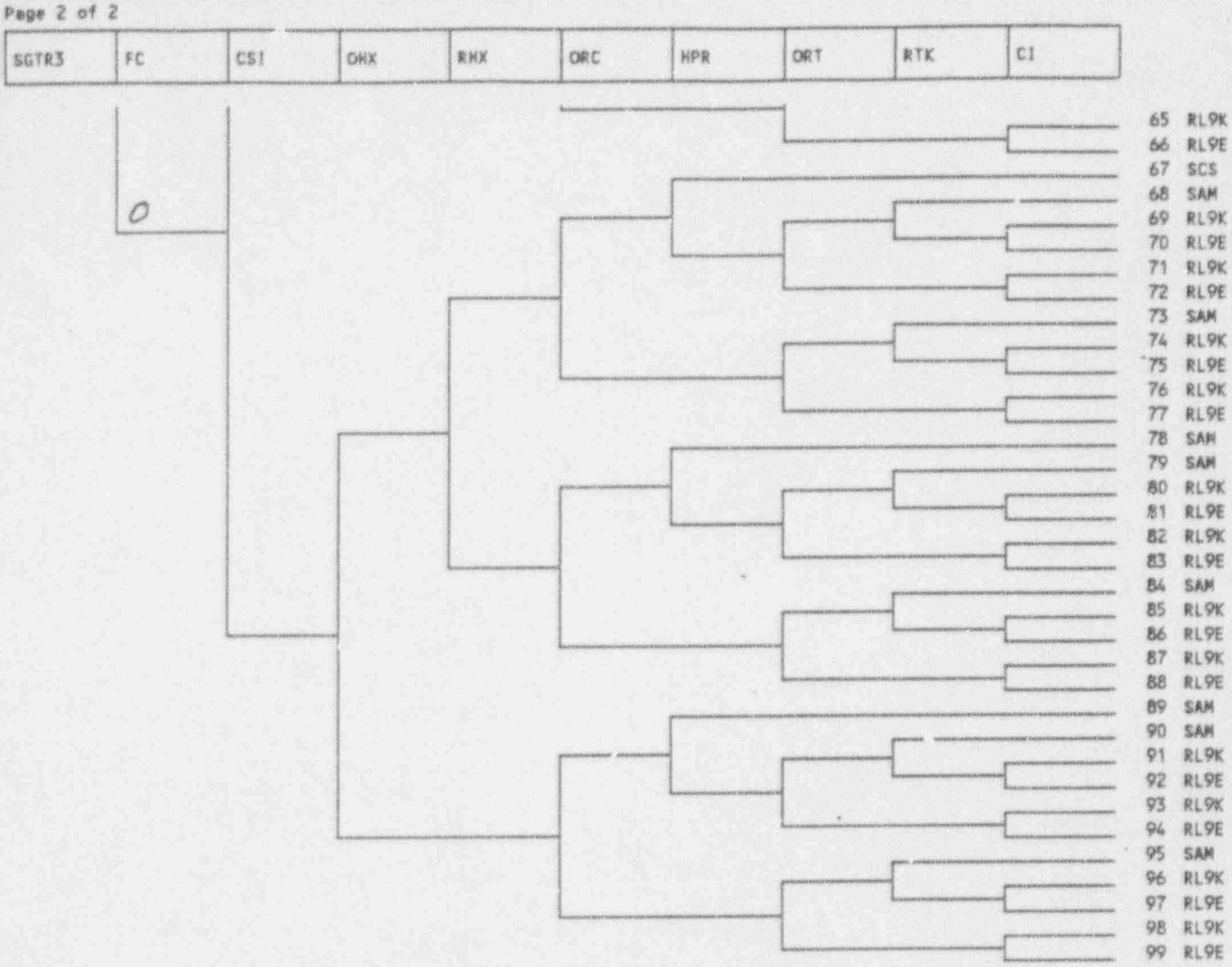


SGTR PRT ENTRY CONDITION SUMMARY

SGTR TREE	EQUIPMENT								
	TK	CCP	SIP	AFW OR ORF/ALT	OBL/BL	OAI/MSI + OAF/AFI (ISOLATE)	ODS/DS	ODP/DP	OIR
TREE SGTR-2 (1) (RWST REFILL)	S	S		S		S	S	S or F	F
TREE SGTR-2 (2) (RWST REFILL)	S	S		S		S	F		
TREE SGTR-2 (3) (RWST REFILL)	S	S		S		F	S		F
TREE SGTR-2 (4) (RWST REFILL)	S	S		S		F	F		
TREE SGTR-2 (5) (RWST REFILL)	S	S		F	F				
TREE SGTR-3 (1) (BLEED & FEED)	S	S		F	S				
TREE SGTR-3 (2) (BLEED & FEED)	S	F	S	F	S				
TREE SGTR-4 (1) (CORE DAMAGE)	S	F	F	S		F			
TREE SGTR-4 (2) (CORE DAMAGE)	S	F	F	F					
TREE SGTR-5 (CORE DAMAGE, NO RWST)	F			F					

S - SUCCESS
F - FAILURE
Alpha-numeric designates number of operational components
Blank denotes "Not Applicable".

STEAM GENERATOR TUBE RUPTURE TREE 4 - CORE DAMAGE

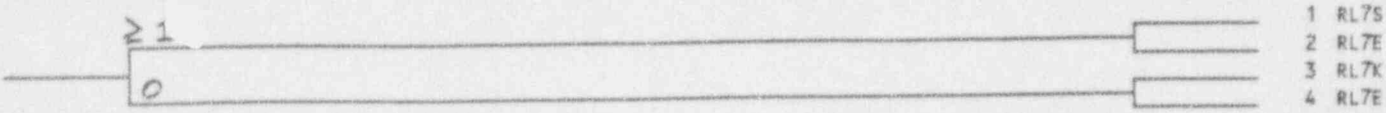
SGTR4	FC	CSI	OHX	RHX	ORC	HPR	ORT	RTK	CI

SGTR PRT ENTRY CONDITION SUMMARY

SGTR TREE	EQUIPMENT								
	TK	CCP	SIP	AFW OR ORF/ALT	OBL/BL	OAI/MSI + OAF/AFI (ISOLATE)	ODS/DS	ODP/DP	OIR
TREE SGTR-2 (1) (RWST REFILL)	S	S		S		S	S	S or F	F
TREE SGTR-2 (2) (RWST REFILL)	S	S		S		S	F		
TREE SGTR-2 (3) (RWST REFILL)	S	S		S		F	S		F
TREE SGTR-2 (4) (RWST REFILL)	S	S		S		F	F		
TREE SGTR-2 (5) (RWST REFILL)	S	S		F	F				
TREE SGTR-3 (1) (BLEED & FEED)	S	S		F	S				
TREE SGTR-3 (2) (BLEED & FEED)	S	F	S	F	S				
TREE SGTR-4 (1) (CORE DAMAGE)	S	F	F	S		F			
TREE SGTR-4 (2) (CORE DAMAGE)	S	F	F	F					
TREE SGTR-5 (CORE DAMAGE, NO RWST)	F			F					

S - SUCCESS
F - FAILURE
Alpha-numeric designates number of operational components
Blank denotes "Not Applicable".

