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EVALUATION OF THE EFFECTS OF CALVERT CLIFF NUCLEAR POWER STATION ELECTRIC POWER, COMPRESSED AIR AND COOLING WATER SYSTEM FAILURES ON PRESSURIZED THERMAL SHOCK EVENT SEQUENCES*

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ACRONYM DEFINITIONS

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Acronym	Definition
ADV	Atmospheric Dump Valve
AFAS	Auxiliary Feedwater Actuation System
AFS	Auxiliary Feedwater System
AFW	Auxiliary Feedwater
BG&E	Baltimore Gas and Electric Co.
CCW	Component Cooling Water
CEDM	Control Element Drive Mechanisms
CSAS	Containment Spray Actuation Signal
CV	Control Valve
CVCS	Chemical and Volume Control System
EHC	Electro-Hydraulic Control (Turbine Control)
ERV	Designation for Pressurizer Relief Valves (ERV-402 and ERV-404)
ESFAS	Engineered Safety Features Actuation System
FSAR	Final Safety Analysis Report
HPSI	High Pressure Safety Injection
HVAC	Heating, Ventilating and Air Conditioning
I/P	Current to Pneumatic (Transducer)
KVAC	Thousand Volts, Alternating Current
LOCA	Loss of Coolant Accident
LPSI	Low Pressure Safety Injection
MCC	Motor Control Center
MFIV	Main Feedwater Isolation Valve
MFW	Main Feedwater
MOV	Motor Operated Valve

ACRONYM DEFINITIONS (Continued)

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Acronym	Definition
MSIV	Main Steam Isolation Valve
MT	Mechanical Trip
MTSV	Master Trip Solenoid Valve
ORNL	Oak Ridge National Laboratory
PRV	Pressurizer Relief Valve
PTS	Pressurized Thermal Shock
RC	Reactor Coolant
RCP or RC Pump	Reactor Coolant Pump
RCS	Reactor Coolant System
SCFM	Standard Cubic Feet per Minute
SG	Steam Generator
SGIS	Steam Generator Isolation Signal
SIAS	Safety Injection Actuation Signal
SLB	Steam Line Breaks
TBV	Turbine Bypass Valve
VAC	Volts, Alternating Current
VCT	Volume Control Tank
VDC	Volts, Direct Current

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1.0 INTRODUCTION

An analysis of the Calvert Cliffs Nuclear Station is being performed by the Oak Ridge National Laboratory (ORNL) to assess the potential risk due to Pressurized Thermal Shock (PTS). The PTS analysis consists of identifying and estimating the frequency of sequences of events leading to low temperature, high pressure conditions at the reactor vessel wall, estimating the thermal response to the reactor vessel wall to these conditions, and calculating the conditional probability of a through wall crack for the sequences of interest. These analysis elements are combined to assess the overall risk due to PTS.

This report describes the response of key plant systems identified in PTS sequences to failures of required support systems. Support system failures can be of importance due to the potential for single support system failures resulting in multiple failures of the systems comprising the PTS event sequences. Based on a review of the Calvert Cliffs systems' designs, the electric power, compressed air and cooling water systems have been identified as required support systems for the systems and associated control instrumentation comprising the Calvert Cliffs PTS event tree sequences.

In addition to these support systems, the necessity of the plant's heating, ventilating and air conditioning (HVAC) systems for continued plant operation was recognized. However, the effect of HVAC failures on equipment performance is expected to be long term with respect to the effects of failures of the other identified support systems. In general, the effects of HVAC failures and severe equipment operating environments is considered to be beyond the scope of this analysis.

The electric power, compressed air and cooling water support systems have been evaluated to specify potentially PTS adverse responses of the systems and functions identified in the PTS event tree sequences to support system failure.

The major results of the support system failure analysis are summarized in Section 2. In Section 3, the methodology used to identify and analyze the plant systems and components responses to support systems failures is

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described. Using this methodology, systems and components which may affect PTS sequences are identified and described in Section 4. The common cause failures adverse to PTS which could occur in response to support system failures are discussed in Section 5.

The identification of support systems failures which could lead to multiple adverse PTS sequence events is the first step in evaluating their impact. Although not assessed in this analysis, the frequency of each support system failure and associated events (including the effects of operator intervention) must be calculated and compared to the frequencies of equivalent sequences occurring independently to evaluate the overall impact of support system failures on the PTS sequences.

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2.0 SUMMARY OF RESULTS

The Calvert Cliffs systems and components identified in the PTS event trees have been analyzed to determine the effects of postulated initiating failures of the electric power, compressed air and cooling water support systems. Support system failure modes were selected based on two criteria: the failure mode resulted in at least one system or component response adverse to PTS and the failure mode could be initiated by a single postulated failure in one of the possible support system configurations (i.e., including non-random multiple failures). Based on the identified support system failure modes, the responses of all systems and components identified from the PTS event trees to each failure mode were analyzed to determine whether multiple, coupled responses existed.

Four support system failure modes were identified which would result in multiple, coupled responses adverse to PTS:

1. Failure of Vital Buses Y01 and Y02: This double vital bus failure would result in opening the pressurizer relief valves (an isolatable small LOCA) and delay of the initiation of High Pressure Safety Injection (HPSI) until manually initiated or either of the vital buses was recovered.
2. Failure of 4 KVAC Buses 11 and 12: Failure of these two buses would result in termination of the cooling water flow to the RC Pump seals (RC pumps assumed to be running) and deenergizing the standby HPSI system. Failure of the operator to trip the RC pumps under these conditions would lead to RC pump seal failure (a small LOCA) and subsequent delayed initiation of the HPSI.
3. Failure of Motor Control Centers (MCC's) 104R and 114R: Failure of MCC's 104R and 114R would result in runback of the main feedwater pumps, loss of the instrument air and plant air compressors' control power (120 VAC buses Y09 and Y10) and deenergizing the HPSI injection valve motors. The eventual depressurization of the instrument air pressure would result in isolation of cooling water to the RC pump seals. Failure of the operator to trip the RC pumps under these conditions would

lead to RC pump seal failure and subsequent delayed initiation of the HPSI. Due to the probable early reactor and turbine trip resulting from the feedwater pump runback, the main feedwater regulating valves are expected to close prior to instrument air depressurization. However, the feedwater bypass valves will open fully.

4. Instrument Air Header Failure: A passive failure of the main instrument air header results in freezing the main feedwater regulating valves in position (open) and isolating cooling water flow to the RC pump seals. Failure of the operator to trip the RC pumps would result in a coupled main feedwater overfeed of both steam generators and an eventual small LOCA.

The four support system failure modes identified are low probability events. In addition, failure of the operator to take available remedial actions is required, in each case, to result in a transient adverse to PTS. The combined frequency of the support system failure and operator action failure should be determined and compared to the uncoupled PTS event tree failure frequencies to evaluate to potential impact on PTS.

In addition to the coupled events described above, support system failures were identified as potential causes of single system and component failures adverse to PTS. These failures, and the coupled events, are listed in Tables 10 and 11 and discussed in Section 5.

3.0 METHODOLOGY

The objective of this study is to identify common cause failures which result from failures in the electric power, compressed air or cooling water systems and affect PTS sequence quantification.

The methodology used in this study is outlined below:

1. Identify plant systems and components potentially affecting the PTS event sequences.
2. Identify the specific failure modes of these systems and components in response to electric power, compressed air or cooling water system failures.
3. Identify the failure modes which are "PTS Adverse" (i.e., make the pressure-temperature response of the reactor coolant system more severe from a PTS standpoint).
4. Identify failures in the electric power, compressed air or cooling water systems which result in one or more PTS adverse failure modes.

Using the methodology outlined above, the common cause effects of support systems failure on PTS sequences can be evaluated. It should be noted that the results obtained are not necessarily applicable to non-PTS accident sequences and have not considered the effects of common cause initiators such as operator errors, severe operating environments, severe natural phenomena or sabotage.

4.0 IDENTIFICATION, SELECTION AND DESCRIPTION OF SYSTEMS AND COMPONENTS AFFECTING PTS SEQUENCES

As discussed in Section 3, the initial tasks of performing the PTS common cause failure analysis involve the selection of systems and components potentially affecting PTS and defining their failure modes in response to support systems failures. In Section 4.1, the selection of Calvert Cliffs' systems and components utilizing the previously developed PTS event sequences is discussed. The designs, interfaces and failure modes of the systems and components are discussed in Section 4.2. The failure modes of the systems and components in response to support systems failures are summarized in Section 4.3.

4.1 SELECTION OF SYSTEMS AND COMPONENTS AFFECTING PTS SEQUENCES

The specific purpose of performing the common cause failure analysis is to determine whether one or more individual "branch events" of the PTS event sequences may occur due to a failure of the support systems. The principal source of information to select the systems and components affecting PTS sequences are the event sequence diagrams.[1] The information contained in the event sequence diagrams was supplemented by associated material used to develop and define the event sequences.[2]

The systems and components identified in the PTS event sequences are listed in Tables 1 and 2. Each system and component identified was evaluated briefly to determine whether a potential failure due to a support system failure was possible. Where no consequential failure was possible, the event need not be considered further.[3] The systems and components identified in the remaining events are analyzed further as discussed in Section 4.2.

4.2 DESCRIPTION OF SYSTEMS' AND COMPONENTS' RESPONSES TO SUPPORT SYSTEMS FAILURES

The designs of systems and components identified in Tables 1 and 2 for which a support system interaction was possible were evaluated to determine the particular response to support system failures. The evaluation of systems' and components' responses typically was performed as follows:

TABLE 1. SYSTEMS AND COMPONENTS IDENTIFIED IN PTS EVENT SEQUENCE INITIATING EVENTS

Systems and Components Identified in Sequence Initiating Events	Potential Initiation Due to Support System Failure*
Reactor Trip (Reactor Protection System)	Yes
Steam Line Breaks (SLB)	
Small Breaks	
Piping Failure	No
Safety Valves Fail Open	No
Atmospheric Dump Valves Fail Open	Yes
Turbine Bypass Valves Fail Open	Yes
Large Breaks	
Piping Failure	No
Failure to Trip Turbine	Yes
Loss of Coolant Accidents (LOCA)	
Small LOCA	
Safety Valves Fail Open	No
Pressurizer Relief Valves Fail Open	Yes
Reactor Coolant Pump Shaft Seal Failures	Yes
Steam Generator Tube Rupture	No
Isolable LOCA Other Than Pressurizer Relief Valves	No
Piping Failure	No
Medium and Large LOCA's	No

*Passive failure events, such as a pipe break, were not considered to occur due to a support system failure. At this level of screening, all "non-passive" events were considered to have a potential for an interaction.

TABLE 2. SYSTEMS AND COMPONENTS IDENTIFIED IN PTS EVENT SEQUENCE BRANCH EVENTS

Systems and Components Identified in Sequence Branch Events	Potential Response To Support System Failure
Main Steam System	
Turbine Trip	Yes
Atmospheric Dump Valves	Yes
Turbine Bypass Valves	Yes
Main Steam Isolation Valves	Yes
Main Feedwater (MFW) System	
MFW Control Valves	Yes
MFW Bypass Valves	Yes
MFW Isolation Valves	Yes
MFW Pump Trip	Yes
Auxiliary Feedwater (AFW) System	
AFW Control Valves	Yes
AFW Isolation Valves	Yes
High Pressure Safety Injection System	Yes
Chemical and Volume Control System	Yes

1. The components of systems potentially affecting system performance due to support system failures (e.g., automatic valves, pump motors, etc.) were identified from system design documentation.
2. The support functions and supplying systems (e.g., 125 VDC Bus 11) required for the operation of the identified components and their control instrumentation circuits were identified from available design documentation or requested from Baltimore Gas and Electric (BG&E) personnel.
3. Failures of identified support system components (e.g., bus at 0 volts, instrument air pressure at 0 psig, etc.) were postulated for each of the systems and components affecting PTS sequences. The responses of the systems and components were identified from available design documentation or requested from BG&E personnel.

The designs of the identified systems and components relating to their failure modes in response to support systems failures are discussed below. Table 3 summarizes the responses to assumed complete failures of support functions.[4] The specific failure modes of the support systems are discussed in Section 5.

The systems and components discussed in Section 4 are described in the Calvert Cliffs Nuclear Power Plants 1 and 2 Updated Final Safety Analysis Report (FSAR). The FSAR information was supplemented by detailed design information provided by Baltimore Gas and Electric Co. (BG&E) as referenced throughout this report.

4.2.1 Reactor Trip

The reactor is tripped by deenergizing each of the control element drive mechanisms (CEDM). The drive mechanisms are energized from either 480 VAC bus 1 or 2 via motor generator sets. The reactor is tripped by opening either trip circuit breaker in each of the four 240 VAC buses from the two motor generator sets.

The trip breakers open when the power from associated 125 VDC buses to their undervoltage coils is interrupted or is supplied to their shunt coils. These

TABLE 3. SUMMARY OF SYSTEM/COMPONENT FAILURE MODES

System/Component	Potential Failure Mode of System/Component Due to Support System Failure			
	Instrument Electric Power Failure (Buses at Zero Volts)	Motive Electric Power Failure (Buses at Zero Volts)	Instrument Air Failure (Supply Piping Depressurized)	Cooling Water Failure (Loss of Cooling Water Flow)
Reactor Trip	Tripped	Tripped	N/A	N/A[6]
Atmospheric Dump Valves	Closed	N/A	Closed	N/A
Turbine Bypass Valves	Closed	N/A	Closed	N/A
Turbine Trip	Trip	N/A	N/A	Eventual Trip
Pressurizer Relief Valves	Open	Closed	N/A	N/A
Reactor Coolant Pump (RCP) Shaft Seals	N/A[2]	N/A[1]	N/A[2]	Eventual Failure
Main Steam Isolation Valves	Open	N/A	N/A	N/A
Main Feedwater (MFW) Regulating Valves	As Is[3]	N/A	As Is	N/A
MFW Bypass Valves	Closed	N/A	Open	N/A
MFW Isolation Valves	Open	Open	N/A	N/A
MFW Pump Trip	Fails to Trip	Trip	N/A	Eventual Trip
Auxiliary Feedwater (AFW) Electric Motor Driven Pump	Off	Off	N/A	N/A[4]
AFW Steam Turbine Driven Pumps	Off	N/A	High Speed	N/A[4]
AFW Control Valves	Closed	N/A	Open[5]	N/A
AFW Isolation Valves	Open	N/A	Open[5]	N/A
High Pressure Safety Injection System	Off	Off	N/A	Eventual Failure
Chemical and Volume Control System	Net Injection	Off	Net Injection	Recirculation Mode

[1]Failure of electric power to RCP motors or pump trip may prevent or delay seal failure on loss of cooling water.
[2]Loss of Instrument Air or instrument power may lead to loss of cooling water to RCP seals.
[3]Loss of electric power to Instrument Air Solenoid valves leads to loss of Instrument Air to MFW Control Valves.
[4]No External Cooling Water System Required.
[5]Backup Accumulators to Compressed Air System Available.
[6]Loss of cooling water to the CEDM can result in dropped rods and possibly eventual reactor trip.

actions are initiated by deenergizing trip circuit breaker relays normally supplied power from the 120 VAC vital instrument buses.

The trip logic is arranged such that failure of any one 120 VAC, 125 VDC, 480 VAC bus or either motor-generator set will not result in reactor trip. However, failure of any two 120 VAC buses, both 480 VAC buses or both motor generator sets will trip the plant. Failure of any three or certain combinations of two 125 VDC buses also will result in reactor trip.[5]

The CEDM's are cooled by the Component Cooling Water (CCW) system.[6] Cooling water is required to maintain electric circuitry within its operating temperature range. Failure of the cooling water supply eventually will result in degradation of the circuitry and release of the individual control rods (rod drop).

4.2.2 Atmospheric Dump (ADV) and Turbine Bypass Valves (TBV)

Four TBV and two ADV are provided to release steam from the main steam line to the condenser or atmosphere, respectively, following main turbine trip. These valves are pneumatically operated and designed to close upon loss of pneumatic pressure.[7,8]

Following turbine trip, the TBV and ADV are "quick opened" by energizing solenoid valves via 125 VDC bus 11 which open to pneumatically pressurize the valve operators. The turbine trip relay (XKT-1194-1) which energizes these solenoids requires power from EHC Cabinet T11 to open the TBV and ADV.[8]

The TBV and ADV may also be opened by manual or automatic signals pressurizing the valve operators via I/P transducers. The manual control station, reactor average temperature (Tav) or steam pressure signals require 120 VAC power from buses Y01, Y02, Y09 and/or Y10 to open the TBV or ADV.[8]

4.2.3 Turbine Trip System

Turbine trip involves closure of the two main stop valves and two main control valves isolating steam from the high pressure turbine.[9] Closure of the stop and control valves results from deenergizing the master trip solenoid valves (MTSV-A, MTSV-B) or energizing the mechanical trip solenoid (MT-5). During

power operation the master trip solenoid valves are energized from Turbine EHC Cabinet T11.[10] EHC Cabinet T11 is energized from 120 VAC bus Y09 or a permanent magnet generator operated off the turbine shaft.[14]

Individual turbine trip conditions result in the Master Trip Bus being energized from T11. Some trip conditions energize the bus directly; others indirectly by energizing 125 VDC relays from 125 VDC bus 11. Energizing the master trip bus energizes the master trip relays which deenergize the master trip solenoid valves.[10]

Loss of T11 directly deenergizes the master trip solenoids resulting in turbine trip. Loss of the 125 VDC bus 11 deenergizes a relay which will energize the master trip bus after a 30 second time delay.[10]

Loss of vital bus Y02 defeats the "reactor tripped" signal to the turbine trip logic.[5] However, following reactor trip, turbine speed cannot be maintained and turbine is expected to trip on other turbine or generator parameters such as low speed.[10]

Although loss of cooling water does not affect turbine trip directly, the service water system does provide cooling water to many turbine, generator and feedwater system components. Loss of service water is expected to result in eventual turbine trip.[6]

4.2.4 Pressurizer Relief Valve (PRV)

The two pressurizer relief valves (PRV) mounted on the pressurizer are designed to open at the high pressurizer pressure trip setpoint to prevent or minimize the lifting of pressurizer code safety valves. PRV's ERV-402 and 404 are opened by energizing their solenoids from 480 VAC motor control centers (MCC) 114R and 104R, respectively. Power is applied by closing contacts in the 480 VAC supply. The contacts are closed by energizing solenoids powered from 120 VAC auxiliary circuits supplied from the associated 480 VAC bus and 125 VDC bus 21.[11,14]

The RCS pressurizer pressure signals used to open the PRV's (energize the control relays) are obtained from the reactor protective system (RPS).