SGTR5	FC	CSI	OHX	RHX	ORC	HPR	ORT	RTK	CI



APPENDIX B

B.1 REVIEW OF EMERGENCY PROCEDURES FOR SGTR

B.1.1 INTRODUCTION

The Emergency Operating Procedures (EOPs) provide the bases used to determine the operator actions that are included on the event tree model. Figure B-1 is a flow diagram to show the relationship between the various emergency procedures. If the operators are in a specific procedure and plant conditions indicate that a more severe condition is occurring, guidance is then provided to transfer to a separate emergency procedure that provides more detailed instructions.

For a SGTR event, reactor trip results due to low pressurizer pressure or overtemperature delta-T. Safety injection occurs soon thereafter due to low pressurizer pressure. The reactor trip and SI signal cause the operators to enter the Zion EOPs at the "Reactor Trip or Safety Injection" procedure (E-0). Coincident with the transfer from the E-0 procedure, the operators begin to monitor the Critical Safety Functions (CSFs) via the CSF Status Trees (F-0.1 through F-0.6). Once in E-0, the operators are instructed to check for reactor trip; if reactor trip cannot be verified, the operators are directed to the subcriticality or Anticipated Transient Without Scram (ATWS) procedure (FR-S.1, Reference 1.14). This type of an event sequence transfers from the SGTR plant response tree to the ATWS plant response tree. The next steps in E-0 verify the status of the safety systems which should have been activated. The only step in E-0 which transfers to another procedure during the verification of safety systems operation is the status of the auxiliary feedwater system.

B.1.2 FAILURE OF AFW - BLEED & FEED

If 340 gpm auxiliary feedwater flow cannot be established, the operators are directed to implement the "Response to Loss of Secondary Heat Sink" procedure, FR-H.1. In FR-H.1, the operators are again instructed to attempt to restore auxiliary feedwater. Failing this, if at least one charging pump is available and the condensate system can be placed in service, the operators are directed to attempt to establish main feedwater by starting the main feedwater pumps and aligning them for injection into the steam generators. If flow cannot be established via the main feedwater pumps to at least one SG, the operators are directed to depressurize the steam generators in order to reduce pressure below the shutoff head of the condensate booster pumps and align the condensate booster pumps to at least one SG. If feedwater flow to a SG can be restored, the level in the SG will begin increasing and the operators are instructed to return to the E-0 procedure. However, as noted in Section 3.0, even if alternate feedwater has not been established, the operator may return to E-0 due to level recovery in the ruptured SG (via the primary to secondary break flow) but will ultimately return to FR-H.1.

If no charging pump is available but at least one SI pump is available, the operators are instructed to immediately begin bleed and feed operations in FR-H.1. If charging is available, but alternate feedwater to at least one SG cannot be established, the operators are instructed to begin bleed and feed operations in FR-H.1 when the level in at least 3 SGs falls below 24% on the wide range indication.

In the bleed and feed operations described in FR-H.1, the operators are instructed first to verify that an ECCS high pressure injection path is available. If ECCS injection (at least one charging pump or one SI pump) is not available, the operators are instructed to return to the beginning of FR-H.1 and attempt to recover a source of feedwater. If a high pressure injection path is established, the operators are instructed to open both of the pressurizer PORVs and associated block valves; if both PORVs cannot be opened, the operators are instructed to open all reactor head vents, depressurize one steam generator to atmospheric via steam dump to the atmosphere, and align service water to the depressurized SG. The next step is to establish component cooling water flow to the RHR heat exchanger. For all cases in which FR-H.1 is entered, the operators are eventually placed in a 'loop' until a secondary heat sink to at least one steam generator can be established (i.e., narrow range level indication greater than 4%). Based on priorities in implementing procedures, the operators will remain in this 'loop' until RWST level decreases to less than 13.6 feet, at which point the operators are instructed to align the ECCS system for cold leg recirculation using ES-1.3, "Transfer to Cold Leg Recirculation", and then return to bleed and feed operations. The only other transfer out of FR-H.1 without establishing a source of feedwater is for the scenario in which the core uncovers and begins to heatup; for this case the operators would transfer to FR-C.1, "Response to Inadequate Core Cooling."

While in the bleed and feed mode of cooling, if level can be recovered in at least one steam generator, the procedures direct the operators to begin terminating high pressure safety injection and closing the PORVs (i.e., terminating bleed and feed cooling mode), until pressurizer level returns. If pressurizer level can be established and normal charging flow implemented, the operators are directed to transfer to the SI termination procedure (ES-1.1, Reference 1.15).

B.1.3 AFW AVAILABLE - NORMAL ACTIONS

For the accident sequence path in which a secondary heat sink is available (or has been reestablished), the procedures then provide criteria for stopping the RCPs (one charging pump running and RCS pressure less than 1250 psig). For a SGTR event, the pressure criteria is not expected to be met thus the RCPs would not be tripped. The operators are then directed to the "Steam Generator Tube Rupture" procedure

(E-3) once the event has been diagnosed per Step 15 of E-0. It is noted that if SI and charging flow cannot be verified during previous steps in E-0, then the operators are simply instructed to align the injection path and manually start the pumps.

The first major action in E-3 is to verify that the RCPs should not be tripped. The subsequent steps in E-3 include the actions for termination of the primary to secondary break flow:

1. Identification and Isolation of the Ruptured SG,
2. RCS Cooldown,
3. RCS Depressurization,
4. ECCS Flow Termination.

First, the operators are instructed to identify the SG with the ruptured tube (via level response and/or steamline radiation), and isolate this SG from the remaining intact SGs by stopping steam flow from and feedwater flow to this SG. Steam flow from the ruptured SG is stopped by closing the Main Steam Isolation Valve (MSIV) and other associated steam paths from the ruptured SG. Alternately, the MSIVs on the intact SGs may be closed to isolate the ruptured SG from the intact SGs. The feedwater flow to the ruptured SG is stopped by terminating auxiliary or alternate feedwater flow to that SG. The only exception to this isolation is: 1) steam flow from the ruptured SG to the turbine driven AFW pump should not be stopped if this is the only AFW pump available and steam from the ruptured SG is the only steam supply to the pump, 2) feedwater flow should not be stopped but rather controlled if the ruptured SG is the only SG receiving AFW flow. Isolation of the ruptured SG is necessary before continuing with the subsequent steps, unless the ruptured SG must be used for RCS cooldown. If steam flow from a ruptured SG cannot be stopped, the operator is instructed to transfer to ECA-3.1, "SGTR with Loss of Reactor Coolant - Subcooled Recovery."