Auxiliary pressurizer pressure trip contacts from the RPS are arranged in a 2 of 4 logic. When any two of the auxiliary contacts trip, indicating high pressurizer pressure, the PRV control relays will be energized and the PRV's opened. When the pressurizer pressure drops below the setpoint the control relays are deenergized by the trip contacts and the PRV's close.[5]

Failure of either the 480 VAC or the 125 VDC buses will result in the PRV's closing or remaining closed. Due to the 2 of 4 logic, failure of any one of the four 120 VAC vital buses supplying the RPS will neither open the PRV nor prevent them from being opened due to high pressurizer pressure. Failure of any two vital buses, however, will result in both PRV's opening and remaining open until manually closed from the control room or one or both vital buses are reenergized.[11,5]

4.2.5 <u>RCP Shaft Seals</u>

The reactor coolant pressure boundaries between the RCS and the RCP shafts are maintained by four mechanical face seals on each RCP shaft. The seals are located above the thermal barrier. Three of the seals are rated for full RCS pressure and the fourth is a low pressure vapor seal.[12]

For proper operation, the shaft seals require a continuous small flow of coolant to lubricate and cool the seals and to equalize the pressure drop across them. The coolant is reduced in temperature in integral pump heat exchangers prior to flowing past the seals. The heat exchangers are cooled by water from the CCW system. After the coolant flows past the three seals it is directed to the Chemical and Volume Control System (CVCS) or diverted to the containment sump.[12,6]

Failure of the CCW flow to the pump heat exchangers will result in higher temperature coolant flowing past the seals and inducing high thermal stresses in the seal faces. After five minutes of operation seal damage could occur.[12] However, pump operation without CCW flow for a longer period of time is expected before complete failure of the seals would occur. If the RCP were tripped prior to seal damage, seal failure would be delayed or prevented.

4.2.6 Main Steam Isolation Valves (MSIV)

The MSIV's (CV-4043 and CV-4048) are designed to isolate the containment and limit the release of steam from the steam generators following main steam line break accidents. One MSIV is located downstream of the main steam safety valves outside the containment in the steam line from each steam generator.[13]

Each MSIV is closed by releasing hydraulic fluid from pressurized accumulators into the upper chamber of the valve's hydraulic actuator and releasing fluid from the lower chamber. The accumulators are designed to close the valve and hold it closed for at least one hour without external motive power requirements. The hydraulic fluid is released to the actuator by opening either of two solenoid valves in the hydraulic flowpath. Either of the two separate solenoid valves are opened to release the fluid from the lower chamber of the actuator.[13]

Each of the four pairs of solenoid valves on the two MSIV's hydraulic circuits are energized to open upon Channel A and Channel B steam generator isolation (SGIS) or Containment Spray Actuation signals (CSAS) from the ESFAS (closing the MSIV's). Since the two solenoid valves in each pair are redundant, failure of one vital bus (120 VAC bus Y01 (ZA) or Y02 (ZB) or associated 125 VDC buses 11 or 21 will not prevent closure of either MSIV on demand. Failure of buses Y01 and Y02 or 125 VDC buses 11 and 12 would prevent closure of both MSIV's.[5,14]

4.2.7 Main Feedwater Regulating Valves

The main feedwater flowrate to each steam generator is controlled by a pneumatically operated regulating valve in response to feedwater demand signals. Flow to steam generators 11 and 12 is controlled by regulating valves CV-1111 and 1121, respectively. The feedwater demand signal for each regulating valve is developed based on steam generator steam and feedwater flowrate and downcomer liquid level. The normal demand signals are overridden by turbine tripped signals which close both regulating valves. The pneumatic supply to the regulating valves from the positioners is isolated automatically by solenoid valves upon low pneumatic supply pressure or loss of power to the control instrumentation. Isolation of the pneumatic supply holds the regulating valve in position.[15,16]

Each valve is opened and closed by admitting pressurized air below or above the pneumatic actuator piston respectively. The air is directed by a transducer/positioner responding to the feedwater demand signal. Steam generator downcomer level is monitored by four measurement channels and the signals combined in a two of four logic. Two or more high steam generator level signals cause turbine trip which results in the feedwater regulating valves being closed.[13]

The regulating valves are designed to remain in position upon loss of pneumatic pressure or control power. A pneumatic supply pressure less than 70 psig to one of the regulating valves' transducers will be detected and results in automatic closure of the regulating valve's three pneumatic supply solenoid valves. This action holds the regulating valve in its existing position.[14,13]

The control instrumentation positioning the regulating valves is powered through 120 VAC panels C35 and C36 for valves CV-1111 and CV-1121 respectively. Panel C35 is supplied power via bus Y01 and an automatically transferred backup bus Y09. Panel C36 is powered via buses Y02 and Y10.[17] Failure of panels C35 or C36 will result in the pneumatic supply isolation valves being deenergized and closing, thus holding the regulating valves in position.[16]

The high SG level input signals to the turbine trip instrumentation are powered from the vital 120 VAC buses. The high level signals are configured in a 2 of 4 logic. A separate high steam generator level signal is developed for each steam generator and combined with the reactor tripped signal in a 1 of 3 logic to develop a turbine trip signal. The 2 of 4 and 1 of 3 ESFAS logic is powered from vital bus Y02 (ZB).[5]

Turbine trip will result in contact signals being sent to the feedwater regulating valve control instrumentation. These relays are powered from 24 VDC panel T11 (EHC Cabinet).[10]

Failure of vital bus Y02 (ZB) will delay turbine trip and feedwater runback depending on the particular plant conditions. Assuming a reactor trip, the

turbine is expected to trip on other resulting parameters such as underspeed. Failure of panel T11 will cause turbine trip as previously discussed. In either case, the normal feedwater controls will reduce feedwater flowrate directly in response to high steam generator level.

4.2.8 Main Feedwater Bypass Valves

Feedwater bypass valves CV-1105 and 1106 are designed to regulate the feedwater flow to steam generators 11 and 12, respectively, at low level conditions. During power operation the bypass valves are normally closed. At low power conditions, the operator normally will manually position the bypass valves to regulate steam generator level. An automatic level control circuit also is available to the operator.[13,14]

Upon turbine trip, the main regulating valves will be closed and a signal generated to open the bypass valve. The valves are positioned by the control circuitry to maintain approximately 5% of the flowrate required at 100% power. The bypass valves continue to maintain this flowrate until manually controlled by the operator.[13]

The control instrumentation for valves CV-1105 and 1106 is powered from 120 VAC panels C35 and C36 respectively. Failure of these panels will produce a zero amp signal to the associated valve transducer and result in valve closure.[15] Failure of T11 (EHC Cabinet) will result in the bypass valves remaining closed and the main regulating valves modulating to control steam generator level as previously discussed. Loss of instrument air to the bypass valves will result in the valves opening.[15]

4.2.9 Main Feedwater Isolation Valves

Main feedwater isolation valves MOV-4516 and 4517 are designed to close and terminate main and bypass feedwater flow to steam generators 11 and 12, respectively. The isolation valves automatically close on a steam generator isolation signal (SGIS) or containment spray actuation signal (CSAS) from the ESFAS and may be manually closed by the operator.[18]

The valve motors for MOV-4516 and 4517 and associated switchgear are powered from 480 VAC MCC-114R and 104R, respectively. MOV-4516 and 4517 each are closed automatically by signals from ESFAS actuation channels A and B.[18,14]

During normal operation the isolation valves are open. Failure of the associated MCC or both ESFAS channel vital power buses will result in the valve remaining open. However, failure of the ESFAS signals will not prevent manual closure provided the 480 VAC power is available.[18,14]

4.2.10 Main Feedwater Pump Trip

ESFAS steam generator isolation or containment spray actuation signals, in addition to closing the MSIV's and MFIV's, will trip the main feedwater, condensate and feedwater heater drain pumps. The pump trip signals are arranged such that the Channel A or Channel B signals will trip the three sets of feedwater pumps. Failure of either channel power supply, 120 VAC vital bus Y01 or Y02, will not prevent pump trip on demand. Failure of 125 VDC bus 11 will prevent tripping pump 11 and failure of 125 VDC bus 21 will prevent tripping pump 12. Failure of both vital buses will prevent steam generator isolation.[14] Although the pump trips require vital power, the main feedwater and condensate booster pumps will trip if the normal power sources to the motor switchgear fail.[14]

In addition to automatic main feedwater pump trip, the speed of the main feedwater pump is regulated to maintain a constant pressure drop across the main feedwater regulating valves.[13] Failure of the 120 VAC power supply to this instrumentation, bus Y09, results in the pump speed being reduced to idle, significantly reducing or terminating train feedwater flow.[14]

Although loss of cooling water will not result directly in a pump trip, loss of service water cooling to the pumps' lube oil coolers will require eventual manual trip on high oil temperature.[6,19]

4.2.11 Auxiliary Feedwater System

The auxiliary feedwater system is designed to provide feedwater to the steam generators if the main feedwater system is incapable of maintaining a minimum steam generator level.

The auxiliary feedwater system consists of two steam turbine driven, 700 gpm pumps and one motor driven 400 gpm pump. The discharge from the turbine driven pumps are combined in a common header and then directed in separate headers to the two steam generators. A pneumatic control valve in each steam generator header controls the flow to 200 gpm. Two pneumatic isolation valves in each header are provided to isolate the flow to a steam generator upon low steam generator pressure via the ESFAS steam generator isolation logic. The flow from the single motor driven pump is directed to the two steam generators in separate headers each with a pneumatic control valve and two pneumatic isolation valves. As designed, the two pumps inject 800 gpm to the two steam generators through four headers. The source of water to the three pumps is condensate storage tank 12.[13,20]

The four steam generator level signals from each steam generator are combined in the ESFAS auxiliary feedwater actuation system (AFAS) in a 2 of 4 logic producing Channel A and Channel B low steam generator level actuation signals. The Channel A signals start the motor driven pump, powered from 4 KVAC bus 11, and open pneumatic steam supply valve CV-4070 from steam generator 11. The channel B signal opens steam supply valve CV-4071 from steam generator 12. Valves CV-4070 and CV-4071 require 125 VDC power from DC buses 11 and 12, respectively, to open.[14] The steam from either steam generator can drive either auxiliary feedwater pump turbine. However, the steam supply to auxiliary feedwater pump turbine 12 is manually isolated to prevent automatic pump start. Downstream of the steam supply valves, pneumatically operated turbine regulating valves are positioned to control turbine speed. The control circuitry is powered by vital bus Y02. Failure of the vital bus will result in maximum turbine speed.[7] Following an AFAS initiation, one steam turbine driven and one motor driven pump will be automatically started.[20,7]

The auxiliary feedwater flowrate from the motor driven pump to each steam generator is controlled separately to 200 gpm with a pneumatic control valve. The flowrate control instrumentation in the motor driven pump flowpaths to the two steam generators is powered from 120 VAC vital bus Y01 (ZA). The flowrate from the steam turbine driven pump is controlled separately in a similar manner with the flowrate control instrumentation powered from 120 VAC vital

bus Y02. In each case, loss of power will result in the associated Train A or Train B control valves closing.[20]

Two pneumatic isolation valves are provided in each of the four flowpaths to the two steam generators. One of the isolation valves in each flowpath is closed by an ESFAS Channel A SGIS signal and the other by a Channel B signal in the event of a steam line break. The ESFAS isolates a steam generator's auxiliary feedwater flow when its steam pressure is greater than 100 psi lower than the other steam generator's pressure.[20]

The twelve valves in the discharge lines and two valves in the steam supply lines are pneumatically operated. Each of these valves are designed to open on loss of instrument air. However, two accumulators are provided to position the feedwater control and isolation valves in the event of a loss of the instrumentation air supply. One accumulator supplies the feedwater control valve in the motor driven pump train and the second supplies the control valves in the steam turbine driven pump train. Each accumulator supplies one of the two isolation valves in each discharge flowpath and one of the two steam supply valves.[20]

The turbine speed regulating valves also are designed to open on loss of pneumatic pressure.[7] However, these valves are not supplied by the accumulators.[20]

The auxiliary feedwater pumps are designed to operate without external cooling water systems.[20]

4.2.12 <u>High Pressure Safety Injection</u>

The High Pressure Safety Injection (HPSI) system is designed to inject borated water from the refueling water storage tank (RWT) to the reactor coolant system in the event of a loss of coolant accident (LOCA).

Borated water from the RWT flows to the three HPSI pumps in two headers which also supply the LPSI and CS pumps. HPSI pumps 11 and 12 are supplied from one header and pump 13 from the other. The three HPSI pumps feed a common header which supplies the main and auxiliary injection header. The main and

auxiliary headers each inject into the four reactor coolant system inlet pipes through separate injection paths.[21]

Electrically, the system is divided into two trains, ZA and ZB, each providing 4 KVAC, 480 VAC and 120 VAC power. HPSI pump 11 and the auxiliary header injection valves are supplied Train ZA power (4 KVAC Unit Bus 11 and 480 VAC MCC 114R), HPSI pump 12 and the main header injection valves train ZB power (4 KVAC bus 14 and 480 VAC MCC 104R). HPSI pump 13 may be electrically connected to ZA or ZB power.[21] The HPSI pump motor circuit breakers, in addition, require 125 VDC power from the associated 125 VDC bus 11 (ZA) or 125 VDC bus 12 (ZB).

The HPSI is initiated by the Train A and B ESFAS safety injection action signals (SIAS) upon a coincidence of 2 of 4 low pressurizer pressure or containment spray actuation signals. Train A signals start HPSI pump 11 and open the auxiliary and main header injection valves. Train B signals start HPSI pump 12 and open the injection valves.[5] HPSI pump 13 is automatically started if the HPSI pump (11 or 12) associated with the HPSI pump 13 power source fails to start (breaker fails to close).[5]

In addition to electric power, the HPSI pumps require cooling water from the Component Cooling Water (CCW) System. Cooling water for the HPSI pumps' bearing and seal coolers is provided from either CCW pump via either CCW heat exchanger.[6,21]

4.2.13 Chemical and Volume Control System

The Chemical and Volume Control System (CVCS) is designed to remove, purify and replace reactor coolant at a controlled flowrate to maintain pressurizer level during reactor operation. The system also is used to inject chemicals to control reactor coolant chemistry, collect and reinject the controlled bleed-off from the RC pump seals and provide high pressure injection of concentrated boric acid following accidents.[22]

The flowrate of letdown reactor coolant is controlled by the letdown flow control valve based on pressurizer level. The reactor coolant is cooled in the letdown heat exchanger and is passed through filters and ion exchangers.

The flow from the ion exchanger to the volume control tank (VCT) is controlled by a three-way valve based on volume control tank level. Normally the flow is routed to the VCT. When boric acid or demineralized water is added to the VCT for reactor coolant chemistry control, the excess flow from the ion exchangers is diverted to the liquid waste processing system.[22]

The coolant in the VCT is injected into the reactor coolant system by three positive displacement charging pumps. One pump is normally in operation. The second and third pump are sequenced on automatically to maintain pressurizer level.[22]

The CVCS emergency mode of operation is initiated by the ESFAS SIAS. In this mode, letdown is isolated, a flowpath from the boric acid tanks to the charging pumps is initiated and the three charging pumps are started.[22]

The CVCS requires instrument air and control power for valve positioning and motive power for the charging pumps to function. Loss of instrument air results in closure of the letdown stop and regulating valves.[6] Injection continues with a single charging pump in operation. Loss of 120 VAC instrument power, bus Y10 or the selected Y01/Y02 bus powering the pressurizer level instrumentation results in a closure signal to letdown control valve CV-110P and starting of the three charging pumps.[23]

Failure of Y02 may affect the charging rate following ESFAS SIAS depending on the selection of Y02 for pressurizer level input. Assuming that bus Y02 is not selected for pressurizer level control, a Y02 bus failure prevents SIAS actuation of charging pump 12 (Note: charging pump 11 continuously operates and need not rely on an SIAS start signal).

Charging pumps 11 and 13 are powered from 480 VAC unit bus 11A (Train ZA) and charging pump 12 from bus 14A (Train ZB).[22]

Cooling water for the letdown heat exchanger is provided by the component cooling water system via component cooling heat exchanger 11. In the event of a loss of cooling water, the CVCS automatically transfers to the recirculation mode, bypassing the ion exchangers, radiation monitor and boron meter.[22]

4.3 SUMMARY OF FAILURE MODE RESPONSES TO SUPPORT SYSTEM FAILURES

In Section 4.2, the responses of the systems and components potentially important to PTS sequences in response to support systems failures were described. These responses are summarized in Section 4.3 and the responses adverse to PTS sequences identified. The responses to electric power, compressed air and cooling water failures are described in Sections 4.3.1, 4.3.2 and 4.3.3.

4.3.1 Responses to Electric Power System Failures

The responses of the systems and components to electric power failures are summarized in Table 4. In addition to summarizing the response, an evaluation of the potential impact on PTS sequences was made. The responses of the systems and components potentially important to PTS sequences are itemized below:

1. Pressurizer Relief valves will fail open following a concurrent failure of two or more vital buses.
2. The main steam isolation valves will fail to close on demand following a concurrent failure of vital buses Y01 and Y02.
3. A main feedwater regulating valve will freeze in position following failure of its associated control power (Panels C35 or C36). Both valves will freeze following a concurrent failure of the two panels.
4. The main feedwater isolation valves will fail to automatically close and main feedwater train pump will fail to automatically trip on demand following a concurrent failure of vital buses Y01 and Y02. The isolation valves also will fail to close if their individual 480 V power supplies fail and the feedwater pumps will fail to trip if their individual 125 VDC power supplies fail.
5. The HPSI will fail to automatically initiate following a concurrent failure of vital buses Y01 and Y02. However, the concurrent failure will initiate the injection mode of the CVCS.