Once the ruptured SG has been isolated, there are several interim steps before RCS cooldown including verifying that the pressurizer PORVs are closed, verifying that no SG is faulted, verifying that a heat sink exists in the intact SGs, resetting SI, and establishing instrument air to containment. Next the RCS cooldown is started by dumping steam from the intact SGs to either the condenser, or if the condenser is unavailable, to the atmosphere via the atmospheric relief valves. This cooldown is necessary to establish or maintain a temperature difference between the RCS and the intact SGs for decay heat removal, plus to keep the RCS subcooled following subsequent RCS depressurization. The amount of RCS cooldown needed is dependent on the ruptured SG pressure; typically the RCS cooldown would be to a core exit temperature of approximately 515°F (based on the ruptured SG pressure being controlled to no-load conditions). Once this target temperature is attained, steam dump is utilized to control the RCS at or less than this temperature. If steam dump from the intact SGs is not possible, the operators are instructed to transfer to ECA-3.1, "SGTR with Loss of Reactor Coolant - Subcooled Recovery."

The next step is RCS depressurization. The RCS is depressurized to minimize the primary to secondary break flow and to refill the pressurizer. Per the shift supervisor's discretion, RCS depressurization may be done concurrently with RCS cooldown IF normal pressurizer spray is available. Otherwise, the RCS depressurization is not started until the RCS cooldown is completed. Ideally, the depressurization is stopped when the RCS pressure is less than the ruptured SG pressure. However, the depressurization is also stopped due to a high pressurizer level or due to a loss of RCS subcooling.

Typically, normal pressurizer spray will be used for RCS depressurization since the RCPs are not tripped; however one pressurizer PORV or auxiliary pressurizer spray can also be used to depressurize the RCS. If RCS depressurization cannot be accomplished via any of these means, the operators are directed to ECA-3.3, "SGTR Without Pressurizer Pressure Control."

After RCS depressurization is complete, high pressure safety injection flow from the charging and/or safety injection pumps is terminated to prevent or limit RCS repressurization and reinitiation of primary to secondary break flow. After SI termination, the RCS pressure is approximately the same as the ruptured SG pressure and the primary to secondary leakage is minimal. Normal inventory and pressure controls are established and a post-SGTR procedure, such as ES-3.1 - "Post SGTR Cooldown Using Backfill", would be used to complete the cooldown and depressurization of the plant to cold shutdown conditions. Using this procedure, the operators maintain the pressurizer level with normal charging and letdown while depressurizing the RCS. The ruptured SG will backfill the RCS as the pressure decreases. The operators maintain ruptured SG level by controlling auxiliary feedwater. Other options for post-SGTR cooldown include blowdown (to radwaste) from the ruptured SG and steam dump (to condenser or atmosphere) from the ruptured SG.

B.1.4 ECA-3.1

As noted previously, continuation of a SGTR via actions in ECA-3.1 - "SGTR with Loss or Reactor Coolant, Subcooled Recovery" occurs for instances in which the ruptured SG cannot be isolated or steam dump from the intact SGs is not possible. Another possibility of transition to ECA-3.1 is for the scenario in which SG overfill occurs. If SG overfill occurs, water will be relieved from the SG relief and/or safety valves. Since these valves are not designed for water relief, such a scenario may result in the failure of a relief or safety valve to reseat, thus resulting in an uncontrolled loss of RCS/secondary inventory. Thus for this scenario, ECA-3.1 will be used.

The actions in ECA-3.1 are very similar to those in E-3. The operators are instructed to establish a 100°F/hr RCS cooldown via steam dump from the intact SGs, or the ruptured SG if the intact SGs are unavailable. Next the RCS is depressurized to minimize the primary to secondary break flow and to refill the pressurizer. Next, two RCPs are tripped, or restarted if already tripped. The ECCS pumps are sequentially terminated based on subcooling criteria. Specifically, first one charging pumps is stopped, then the second charging pump is aligned to the VCT for normal charging. Finally, the last two SI pumps are stopped in order. However, the criteria for the SI termination is based on the availability of normal charging flow so establishing this normal charging is very important.

Once all ECCS is stopped, normal charging flow is used to control pressurizer level and the RCS is again depressurized to minimum subcooling, 30-40°F. The RCS cooldown and depressurization steps are continued until RHR conditions are attained and RHR cooldown can continue until cold shutdown conditions are reached. For the case in which SG overfill occurs and a safety valve fails to reseat, it is necessary to achieve cold shutdown in order to terminate the primary to secondary break flow and the release to the atmosphere through the open safety valve.

B.1.5 ECA-3.2

Continuation of a SGTR via actions in ECA-3.2, "SGTR with Loss of Reactor Coolant - Saturated Recovery", occurs due to transition from ECA-3.1 on low RWST level or high level in the ruptured SG. The actions in ECA-3.2 are basically identical to ECA-3.1 except that the subcooling criteria for the RCS depressurization is relaxed in order to attain RHR conditions sooner. Additionally, the operators are instructed to initiate RWST refill upon entry into this procedure.

B.1.6 ECA-3.3

As noted previously, continuation of a SGTR via actions in ECA-3.3, "SGTR without Pressurizer Pressure Control", occurs for those cases in which RCS depressurization via normal spray, PORV or auxiliary spray cannot be accomplished. ECA-3.3 instructs the operators to recover some means of RCS depressurization; failing that the operators are instructed to stop all ECCS flow except for one charging pump when the ruptured SG level rises above 70% narrow range. The remaining charging pump is then aligned to the VCT for normal charging. The RCS cooldown initiated in E-3 is maintained at 100°F/hr, and RCS depressurization to RHR cut-in is achieved via backfill, blowdown or steam dump. During any of these RCS depressurization mechanisms, normal charging and the pressurizer heaters are utilized to maintain RCS subcooling.

RCS and SG depressurization using backfill involves using normal charging and letdown flow to depressurize the RCS thereby 'backfilling' the ruptured SG into the RCS. The ruptured SG level is maintained via operator control of auxiliary feedwater. RCS and SG depressurization using blowdown involves steam dump from the ruptured SG to radwaste via the blowdown isolation valve. Again, auxiliary feedwater is used to control the level in the ruptured SG. Finally, RCS and SG depressurization using steam dump involves steam dump from the ruptured SG to the condenser or the atmosphere using steam dump valves and atmospheric relief valves, respectively. Secondary level is maintained via auxiliary feedwater.

B.1.7 COLD LEG RECIRCULATION

Since a SGTR involves a loss of primary coolant to the secondary system, and not to the containment, the only scenario in which recirculation would be necessary is during bleed and feed cooling (due to failure of AFW). In this instance, low RWST level during bleed and feed cooling directs the operators to ES-1.3, "Transfer to Cold Leg Recirculation".