TABLE 4. SUMMARY OF SYSTEM/COMPONENT FAILURE MODES IN RESPONSE TO ELECTRIC POWER SYSTEM FAILURES

System/Component	Failure Mode Response	Potential Impact on PTS Sequences
Reactor Trip	Spurious trip will occur following two or more failures of redundant electric power supplies.	None. Reactor is expected to trip as part of any PTS sequence of interest.
Atmospheric Dump and Turbine Bypass Valves	ADV and TBV operate as designed or fail closed following electric power failures.	No adverse impact. Failure of valves to open will result in a challenge to main steam safety valves.
Turbine Trip	Turbine will trip as designed or spuriously trip following most power supply failures. Failure of vital instrument bus Y02 may result in a delayed turbine trip on demand (failure to trip on reactor trip signal).	Small or no adverse impact. Failure of EHC power results in spurious turbine trip and failure of "quick open" ADV/TBV feature which challenges steam safety valves. Turbine is expected to trip rapidly even if reactor trip input failed based on exceeding other trip setpoints such as speed.
Pressurizer Relief Valves	PRV's will operate properly or close following any single electric bus failure. Failure of two (or more) vital buses will open PRV's (manual closure possible).	Impact on PTS sequences will depend on relative frequency and duration of double bus failures.
RCP Shaft Seals	N/A	No direct impact. However, loss of electric power can result in loss of cooling water to the RCP seals.
Main Steam Isolation Valves	MSIV's will close on demand following any single electric bus failure. Failure of buses Y01 and Y02 will prevent closure on demand.	Impact on PTS sequences depends on relative frequency of and duration of double bus failures.

TABLE 4. (Continued)

System/Component	Failure Mode Response	Potential Impact on PTS Sequences
Main Feedwater Regulating Valves	Failure of the associated control power (C35 or C36) will result in one of the regulating valves freezing in-position (As Is). Failure of the EHC power results in delayed valve closure based on high steam generator level rather than on turbine trip.	Failure of a regulating valve to close can result in a steam generator overfill following reactor trip. EHC power failure not expected to be significant.
Main Feedwater Bypass Valves	Failure of the associated control power will result in one of the bypass valves remaining closed. Failure of EHC power results in the valve not being automatically opened.	No adverse impact. Failure of the valve to open may result in auxiliary feedwater actuation.
Main Feedwater Isolation Valves	Failure of associated instrument buses (Y01 and Y02) or motive power will prevent closure of one or both MFIV on demand.	Impact of failure limited due to expected closure of regulating valve. Flow through bypass valve continues.
Feedwater Pump Trip	Main feedwater, condensate booster and heater drain pumps will trip on demand or spuriously trip following single bus failures. Failure of buses Y01 and Y02 will cause failure to automatically trip the pumps following SGIS or CSAS conditions. In addition, failure of 120 VAC bus Y09 will result in the main feedwater pump speed being reduced to idle speed.	Impact will depend on relative frequency and duration of double bus failures.

TABLE 4. (Continued)

System/Component	Failure Mode Response	Potential Impact on PTS Sequences
Auxiliary Feedwater System	Failure of either bus Y01 or Y02 will reduce the capacity of the system to 400 gpm (from 800 gpm). Failure of 4 KVAC bus 11 also results in a reduction of capacity to 400 gpm. Failure of both vital buses Y01 and Y02 results in a failure to initiate the auxiliary feedwater system.	No adverse impact on PTS sequences.
High Pressure Safety Injection	Failure of bus Y01 or Y02 or failure of 4 KVAC bus 11 or 14 reduces the capacity of the system by half. Failure of the vital power or motive power in both trains results in a failure to initiate the HPSI on demand.	Small or no adverse impact on PTS sequences. Impact will depend on relative frequency and duration of double bus failures.
Chemical and Volume Control System	Failure of the selected pressurizer level power (Y01 or Y02) or control power (Y10) results in spurious actuation of the three charging pump injection mode. Failure of non-selected pressurizer level power Y02 reduces the capacity of the system to one pump in the SIAS mode. Failure of 480 VAC bus 11A or 14A reduces the capacity of the system to one or two pumps.	Small impact. Initiation of the SIAS injection mode expected in all PTS sequences of interest.

In addition to the feedwater regulating valves freezing in position and possibly contributing to a steam generator overfill, the concurrent failure of two vital buses has been identified as a small LOCA initiator. The importance of this initiator will depend, as noted, on its expected frequency and duration.

In several cases where the failure of electric power had no direct impact on a component response, the potential impact of electric power failures on other support systems has been noted for reference.

4.3.2 Responses to Compressed Air System Failures

The responses of the systems and components to compressed air system failures are summarized in Table 5. The responses potentially important to PTS sequences are itemized below:

1. Both feedwater regulating valves will freeze in position and both feedwater bypass valves will open following a loss of instrument air pressure.
2. A passive failure of the "B" AFS instrument air train will result in spurious initiation of the steam driven AFS pump and opening of the associated AFS control valves.

In addition to the direct response of the systems and component to instrument air failures, the impacts of instrument air failures on other support systems affecting the components have been noted.

4.3.3 Responses to Cooling Water System Failures

The responses of the systems and components to cooling water failures are summarized in Table 6. The responses potentially important to PTS sequences are itemized below:

1. Continued operation of the reactor coolant pumps following loss of component cooling water would result in eventual seal failure and a small LOCA.
2. Operation of the HPSI pumps for periods of time greater than 2 hours following loss of component cooling water may result in eventual pump bearing failure.[6]

TABLE 5. SUMMARY OF SYSTEM/COMPONENT FAILURE MODES IN RESPONSE TO COMPRESSED AIR SYSTEM FAILURES

System/Component	Failure Mode Response	Potential Impact on PTS Sequences
Reactor Trip	N/A	No direct impact. Reactor expected to trip following loss of instrument air.
Atmospheric Dump and Turbine Bypass	Loss of instrument air pressure results in closure of all TBV and ADV.	No adverse impact. Failure of ADV and TBV to open on demand increases frequency of steam safety valve challenges.
Turbine Trip	N/A	No impact.
Pressurizer Relief Valve	N/A	No impact.
RCP Shaft Seals	N/A	No direct impact. However, loss of instrument air results in isolation of cooling water flow to RCP seals.
Main Steam Isolation Valves	N/A	No impact.
Main Feedwater Regulating Valves	Decrease in instrument air pressure results in isolation of pneumatic supply to both regulating valves, freezing them in position.	Failure of the regulating valves to close results in a steam generator overfill following reactor trip.
Main Feedwater Bypass Valves	Failure of instrument air results in the bypass valves opening.	Small impact with respect to response of feedwater regulating valve response.
Main Feedwater Isolation Valves	N/A	No impact.
Main Feedwater Pump Trip	N/A	No impact.

TABLE 5. (Continued)

System/Component	Failure Mode Response	Potential Impact on PTS Sequences
Auxiliary Feedwater System	Failure of the main instrument air supply to the AFS will not cause an actuation nor prevent proper operation for approximately two hours. A passive failure of the AFS Train B (accumulator 11B) pneumatic tubing will result in automatic start of the steam driven pump and operation with the control valves fully open.	Small adverse impact. Depending on the effect of a passive failure on the main instrument air pressure, the spurious initiation of AFS may exacerbate a main feedwater overfill.
High Pressure Safety Injection	N/A	No impact.
Chemical and Volume Control System	Instrument air failure will result in reactor coolant letdown isolation and continued CVCS operation with one pump.	Small or no adverse impact.

TABLE 6. SUMMARY OF SYSTEM/COMPONENT FAILURE MODES IN RESPONSE TO COOLING WATER FAILURES

System/Component	Failure Mode Response	Potential Impact on PTS Sequences
Reactor Trip	Loss of component cooling water to CEDM can result in CEDM damage and potential release of control elements.	Small or no adverse impact. Reactor is expected to be tripped following loss of cooling water.
Atmospheric Dump and Turbine Bypass Valves	N/A	No direct impact. However, loss of service water may lead to loss of instrument air and plant air compressors.
Turbine Trip	Loss of service water to the turbine and generator is expected to eventually require turbine trip.	No adverse impact.
Pressurizer Relief Valves	N/A	No impact.
RCP Shaft Seals	Loss of component cooling water to seals may result in seal damage and possible seal failure.	Small LOCA initiator would result if the operator failed to trip the reactor coolant pumps following a loss of component cooling water.
Main Feedwater Regulating Valve	N/A	No direct impact. However, loss of service water may lead to loss of instrument air compressors.
Main Feedwater Bypass Valves	N/A	No direct impact. However, loss of service water may lead to loss of instrument air compressors.
Main Feedwater Isolation Valves	N/A	No impact.

TABLE 6. (Continued)

System/Component	Failure Mode Response	Potential Impact on PTS Sequences
Main Feedwater Pump Trip	Loss of service water to main feedwater pump turbine and condensate booster pump lube oil coolers is expected to require eventual pump trip to prevent bearing damage.	Small or no adverse impact. Trip of the main feedwater pumps will result in actuation of the auxiliary feedwater system.
Auxiliary Feedwater System	N/A	No impact due to external cooling water systems failure.
High Pressure Safety Injection	Loss of component cooling to the HPSI pumps during HPSI operation could lead to eventual pump failure. The HPSI pumps are designed to operate a minimum of 2 hours following a complete loss of component cooling water.	Small adverse impact. Failure of the operating HPSI pumps may increase the likelihood of Safety Injection Tank or Low Pressure Safety Injection in some PTS sequences. Impact will depend on relative frequency and duration of multiple component cooling water system failures.
Chemical and Volume Control System	Loss of component cooling water to letdown heat exchanger results in automatic transfer to the recirculation mode bypassing the boron and radiation monitors and ion exchangers.	No adverse impact. However, loss of service water may lead to loss of instrument air compressors.

As above, the potential impact of cooling water failures on other support systems affecting the systems and components have been noted.

5.0 COMMON CAUSE SUPPORT SYSTEM FAILURES

The dependence of systems and components identified in the PTS sequences on electric power, compressed air and cooling water systems has been discussed in Section 4. In Section 5, the failure modes of the systems and components in response to specific failure modes of the support systems are identified and discussed. In Section 5.1, the designs of the Calvert Cliffs electric power, compressed air and cooling water systems are described briefly and the failure modes resulting in the important system responses itemized in Section 4.3 identified. The responses of the systems and components to these support system failure modes are described in Section 5.2 in a failure modes and effects format.

5.1 CALVERT CLIFFS SUPPORT SYSTEMS DESIGNS

The designs of the Calvert Cliffs electric power, compressed air and cooling water systems are described in Sections 5.1.1, 5.1.2 and 5.1.3. The interfaces with the system and components affecting PTS sequences and the interfaces among the support systems are identified and support system failure modes defined.

5.1.1 Electrical Power Systems

The Calvert Cliffs Unit 1 AC electric power distribution is shown in a simplified schematic diagram, Figure 1. The plant power requirements normally are supplied from the switchyard through 13 KV service buses 11 and 12. Bus 12 supplies the four reactor coolant pump buses and bus 11 supplies the 4 KV unit buses.[24]

4 KV buses 11 and 14 supply the safety related Channel ZA and ZB power requirements respectively. These buses are energized by two of the three emergency diesel generators shared by the two Calvert Cliffs Units.[24]

The 4 KV buses supply the 480 V buses through transformers. In particular, 4 KV bus 11 supplies 480 V buses 11A and 11B; 480 V bus 11B supplies 480 V reactor MCC 114R. 4 KV bus 14 supplies 480 V buses 14A and 14B and 480 V bus 14A supplies 480 V reactor MCC 104R.[24]

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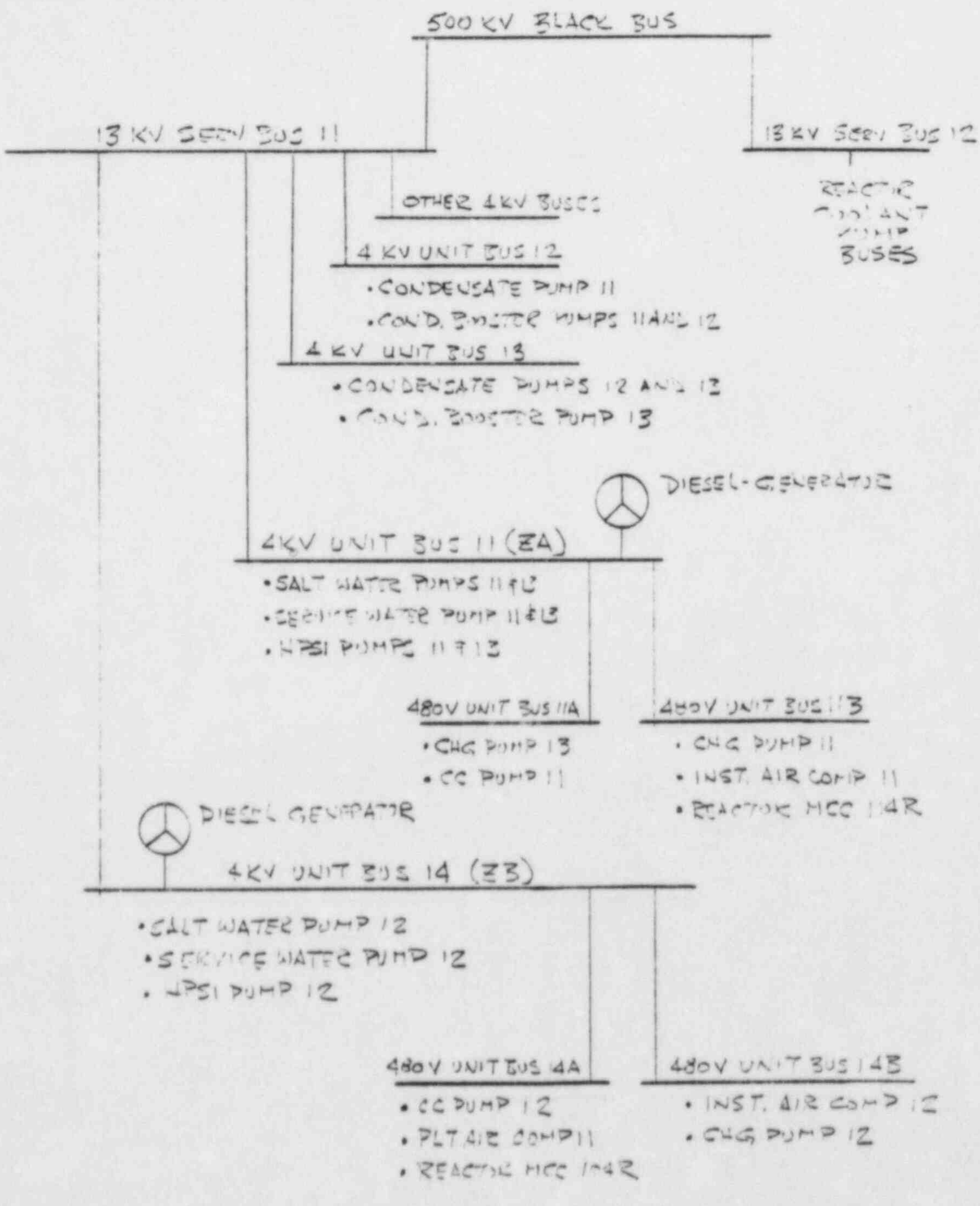
FIG 1 ~ SIMPLIFIED SCHEMATIC OF CALVERT CLIFFS UNIT 1 AC POWER DISTRIBUTION



Plant DC loads are supplied by 125 VDC buses 11, 12, 21 and 22, and 250 VDC bus 13 which are shared between the two units. Each DC bus normally is fed by its associated battery charger (i.e., bus 11 fed by battery 11 and battery charger 11). The four 125 VDC battery chargers, 11, 12 and 21, are fed by 480 VAC unit buses 11A, 14B, 21B and 24A respectively.[24]

120 VAC instrument buses are fed from the DC buses through inverters or from the 480 VAC MCC's through transformers. 120 VAC vital buses 11, 12, 13 and 14 are supported through their associated inverters from DC buses 11, 21, 12 and 22 respectively. The vital buses may also be fed, by manual transfer, from 120 VAC bus Y11. 120 VAC buses Y10 and Y11 are fed through their transformers from 480 VAC MCC 104R. Bus Y09 is fed from MCC 114R.[24]

Electric bus failures can occur for a variety of reasons including isolation or failure of feeder buses or shorts which could occur during maintenance. For purposes of this analysis, single unspecified failures have been postulated at various points in the power distribution circuitry. The failure has been assumed to deenergize the directly affected bus, buses only fed from this bus and possibly the feeder buses to the affected bus. In cases where a maintenance tie between existed, failures affecting both normally isolated buses were considered.

The 4 KV buses shown on Figure 1 have multiple sources of power (13 KV bus 11 and the emergency diesel-generators). Thus, 4 KV bus failures were assumed due to postulated faults on the 4 KV buses. This fault results in deenergizing lower voltage bus fed from the affected bus. Similar faults have been postulated on lower voltage buses. In addition, the existence of maintenance ties between 4 KV buses 11 and 14 and between MCC's 104R and 114R were considered possible mechanisms for propagating a single fault to both buses or MCC's.[24].

125 VDC buses 11, 12, 21 and 22 each have multiple independent power supplies and have no maintenance ties.[24]. Therefore, only faults affecting single buses were considered.

Each 120 VAC vital buses, Y01, Y02, Y03 and Y04 is normally fed from a separate DC bus through an inverter. However, one or more vital buses may be fed from 120 VAC bus Y11. Therefore, single and multiple vital bus failures were considered.

Where either of two instrument buses supply a single instrument panel by automatic selection, two failure modes were considered. A fault in the panel could result in both feeder buses being isolated from the panel. The feeder buses would continue to supply other loads in this case. The analysis also considered the possibility of a panel fault propagating to the primary supply bus and subsequently propagating to the backup supply bus on automatic transfer. In this case, the two buses feeding the panel would be deenergized.

5.1.2 Compressed Air Systems

The 260 SCFM instrument air requirements of Calvert Cliffs Unit 1 are supplied by instrument air compressors 11 and 12, each rated at 470 SCFM. The instrument air compressors are in intermittent operation to maintain pressure in their associated air accumulators. The instrument air compressors discharge into a common header upstream of the accumulators. Additional cross-connecting headers are also installed upstream of the distribution piping to the plant components. In addition, the 616 SCFM plant air compressor 11 is aligned automatically to supply instrument air requirements if the pressure in the instrument air header falls below a preset value.[6]

AC electrical motive power supplies for the three compressors are shown in Figure 1. Control power for instrument air compressor 12 and plant air compressor 11 is supplied from 120 VAC bus Y10; control power for instrument air compressor 11 is supplied by 120 VAC bus Y09. As shown, the compressors are supplied from independent electric power trains. The three compressors are supplied cooling water from service water pump 11 and heat exchanger 11. The cooling water supply is automatically isolated on SIAS signals, loss of power to the isolation valve solenoids, 125 VDC buses 11 and 21, or loss of instrument air pressure to the isolation valves.