In this procedure, the operators are first instructed to stop all but one containment spray pump. (Containment spray may have been initiated depending upon the number of operational Reactor Containment Fan Coolers (FCs)). Next the operators are instructed to verify that the RHR pumps and the RHR heat exchanger are available and that the containment sump level is at least 37 inches. If these indications are not available, the operators are instructed to transfer to ECA-1.1, "Loss of Emergency Coolant Recirculation." If the recirculation system is operable, the operators are next instructed to check the RCS pressure to determine whether the SI pumps or charging pumps are required. For this case, one of the high pressure injection pumps will be necessary for high pressure recirculation. The operators are then directed to manually align the ECCS system for recirculation. If the containment spray system was actuated during the event, the operators are then instructed to close the isolation valves to the two cold legs from one of the operating RHR pumps and align that pump to the containment spray header. If these actions are successful, the plant will be maintained in a coolable core condition. If recirculation can not be implemented or maintained, the operators are instructed to transfer to the "Loss of Emergency Coolant Recirculation" procedure. Once ECCS recirculation cooling has been established, the procedures prohibit the operators from attempting to establish normal RHR cooling.

B.1.8 RWST REFILL

The ECA-1.1 procedure ,"Loss of Emergency Coolant Recirculation", is entered if ECCS recirculation cannot be established. The operators are first instructed to initiate makeup to the RWST and then to trip all RCPs. A 100°F/hr cooldown using the steam generators is initiated using whatever means is available. If the RWST level is greater than 5 feet, the operators are instructed to minimize containment spray flow, and to minimize ECCS flow. The operators then begin a 'loop' between the beginning of this procedure and the minimization of ECCS flow until the RWST level falls to less than 5 feet. If the RWST level falls to less than 5 feet, all pumps taking suction from the RWST are stopped and normal charging flow from the VCT is initiated. The operators are then instructed to depressurize the steam generators to 700 psig using whatever means are available. The operators are then instructed to continue to depressurize the steam generators to 160 psig in order to actuate accumulator injection. Further depressurization of the steam generators to atmospheric pressure, after isolating or venting the accumulators, is then directed by the procedure.

At this point a determination is to be made by the TSC concerning whether the normal RHR system can be placed in service for heat removal. If normal RHR cooling cannot be established, cold shutdown can be achieved through continued steam generator cooling if sufficient inventory is available in the VCT. If the RWST refill results in an increasing level in the RWST above 5 feet, the operators are instructed to return to the beginning of ECA-1.1 which deals with maintaining minimum draining of the RWST via the ECCS and containment spray pumps. If the RWST level can not be restored and normal makeup cannot be established and maintained, the accident would progress to core overheating. The final instruction in this procedure is to consult the TSC for further directions.

B.1.9 INADEQUATE CORE COOLING

The operators are directed to FR-C.1, "Response to Inadequate Core Cooling", by the CSF Status Tree from an indication of either 1) core exit thermocouple temperatures in excess of 1200°F, or 2) core exit thermocouple temperatures in excess of 700°F and the Reactor Vessel Level Instrumentation System (RVLIS) narrow range reading of less than 40%. The major actions in FR-C.1 are to open both PORVs and block valves, and the reactor vessel head vent; also depressurize all steam generators to atmospheric pressure. Core damage is predicted to occur for all SGTR scenarios which lead to inadequate core cooling indications.

B.1.10 HIGH CONTAINMENT PRESSURE

If the containment pressure exceeds 23 psig (orange path) or 47 psig (red path), the operators are instructed via the CSFSTs to transfer to the "Response to High Containment Pressure" procedure (FR-Z.1).

B.2 PLANT RESPONSE TREE MODELING OF EOPs

The plant response tree includes operator actions that are necessary to prevent core damage and containment failure. The emergency procedures listed below were reviewed to determine the expected tasks that the operators would perform.

EOP/FRP	Name	Reviewed in
E-0	Reactor Trip or Safety Injection	Table B-1
E-3	Steam Generator Tube Rupture	Table B-2
ECA-3.1	SGTR with Loss of Reactor Coolant Subcooled Recovery	Table B-3
ECA-3.2	SGTR with Loss of Reactor Coolant Saturated Recovery	Table B-4
ECA-3.3	SGTR without Pressurizer Pressure Control	Table B-5
FR-H.1	Response to Loss of Secondary Heat Sink	Table B-6

EOP/FRP	Name	Reviewed in
ES-1.3	Transfer to Cold Leg Recirculation	Detailed in Human Error Analysis
ECA-1.1	Loss of Emergency Coolant Recirculation	Table B-7
FR-S.1	Subcriticality (ATWS)	Modeled in ATWS Event Tree
FR-C.1	Response to Inadequate Core Cooling	Table B-8
FR-Z.1	Response to High Containment Pressure	Table B-9

The EOPs/FRPs were reviewed in detail to:

- o Determine the key actions that the operators must perform to prevent core damage or containment failure.
- o Evaluate the impact of the EOPs in terms of the frontline success criteria.
- o Ensure that all appropriate alternate means to satisfy the safety functions are addressed.
- o Ensure that the EOPs do not lead the operators to perform unnecessary tasks or allow them to enter a "logic loop" that is difficult to exit.

- Ensure that the EOPs do not lead the operators to perform activities which could worsen an event sequence which progresses to core damage.

TABLE B-1
OPERATOR ACTIONS FOR E-0

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
1. Verify Reactor trip	Decreasing neutron flux and power range channels less than 5% will be indicated if reactor trip; otherwise transfer to ATWS plant response tree.
2. Verify Turbine trip	Turbine trip and generator trip should occur on reactor trip. Turbine can be tripped manually. This operator action is not modeled.
3. 4KV ESF Buses - ALL ENERGIZED	Availability of Engineered Safeguards Features (ESF) buses included in support state, operator actions to establish failed buses are not included on the event tree or in the support state model.
4. Check if SI Actuated	SI signal and manual actuation of SI modeled in support state.
5. Verify ESF equipment Alignment	Manual actuation included in support state model.
b. Verify affected Unit's auxiliary building cooler SW supply valve OAOV SW0020 -open (U1) OAOV SW0021 -open (U2)	Room coolers do not need to be specifically modeled in system analyses (Reference 17)
6. Verify BIT flow	No impact on accident for failure of BIT to open.
7. Check if SI pumps should have flow:	
a. RCS pressure less than 1850 psig	RCS pressure expected to be < 1850 psig. SI pumps should have flow.
b. Verify SI pump flow	Manual action modeled in support states.

TABLE B-1
OPERATOR ACTIONS FOR E-0

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
8. Check RHR pumps should have flow:	
a. RCS pressure less than 500 psig	RCS pressure expected to be greater than 500 psig, therefore no flow expected; CCW established for RHR mini-flow recirculation, HX isolation valves MOV-CC9412 A & B opened. CCW to HXs prevents RHR pump failure while on miniflow. Operator actions specifically modeled.
b. Verify RHR flow	RHR pumps will not have flow.
9. Verify total AFW flow	If flow is less than 340 gpm, go to FR-H.1, Step 1. This action is specifically modeled.
10. Verify CS flow	Containment pressure < 23 psig, therefore no spray pumps running; Go to Step 11.
11. Check RCS Avg. Temp trending to	If T less than 547°F verify steam dump valves, SG atmospheric relief valves, and main Feedwater (FW) regulating valves CLOSED; isolate steam to Main Steam Reheaters (MSRs), close MSIVs. If T greater than 547°F, operators would dump steam as described above.
12. Check PZR PORVs & Spray	Open PORV(s) or active spray not expected due to depressurization transient; action not modeled.
13. Transfer Steam Dump to Steam Pressure Mode	Steam dump to control Tavg via condenser or atmospheric relief valves gives same results; action not modeled.