Compressed air system failure (low pneumatic supply pressure), can be caused by a postulated passive failure of the pneumatic piping failure of the three

compressors or their associated motive or control power. Normal plant instrument air requirements can be satisfied by either instrument air compressor or the plant air compressor. Thus, failure of one or two of the compressors will not result in system failure. As shown in Figure 1, single bus failures will result in, at most, two of the three compressors. Failure of service water pump 11 or isolation of service water to the compressors would lead, ultimately, to failure of the three compressors. The time required for the compressors to fail following a loss of service water is unknown. However, following a loss of cooling water, the operator may choose to trip the compressors rather than allowing them to run to failure. Following loss of the compressors, the instrument air system is expected to depressurize over a period of minutes. The operator has the option of manually aligning the Unit 2 Compressed Air Systems.

Auxiliary feedwater system pneumatic valves are supplied by two 55 ft^3 accumulators in addition to the primary instrument air source. Failure of the pneumatic supply to one train of auxiliary feedwater system valves would require a passive piping failure in one of the two auxiliary feedwater system pneumatic supply headers.

The effects of low instrument air pressure on the systems and components affecting PTS sequences have been summarized in Table 5. Excluding the effects on the auxiliary feedwater system, low pressure in the instrument air distribution piping will occur following a passive failure of the instrument air headers or failure of the compressors due to a single failure of the service water supply combined with a failure of the operator to manually align an alternate instrument air supply.

Low instrument air pressure in either of the auxiliary feedwater supply headers will result in the control valves associated with that train opening. Failure of the "B" pneumatic train, in addition to opening the control valves, will result in the turbine driven pump starting and accelerating to maximum speed. Due to the two auxiliary feedwater system accumulators, this failure is expected to result in the near term (<2 hours) only from a passive failure in the auxiliary feedwater pneumatic piping. The postulated passive failure would only affect one of the two auxiliary feedwater pneumatic trains.

If the postulated failure depressurizing the auxiliary feedwater pneumatic piping also depressurized the main instrument air system, the effects associated with failure of the instrument air system also would occur. However, depressurization of the instrument air system due to a failure of auxiliary feedwater instrument air branch tubing is considered highly unlikely.[14]

5.1.3 Cooling Water Systems

Cooling water for normally operating and standby Calvert Cliffs components and systems is supplied by the component cooling water system and the service water system. These two closed loop systems reject heat to the open loop salt water system.

The component cooling water system consists of component cooling pumps 11, 12 and 13, which feed component cooling heat exchangers 11 and 12 through a common discharge header. Normally one component cooling water pump and heat exchanger 11 are in operation. During normal operation the component cooling water system provides cooling water for the CEDM, the reactor coolant pump mechanical seals and lube oil heat exchangers and the letdown heat exchanger.[6]

Emergency operation of the system is initiated by ESFAS Containment Isolation signals. Pumps 11 and 12 are started, flow through component cooling heat exchanger 12 and shutdown heat exchangers 11 and 12 initiated and cooling water for the reactor coolant pumps and CEDM isolated. In this mode of operation, cooling water from either component cooling heat exchanger can supply the shutdown heat exchangers and safety injection pumps' seals and coolers.[6] The AC power sources for the component cooling water system are shown in Figure 1. Instrument air and solenoid power is required to position system valves. Solenoid power for isolation valves CV-3832 and CV-3833 is supplied from 125 VDC buses 11 and 21, respectively. Loss of either instrument air or solenoid power results in isolation of cooling water to the reactor coolant pumps and CEDM and opening the isolation valves in the component cooling and shutdown heat exchangers.

The service water system consists of two independent loops. Pump 11 feeds heat exchanger 11 and pumps 12 and 13 feed heat exchanger 12. Normally pumps 11 and 12 are in operation and pump 13 is in standby. The cooling water from heat exchanger 11 supplies the instrument air and plant air compressors, the turbine electro-hydraulic oil and lube oil coolers. Heat exchanger 12 supplies the feedwater and condensate booster pump lube oil coolers, the generator coolers, spent fuel cooler and nitrogen compressor.[6]

Emergency operation is initiated by ESFAS SIAS signals which start the service water pumps, isolate the turbine plant, spent fuel and instrument air cooling water and initiate flow to emergency equipment such as the containment coolers and emergency diesel-generators.[6]

Service water heat exchangers 11 and 12 are fed cooling water via salt water pumps 11 and 12 respectively. Service water AC power requirements are shown in Figure 1. Instrument air and solenoid power are required to position system valves. Solenoid power for isolation valves CV-1600 and CV-1637 is supplied by 125 VDC bus 11 and for valves CV-1638 and CV-1639 by 125 VDC bus 21. Loss of either instrument air or either 125 VDC bus will result in isolating the cooling water to the turbine plant components, air and nitrogen compressors and the spent fuel cooler and initiating flow to the emergency equipment.[6]

The effects of loss of cooling water on the systems and components affecting PTS sequences have been shown in Table 6.

5.2 EFFECTS OF SUPPORT SYSTEMS FAILURE MODES

The systems and components identified in the PTS event trees have been analyzed to determine their individual failure mode responses to support system failures. The failure modes of potential significance to PTS sequences have been summarized in Section 4.3. In Section 5.2, the combinations of failure mode responses of the systems and components to particular failure modes of the support systems are identified and evaluated. In Section 5.2.1, the specific support system failure modes are identified and, in Section 5.2.2, the overall response of plant systems to these failure modes are determined.

5.2.1 Identification of Support System Failure Modes

The system and component failure modes judged to be potentially significant to PTS sequences in Section 4.3 were analyzed to identify specific initiating failures of the electric power, compressed air or cooling water systems. The initiating support systems failure modes are listed in Table 7.

In addition to support system failures directly resulting in a system or component failure affecting PTS, a failure of one support system may result in a failure of another. To evaluate this interactive effect, each of the support system failure modes listed in Table 7 was analyzed to determine possible initiating failures in other support systems. The interactive support system failure modes are listed in Table 8.

The initiating support system failure modes listed in Tables 7 and 8 have been summarized in Table 9. This list of support systems failure modes consists of the failures for which at least one PTS adverse response has been identified. Multiple system failure mode responses to each support system failure are identified and evaluated in Section 5.2.2.

Initiating electrical system failures were selected from those identified in Tables 7 and 8, if they could result from a single deenergized bus or from a single postulated failure (e.g., short to ground) of a possible electrical connection. Multiple 120 VAC vital bus failures were selected, on this basis, due to the common, manually connected backup supply bus Y11. 4 KVAC buses 11 and 12 and 480 VAC MCC's 104R and 114R also may be manually connected. Panel C35 is supplied 120 VAC power from bus Y01 or Y09 by automatic transfer. The double failure of these buses is postulated on this basis. A similar condition exists for buses Y02 and Y10 via panel C36.

Compressed air system failures selected were limited to single postulated piping failures. Multiple compressor failures were considered only to the extent that they may be caused by a common support system failure.

Component failures resulting from a loss of cooling water flow have been considered. However, it is recognized that a significant period of time may

TABLE 7. INITIATING SUPPORT SYSTEM FAILURE MODES

Failed System/Component	Initiating Electrical System Failures	Initiating Compressed Air System Failures	Initiating Cooling Water System Failures
PRV Fail Open	Vital Buses Y01 & Y02, Y01 & Y03, Y01 & Y04, Y02 & Y03, Y02 & Y04, Y03 & Y04	None	None
MSIV Fail to Close on Demand	Vital Buses Y01 & Y02	None	None
MFW Regulating Valve CV-1111 Freezes in Position (Open)	Panel C35, Y01 & Y09	Failure of all compressors, passive instrument air line failure	None
MFW Regulating Valve CV-1121 Freezes in Position (Open)	Panel C36, Y02 & Y10	Failure of all compressors, passive instrument air line failure	None
MFW Bypass Valves CV-1105 & 1106 Fail Open	None	Failure of all compressors, passive instrument air line failure	None
MFW Isolation Valve MOV-4516 Fails to Close on Demand	Buses Y01 & Y02, 480 V MCC 114R, 480 VAC Bus 11B, 4 KVAC Bus 11	None	None
MFW Isolation Valve MOV-4517 Fails to Close on Demand	Buses Y01 & Y02, 480 V MCC 104R, 480 VAC Bus 14A, 4 KVAC Bus 12	None	None
MFW Pump 11 Fails to Trip on Demand	Buses Y01 & Y02, 125 VDC Bus 11	None	None
MFW Pump 12 Fails to Trip on Demand	Buses Y01 & Y02, 125 VDC Bus 12	None	None

TABLE 7. (Continued)

Failed System/Component	Initiating Electrical System Failures	Initiating Compressed Air System Failures	Initiating Cooling Water System Failures
Spurious Initiation of AFS Steam Driver Pump Train	None	Passive failure of AFS instrument air line - Train B	None
HPSI Fails to Initiate on Demand	Buses Y01 & Y02, 4KV Buses 11 & 12, 480 V MCC 104 & 114, 480 V Bus 11B & 14A	None	None*
RCP Seal Failures	None	None	Failure of operating CCW Pump 11, closure of CV-3832, closure of CV-3833

*Multiple failures or a passive failure of the CCW could be postulated which would stop cooling water flow to the HPSI pumps. However, loss of CCW does not prevent initiation or operation of the HPSI pumps for two hours or more. Delayed initiation of HPSI rather than long term failure is of concern to PTS sequences.