TABLE B-1 (continued)
OPERATOR ACTIONS FOR E-0

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
14. Check if RCPs should be stopped	RCS pressure expected to be greater than 1250 psig; RCPs not stopped. Inadvertent trip of RCPs considered in Node DP via inability to use normal spray for RCS depressurization.
15. Go to E-3	Steamline radiation, pressure and rising SG level will cause transfer to EOP E-3.

TABLE B-2
OPERATOR ACTIONS FOR E-3

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
1. Notify Support Personnel	Action not modeled, task will not impact progression of event nor success criteria.
2. Stop RCPs	RCS pressure expected to be greater than 1250 psig; RCPs not stopped. Inadvertent trip of RCPs considered in Node DP via inability to use normal spray for RCS depressurization.
3. Identify Ruptured SG	Ability to identify ruptured SG affects time available to perform actions to stop SGTR break flow. Action modeled as part of isolation steps in PRT.
4. Close Ruptured SG MSIV	Action specifically modeled in PRT. If Ruptured SG MSIV can not be closed, close intact SGs MSIVs; this action specifically modeled in PRT. If any ruptured SG can not be isolated from intact SGs, Go to ECA-3.1; this action specifically modeled in PRT.
5. Isolate Flow from Ruptured SG - Close ARV - Close TD AFW pump Steam Supply - Close Blowdown Isolation Valve	Action modeled in PRT as part of operator action to close MSIV (Step 4), thereby isolating ruptured SG from intact SGs.
6. Isolate AFW Flow to Ruptured SG	Action Specifically Modeled in PRT.
7. Check PZR PORVs and Block Valves	PZR PORVs not expected to be open due to RCS depressurization; action not modeled.

TABLE B-2 (continued)
OPERATOR ACTIONS FOR E-3

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
8. Check for Faulted SG	Secondary break not expected as consequential event; action not modeled.
9. Control Intact SG Level	Level should be stable with AFW flow; failure of AFW modeled in E-0. Action not modeled here.
10. Verify AC Buses - Energized by Offsite Power	Actions to ensure service air and instrument air in the event of a loss of offsite power are not specifically modeled.
11. Reset SI	If offsite power is lost after SI reset, some safeguards equipment would have to be restarted; the probability of a loss of offsite power during this time interval is small and not modeled. Action not modeled.
12. Establish Instrument air to containment	Action not specifically modeled; task will not impact progression of event nor success criteria.
13. Check Ruptured SG Press - LESS THAN 600 PSIG	Pressure expected to be controlled to no-load Temp, thus greater than 600 psig. However, if SG overfill occurs, failure to reseat of a safety valve may result in response obtained and transfer to ECA-3.1; action specifically modeled via SG overfill.
14. Initiate RCS cooldown via steam dump from Intact SGs	Action specifically modeled in PRT.
f. Begin concurrent RCS depressurization if normal spray available	Action not modeled; assumption in PRT that RCS cooldown complete prior to RCS depressurization

TABLE B-2 (continued)
OPERATOR ACTIONS FOR E-3

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
15. Check Ruptured SG Press - STABLE OR INCREASING;	Action implicitly modeled via transfer to ECA-3.1 after SG overfill, failure of safety valve to reseat and ruptured SG depressurization.
16. Check RCS Subcooling - GREATER THAN 30°F	Action implicitly modeled via consideration of RCS cooldown in Step 14 and SG overfill.
17. Check if RCS Depress should be stopped, IF in progress	Action not modeled, Concurrent RCS depressurization not assumed.
18. Depressurize RCS	Action specifically modeled in PRT. If RCS depressurization can not be performed, transfer to ECA-3.3; action specifically modeled in PRT.
19. Stop RCS Depress	Action specifically modeled as part of Step 18.
20. Check RCS Pressure - INCREASING	Failure to stop RCS depressurization not specifically modeled; task will not impact progression of event nor success criteria.
21. Check for SI termination	Action specifically modeled in PRT as part of Step 22. If criteria for SI termination not met, go to ECA-3.1; action specifically modeled in PRT via SG overfill.
22. Stop all ECCS Pumps but one charging pump	Action specifically modeled in PRT.
23. Close IVSW Injection to Letdown and RCP Seal Return Lines	Action implicitly modeled in PRT as part of Step 24 to establish normal charging.

TABLE B-2 (continued)
OPERATOR ACTIONS FOR E-3

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
24. Establish Normal Charging Flow with remaining charging pump	Action specifically modeled in PRT.

NOTE: Successful completion of these 24 steps will result in termination of primary to secondary break flcw, and a 'successful' end state. Otherwise, the operators will be in a different EOP. Thus there will be no further consideration of E-3.

TABLE B-3
OPERATOR ACTIONS FOR ECA-3.1

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
1. Reset SI	Action not specifically modeled in PRT. See Step 11 in E-3.
2. Verify all AC Buses - Energized by Offsite Power	Action to ensure service air and instrument air in the event of a loss of offsite power are not specifically modeled.
3. Establish Instrument Air to Containment	Action not specifically modeled; task will not impact progression of event nor success criteria.
4. Check Containment Spray - pumps running	Spray pumps not expected to be running; Go to step 5.
5. Initiate Evaluation of Plant Status	Action not modeled; task will not impact progression of event nor success criteria.
6. Check for Faulted SG	Secondary break not expected as consequential event; action not modeled.
7. Control Intact SG Level	Level should be stable with AFW flow; failure of AFW modeled in E-0. Action not modeled here.
8. Initiate RCS Cooldown with intact SGs OR ruptured SG OR RHR	Action tc initiate RCS cooldown with intact SGs specifically modeled in PRT.
9. Check RCS Subcooling - GREATER THAN 30°F	Action modeled implicitly as a necessity before next modeled operator action: ECCS reduction.
10. Check for transfer to ECA-3.2: - RWST Level > 19.5 ft - SG Level > 96% NR	Action implicitly modeled in PRT via SG overfill.

TABLE B-3 (Continued)
OPERATOR ACTIONS FOR ECA-3.1

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
11. Check if ECCS in Service	Action not specifically modeled; task will not impact progression of event nor success criteria.
12. Turn off PZR Heaters	Action not specifically modeled; task will not impact progression of event nor success criteria.
13. Depressurize RCS to fill PZR	Action not specifically modeled in PRT. Once in ECA-3.1, only RCS cooldown and ECCS reduction to 1 high pressure injection pump is considered.
14. Check RCP Cooling	RCP Cooling expected; action not specifically modeled.
15. Start/Stop 2 RCPs	Insignificant impact on transient; only impact on normal spray capability. Action not modeled.
16. Stop 1 Charging Pump	Action specifically modeled in PRT as part of SI reduction step.
17. Check if Normal Charging should be established	Action not specifically modeled in PRT. Once in ECA-3.1, only RCS cooldown and ECCS reduction to 1 high pressure injection pump is considered.
18. Close IVSW Injection to RCP Seal Water Return Valves	Action not specifically modeled in PRT. Once in ECA-3.1, only RCS cooldown and ECCS reduction to 1 high pressure injection pump is considered.
19. Establish Normal Charging Flow	Action not specifically modeled in PRT. Once in ECA-3.1, only RCS cooldown and ECCS reduction to 1 high pressure injection pump is considered.
20. Stop 1 SI Pump	Action specifically modeled in PRT as part of SI reduction step.

TABLE B-3 (continued)
OPERATOR ACTIONS FOR ECA-3.1

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
21. Stop Last SI Pump	Action specifically modeled in PRT as part of SI reduction step.

NOTE: Successful RCS cooldown and reduction of ECCS to 1 high pressure injection pump will result in Success with Accident Management (SAM) end state; no further steps are considered.

TABLE B-4
OPERATOR ACTIONS FOR ECA-3.2

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
1. Initiate Makeup to RWST	Action specifically modeled in PRT.
2. Check for Faulted SG	Secondary break not expected as consequential event; action not modeled.
3. Control Intact SG Level	Level should be stable with AFW flow; failure of AFW modeled in E-0. Action not modeled here.
4. Initiate RCS Cooldown with intact SGs OR ruptured SG OR RHR	Action to initiate RCS cooldown with intact SGs specifically modeled in PRT.
5. Check RCS Subcooling - GREATER THAN 30°F	Action modeled implicitly as a necessity before next modeled operator action: ECCS Reduction.
6. Check if ECCS in Service	Action not specifically modeled; task will not impact progression of event nor success criteria.
7. Turn off PZR Heaters	Action not specifically modeled; task will not impact progression of event nor success criteria.
8. Depressurize RCS (to fill PZR)	Action not specifically modeled in PRT. Once in ECA-3.2, only RWST refill or RCS cooldown and ECCS reduction to 1 high pressure injection pump considered.
9. Check RCP Cooling	RCP Cooling expected; action not specifically modeled.
10. Start/Stop 2 RCPs	Insignificant impact on transient; only impact on normal spray capability. Action not modeled.
11. Stop 1 Charging Pump	Action specifically modeled in PRT as part of SI reduction step.

TABLE B-4 (continued)
OPERATOR ACTIONS FOR ECA-3.2

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
12. Check if Normal Charging should be established	Action not specifically modeled in PRT. Once in ECA-3.2, only RWST refill or RCS cooldown and ECCS reduction to 1 high pressure injection pump considered.
13. Close IVSW Injection to RCP Seal Water Return Valves	Action not specifically modeled in PRT. Once in ECA-3.2, only RWST refill or RCS cooldown and ECCS reduction to 1 high pressure injection pump considered.
14. Establish Normal Charging Flow	Action not specifically modeled in PRT. Once in ECA-3.2, only RWST refill or RCS cooldown and ECCS reduction to 1 high pressure injection pump are considered.
15. Stop 1 SI Pump	Action specifically modeled in PRT as part of SI reduction step.
16. Stop Last SI Pump	Action specifically modeled in PRT as part of SI reduction step.

NOTE: Successful RCS cooldown and reduction of ECCS to 1 high pressure injection pump will result in Success with Accident Management (SAM) end state; no further steps are considered.

TABLE B-5
OPERATOR ACTIONS FOR ECA-3.3

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
1. Check Ruptured SG Level - less than 70%	Assume level at or near 70% by the time ECA-3.3 implemented or during unsuccessful attempt to restore pressurize pressure control; therefore go to Step 10.

NOTE: Steps 2 through 7 involve establishing pressurizer pressure control. These actions are not modeled in the PRT since it is assumed that there is no pressurizer pressure control.

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
8. Control Intact SG Level	Level should be stable with AFW flow; failure of AFW modeled in E-0. Action not modeled here.
9. Check PRZR Level - GREATER THAN 4%	Level not expected in pressurizer without PRZR pressure control, Go to next step.
10. Check for SI termination	Action specifically modeled in PRT as part of Step 11.
11. Stop all ECCS Pumps but one charging pump	Action specifically modeled in PRT.
12. Close IVSW Injection to Letdown and RCP Seal Return Lines	Action implicitly modeled in PRT as part of Step 13 to establish normal charging.
13. Establish Normal Charging Flow with remaining charging pump	Action specifically modeled in PRT.

NOTE: Successful completion of these 13 steps will result in termination of primary to secondary break flow, and a 'successful' end state. Thus there will be no further consideration of ECA-3.3.

TABLE B.6
OPERATOR ACTIONS FOR FR-H.1

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
1. Check for Secondary Heat Sink	RCS Pressure > SG Pressure, therefore operator stays in FR-H.1.
2. Try to Establish AFW Flow	Manual actuation of AFW modeled in fault trees.
3. Stop all RCPs	Action modeled in subsequent action to initiate RCS bleed and feed.
4. Check if at least 1 charging pump available	Action specifically modeled in PRT; if no charging pump available, go to Step 14 and begin bleed and feed.
5. Check for Offsite Power	Action not modeled in PRT; task will not impact event progression nor success criteria.
6. Check Condensate System	Action modeled as part of action to establish alternate feedwater.
7. Align Safeguards for FW pump	Action modeled as part of action to establish alternate feedwater.
8. Check Condenser Hotwell level - GREATER than (-) 30 in.	Action modeled as part of action to establish alternate feedwater.
9. Establish Main FW Flow to at least 1 SG	Action specifically modeled in PRT.
	If FW pump can not be started, go to Step 11.
10. Check SG Level GREATER THAN 4%	Action specifically modeled in PRT; if Step 9 successful, return to E-0. Otherwise continue with FR-H.1.

TABLE B.6 (continued)
OPERATOR ACTIONS FOR FR-H.1

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
11. Establish Flow from Condensate System	Action modeled as part of action to establish alternate feedwater.
12. Check SG Level GREATER THAN 4%	Action specifically modeled in PRT; if Step 11 successful, return to E-0. Otherwise continue with FR-H.1.

NOTE: Due to return of level in ruptured SG, operator may transfer back to E-0. However, loss of level in all 4 SGs following attempted RCS cooldown will return operator to FR-H.1

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
13. Check SG Level: - <24% in 3 SGs	Action specifically modeled in PRT; go to next step. If >24%, operator will continue attempts to establish alternate feedwater.
14. Initiate Manual SI	High pressure injection already modeled.
15. Verify ECCS Injection path	High pressure injection already modeled.
16. Establish RCS Bleed path	Action specifically modeled in PRT.
17. Verify RCS Bleed path	Action modeled as part of Step 16.
18. Maintain RCS heat removal	Action not specifically modeled; task will not impact event progression nor success criteria.
19. Open CC water from RHR HX isolation valves	Action specifically modeled in PRT.
20. Reset SI	Action not specifically modeled; task will not impact event progression nor success criteria.
21. Establish Instrument Air to Containment	Action not specifically modeled; task will not impact event progression nor success criteria.

TABLE B.6 (continued)
OPERATOR ACTIONS FOR FR-H.1

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
22. Continue attempts to establish heat sink	Action to establish alternate feedwater after bleed and feed initiation not modeled; see also Section 3.0.
23. Check SG level	No SG level if heat sink not established; return to Step 22. Operator remains 'caught' between Steps 22 and 23 until RWST low level alarm. At this time, transfer to ECA-3.1, Cold Leg Recirculation.

NOTE: Operator may continue with FR-H.1 due to level in the ruptured SG. Subsequent actions include closing PORVs, and sequentially stopping ECCS pumps. However, lack of RCS cooldown capability will result in reinitiation of bleed and feed.

TABLE B-7
OPERATOR ACTIONS FOR ECA-1.1

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
1. Try to Restore ECCS Recirculation Equipment	Action not specifically modeled; task will not impact event progression nor success criteria.
2. Initiate Makeup to RWST Using Appendix A	Discussed separately.
3. Stop All RCPs	RCPs expected to be stopped, action not modeled.
4. Initiate RCS Cooldown to Cold Shutdown	RCS cooldown already initiated, action not modeled.
5. Verify RCFCs -RUNNING IN LOW SPEED	Fault tree models RCFCs running in low speed.
6. Check RWST Level - GREATER THAN 5 FEET	If less than 5 feet go to step 12.
7. Minimize Containment Spray Flow, If Activated:	
a. Check CS - ACTIVATED	CS expected to be activated, if not go to step 8.
b. Check containment pressure LESS than 47 PSIG	Containment pressure expected to be less than 47 PSIG (if not stop all but two CS pumps; go to step 8).
c. Check containment pressure LESS than 23 PSIG	Containment pressure expected to be less than 23 PSIG if ECCS injection is successful (if not and if at least 3 RCFCs are running in LOW speed, then stop all CS pumps).
d. Reset Phase B	Action not modeled; task will not impact event progression nor success criteria.
e. Stop all CS pumps	Action not specifically modeled, but flow rate would depend on no CS pumps operating.
8. Reset SI	Action not modeled; task will not impact event progression nor success criteria.

TABLE B-7 (continued)
OPERATOR ACTIONS FOR ECA-1.1

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
9. Minimize ECCS flow	Action specifically modeled in refill operator actions.
10. Verify Adequate ECCS flow	Action not specifically modeled; task will not impact progression of event nor success criteria.
11. Check RWST Level - LESS Than 5 feet	If greater than 5 feet return to step 1, observe caution which states that "If ECCS recirculation capability is restored during this procedure, further actions should continue by returning to procedure and step in effect. If suction source is lost to any ECCS or spray pump, the pump must be stopped." Action not specifically modeled.
12. Stop Pumps Taking Suction From RWST	Action not specifically modeled; task will not impact progression of event nor success criteria.
13. Maximize Makeup to VCT	Action not specifically modeled; task will not impact progression of event nor success criteria.
14. Establish Normal Charging Flow	Action modeled in refill node on PRT.
15. Depressurize All Intact SGs to 700 PSIG at maximum rate	RCS already depressurized below 700 PSIG.
16. Depressurize All Intact SGs inject Accumulators	Action not specifically modeled; task will not impact progression of event nor success criteria.
17. Energize and close all SI Accumulator Isolation criteria. Valves	Action not specifically modeled; task will not impact progression of event nor success

TABLE B-7 (continued)
OPERATOR ACTIONS FOR ECA-1.1

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
18. Initiate Depressurization of Intact SGs to Atmospheric Pressure	RCS cooldown already initiated.
19. Check if RHR should be placed in service	Action implicitly modeled in refill operation in PRT.

TABLE B-7 (continued)
OPERATOR ACTIONS FOR ECA-1.1
APPENDIX A

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
1. Refill RWST Using Any Method Available	
- Refill RWST using blender makeup 1. Close makeup injection to VCT isolation valve FCV-VC0111B 2. Close makeup injection to charging pump header isolation valve FCV-VC0110B 3. Locally open blender to RWST stop VC-8434 4. Locally open blender isolation to RWST VC-8434. 5. Adjust makeup controls for MAXIMUM primary water and boric acid flows 6. Start makeup flow	Method included as part of refill node on PRT.
- Refill RWST from other Unit's RWST:	
Gravity feed by opening refueling water purification pump suction from RWST valves 1SF8758 and 2SF8758	Method included as part of refill node on PRT.
OR	
Use portable sump pump	Method NOT included, since item above was included and this is an OR statement.
OR	
Use refueling water purification pump	Method NOT included, since item above was included and this is an OR statement.

TABLE B-7 (continued)
OPERATOR ACTIONS FOR ECA-1.1
APPENDIX A

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
- Refill RWST from spent fuel pit	Method included as part of refill node on PRT.
- Consult TSC on refilling RWST from: - Primary Water - Demineralized Water - Fire Water	These methods were NOT included since they are not borated and the TSC is to be consulted prior to using.

TABLE B-8
OPERATOR ACTIONS FOR FR-C.1

NOTE: FR-C.1 actions not modeled on PRT (See assumptions in section 3.0). The description of actions are included here for completeness.

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
1. Verify ESF Equipment Lineup	Recovery of ESF equipment not specifically modeled on PRT; task will not impact event progression nor success criteria.
b. Verify affected Unit's Aux Building coolers SW supply open	Room coolers do not need to be specifically modeled in system analyses (Reference 17).
2. Verify Bit Flow	If BIT flow cannot be verified, then operators start charging pumps and align valves. Action not modeled.
3. Check if SI pumps should have flow	Credit for manual action included in support state model.
4. Check if RHR pumps should have flow	Credit for manual action included in support state model.
5. Check RCP support conditions available	RCPs will probably be stopped. No impact on accident; action not modeled.
6. Align SI Accumulators	Accumulators are assumed to discharge if pressure is $\leq$ 650 psig; accumulators already aligned; manual alignment not modeled.
7. Check Core Cooling a. Exit TCs < 1200°F	If TCs > 1200°F, go to step 8.
b. Check Reactor Vessel Level Instrumentation (RVLIS) - narrow range available	Action not modeled; task will not impact event progression nor success criteria.

TABLE B-8 (Continued)
OPERATOR ACTIONS FOR FR-C.1

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
c. RVLIS narrow range - greater than 40% (50% adverse containment)	If increasing return to step 1. If RVLIS either not available or decreasing go to 7.e.
d. Return to procedure and step in effect	If inadequate core cooling, then would not return to step in effect.
e. Check core exit TCs - less than 700°F	If decreasing return to step 1, if decreasing go to step 8. Step 7 not specifically modeled as actions in steps 1 through 6 are not modeled.
8. Check Containment Hydrogen	
a. notify Rad Chem to align hydrogen analyzer	Rad Chem is notified to sample containment for hydrogen concentration. This action is not modeled.
b. Hydrogen concentration	If greater than 0.5%, consult TSC for actions to reduce hydrogen concentration. This step should be evaluated (what will TSC do?).
9. Reset SI	Action not specifically modeled; task will not impact progression of event nor success criteria.
10. Check Intact SG Levels	Action not required or modeled; task will not impact progression of event nor success criteria.
11. Check RCS Vent Paths	Action to close vent paths not specifically modeled on event tree.
12. Depressurize all intact SGs to 160 psig	Action not required or modeled; task will not impact progression of event nor success criteria.

TABLE B-8 (Continued)
OPERATOR ACTIONS FOR FR-C.1

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
13. Close all SI Accumulator Isolation Valves	Action not modeled; task will not impact progression of event nor success criteria.
14. Stop all RCPs	RCPs should be stopped or not functional, action not modeled.
15. Depressurize all intact SGs to atmospheric	This would be a continuation of depressurization in ES-1.3; action not modeled.
16. Verify ECCS flow	Credit for manual action is included in support state model.
17. Check Core Cooling a. Core exit TCs < 1200°F	If Core exit TCs stable or decreasing and RVLIS greater than 70% (adverse) then go to step 18. If > 1200°F go to step 19. Action not modeled.
18. Go to E-1	Only if conditions on core cooling are okay.
19. Core Exit TCs < 1200°F	If > 1200°F, perform the following: start RCPs, open PORVs and block valves, open reactor head vent valves. Operator action to open PZR PORVs specifically modeled.
20. Depressurize all intact SGs to Atmospheric	Minimal impact and not modeled.
21. Check if SI Accumulators should be isolated.	Accumulators expected to inject for most cases; action not modeled.
22. Check if RCPs should be stopped.	RCPs not expected to be operable. Action not modeled.

TABLE B-8 (continued)
OPERATOR ACTIONS FOR FR-C.1

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
23. Verify ECCS flow	Verification action not specifically modeled.
24. Check core cooling	If inadequate, return to step 19. May continue indefinitely in procedure if core cooling cannot be established.
25. Go to E-1, Step 11	If step 19 successful, and RHR pumps have flow, would return to E-1.

TABLE B-9
OPERATOR ACTIONS FOR FR-Z.1

NOTE: FR-Z.1 actions not modeled on PRT (See assumptions in section 3.0). The description of actions are included here for completeness.

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
1. Verify containment isolation and IVSW injection	Not modeled on event tree until containment isolation is addressed.
2. Verify RCPs - off	Action not modeled; task will not impact event progression nor success criteria.
3. Verify CS flow	Manual start of pumps included in system analysis, operator action not modeled on event tree.
4. Verify RHR aligned for spray	RHR spray recirculation not required for containment heat removal for initial 24 hours of event; action not modeled.
5. Verify proper RCFCs operation	Manual start of non-running RCFCs included in system analysis, operator action not modeled on event tree.
6. Verify MSIVs & bypass valves closed	Action not specifically modeled on event tree, MSIVs expected to close on Phase B isolation.
7. Check if faulted SGs are isolated and verify feedwater system isolated	Not expected and action is not modeled. Action not specifically modeled on event tree.
8. Check Containment Hydrogen a. notify Rad Chem to align	Rad Chem is notified to sample containment for hydrogen concentration. This action is not modeled.

TABLE B-9
OPERATOR ACTIONS FOR FR-Z.1

STEP	IMPACT ON PLANT RESPONSE TREE MODEL
b. Hydrogen concentration	If greater than 0.5%, consult TSC for actions to reduce hydrogen concentration. This step should be evaluated (what will TSC do?).
9. Periodically Monitor Hydrogen in Containment	Action not modeled; task will not impact progression of event nor success criteria.

Figure B.1 [Page 1 of 2]
Flow of Zion EOPs For SGTR

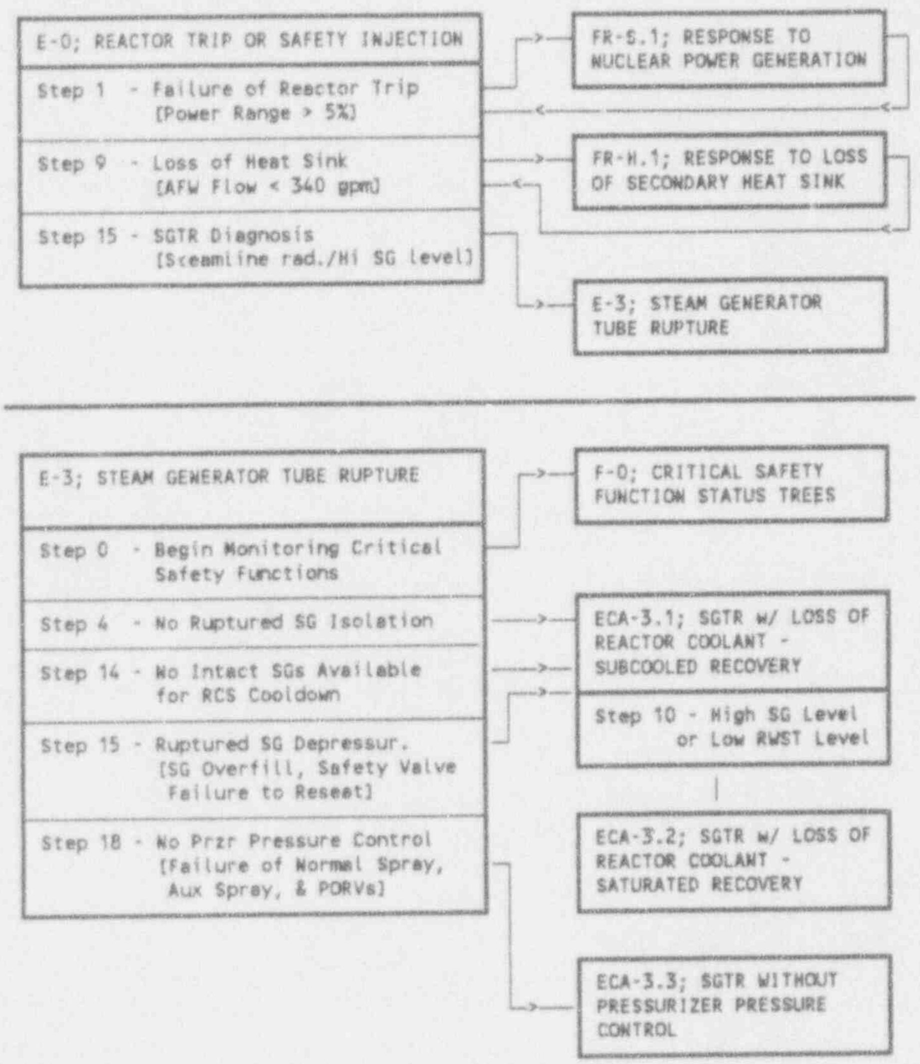


Figure B.1 [Page 2 of 2]
Flow of Zion EOPs For SGTR