TABLE 8. INTERACTIVE FAILURE MODES AMONG SUPPORT SYSTEMS

Failed System/Component	Initiating Electrical System Failures	Initiating Compressed Air System Failures	Initiating Cooling Water System Failures
Failure of Vital Buses	Failure of associated 125 VDC Buses 11, 12, 21, 22 or manual transfer to Y11 and subsequent failure of Y11	N/A	N/A
Failure of All Instrument Air Compressors	4 KV Buses 11 & 12, MCC's 104R and 114R, 120 VAC buses Y09 and Y10	N/A	Failure of service water pump 11, closure of CV-1637, closure of CV-1639
Failure of CCW Pump 11	4 KV Bus 11, 480 V Bus 11A	None	None
Closure of CCW CV-3832	125 VDC Bus 11	Failure of all compressors, passive instrument air line failure	None
Closure of CCW CV-3833	125 VDC Bus 21	Failure of all compressors, passive instrument air line failure	None
Failure of Service Water Pump 11	4 KV Bus 11	None	None
Failure of Service Water CV-1637	125 VDC Bus 11	Failure of all compressors, passive instrument air line failure	None
Failure of Service Water CV-1639	125 VDC Bus 21	Failure of all compressors, passive instrument air line failure	None

TABLE 9. SUPPORT SYSTEMS INITIATING FAILURES

Initiating Support System Failure Mode	Comments
Electrical System Failures	
Multiple 120 VAC Instrument Bus Failures	
1. Y01 and Y02	Multiple vital bus failures have occurred due to improper maintenance actions. Y11 is a common backup supply for buses Y01 - Y04.
2. Other double vital bus failure	Multiple vital bus failures have occurred due to improper maintenance actions. Y11 is a common backup supply for buses Y01 - Y04.
3. Y01 and Y09	Y01 and Y09 supply panel C35.
4. Y02 and Y10	Y02 and Y10 supply panel C36.
5. Panel C35 or C36 Deenergized	Instrument buses supplying panels assumed to remain energized.
6. 125 VDC Bus 11	Postulated single failure.
7. 125 VDC Bus 12	Postulated single failure.
8. 4 KVAC Bus 11 Failure	Postulated single failure.
9. 4 KVAC Buses 11 and 12 Fail	Postulated fault while buses are electrically connected.
10. 480 VAC MCC's 104R and 114R Fail	Postulated fault while MCC's are electrically connected.
Compressed Air System Failures	
11. Passive Failure of Instrument Air Header	Postulated single failure.
12. Passive Failure of Auxiliary Feedwater Instrument Air Header	Postulated single failure.

TABLE 9. (Continued)

Initiating Support System Failure Mode	Comments
<u>Cooling Water System Failures</u>	
13. Failure of CCW Pump 11	Postulated single failure.
14. Closure of CCW CV-3832 or CV-3833	Postulated single failure.
15. Failure of Service Water Pump 11	Postulated single failure.
16. Closure of Service Water CV-1637 or CV-1639	Postulated single failure.

elapse prior to component failure. For this reason, only failures resulting in a complete loss of flow to a serviced component have been selected as cooling water initiating failures (e.g., loss of service water flow to the air compressors). Failures of the salt water flow to the component cooling and service water heat exchangers have not been selected since they do not result in a loss of flow to a serviced component.

5.2.2 Effects of Support Systems Failure Modes on PTS Sequences

The responses of each of the systems and components identified from the PTS event sequences to the sixteen postulated support system failures listed in Table 9 have been evaluated. The responses of each are summarized in Table 10.

The responses listed in Table 10 describe the status of each system or component in response to the postulated failure prior to possible remedial by the operator. The responses listed include both direct responses to a postulated support system failure (e.g., a valve closes in response to a loss of instrument air pressure) and indirect responses (e.g., instrument air pressure is lost due to air compressor cooling water failure which results in valve closure). The "operable" response is used to indicate that a system or component will respond as designed to plant conditions. Supplementary information concerning the particular "operable" responses of components or the status of manual controls for components responding to failed automatic controls has been added where possible.

Detailed information concerning the responses of systems and components to support systems failures has been provided in Section 4 and the interactive responses of the support systems in Section 5.1.

The overall effects of the support systems failures depend on the potential severity of the resulting transient and the availability of remedial actions to the operator. These factors have been evaluated, to the degree possible, for each of the support systems failures to identify the support systems failures of greater importance to the PTS sequence analysis. The frequency of support system failure leading to multiple adverse PTS sequence events is to be calculated for the support systems failures of greater importance in

TABLE 10. RESPONSE OF IDENTIFIED PLANT SYSTEMS AND COMPONENTS TO POSTULATED SUPPORT SYSTEM FAILURES

Initiating Failure	System/Component Response												
	Reactor Trip	ADV/TBV	Turbine Trip	RC Pumps	PRV's	MSIV's	MFW Reg. Valves	MFW Bypass Valves	MFW Pumps	MFIV	AFS	HPSI	CVCS
Electrical System Failures													
1. Buses Y01 & Y02	Tripped	Operable	Tripped**	Operable	Open*	Open*	Operable, closed following turbine trip	Operable	Operating, pump trip failed	Open*	Off*	Off*	3-Pump Injection
2. Other Double Vital Bus Failures	Tripped	Operable	Tripped	Operable	Open*	Operable	Operable, closed	Operable	Operable	Operable	One or Both Trains Operable	One or Both Trains Operable	Operable or 3-Pump Injection
3. Buses Y01 & Y09	Operable, probable trip	Closed* or operable	Operable, probable trip	Operable	Operable	Operable	CV-1111 open, CV-1121 operable, closed	CV-1105 closed, CV-1106 operable	Minimum speed, pump trip operable	Operable	Operable	Operable	Operable or 3-Pump Injection
4. Buses Y02 & Y10	Operable, probable trip	Closed* or operable	Probable Trip**	Operable	Operable	Operable	CV-1111 operable, closed, CV-1121 open	CV-1105 operable, CV-1106 closed	Operable, high speed	Operable	Operable	Operable	3-Pump Injection

TABLE 10. (Continued)

Initiating Failure	System/Component Response												
	Reactor Trip	ADV/TBV	Turbine Trip	RC Pumps	PRV's	MSIV's	MFW Reg. Valves	MFW Bypass Valves	MFW Pumps	MFIV	AFS	HPSI	CVCS
5. Panel C35 or C36 Deenergized	Operable, eventual trip	Operable	Operable, eventual trip	Operable	Operable	Operable	CV-1111 or CV-1121 open, other valve closes on turbine trip	CV-1105 or CV-1106 closed, other valve opens on turbine trip	Operable	Operable	Operable	Operable	Operable
6. 125 VDC Bus 11	Operable, trip after 30 sec.	"Quick Open" failed, auto controlled on pressure or Tav until Instrument Air Pressure lost. Valves then close	Trip after 30 sec	Eventual failure of seals unless tripped	Operable	Operable	Operable, closed	Operable until Instrument Air Pressure is lost. Valves then will open	Operating, pump 11 trip failed	Operable	One Train Operable	One Train Operable	Operable until Instrument Air Pressure lost. Letdown then will be isolated

TABLE 10. (Continued)

Initiating Failure	System/Component Response												
	Reactor Trip	ADV/TBV	Turbine Trip	RC Pumps	PRV's	MSIV's	MFW Reg. Valves	MFW Bypass Valves	MFW Pumps	MFIV	AFS	HPSI	CVCS
7. 125 VDC Bus 21	Operable	Operable until Instrument Air Pressure lost. Valves then close	Operable	Eventual failure of seals unless tripped	Closed	Operable	Operable, closed	Operable	Operating, pump 12 trip failed	Operable	Operable	One Train Operable	Operable
8. 4 KVAC Bus 11	Operable, probable trip	Closed* or operable	Operable, probable trip	Eventual failure of seals unless tripped	ERV-402 closed, ERV-404 operable	Operable	Operable, closed	Operable	Min. speed, pump trip operable	MOV-4516 open, MOV-4517 operable	One Train operable	One Train operable	Pump 12 operating, letdown isolated
9. 4 KVAC Buses 11 & 12	Operable, probable trip	Closed*	Operable, probable trip	Eventual failure of seals unless tripped	Closed	Operable	Operable, closed	Operable	Min. speed, pump trip operable	Open	One Train operable	Off	Off

TABLE 10. (Continued)

Initiating Failure	System/Component Response												
	Reactor Trip	ADV/TBV	Turbine Trip	RC Pumps	PRV's	MSIV's	MFW Reg. Valves	MFW Bypass Valves	MFW Pumps	MFIV	AFS	HPSI	CVCS
10. 480 VAC MCC's 104R & 114R	Operable, probable trip	Closed*	Operable, probable trip	Eventual failure of seals unless tripped	Closed	Operable	Operable until Instrument Air Pressure lost, valves then remain closed	Operable until Instrument Air Pressure lost, valves then open	Min. speed, pump trip operable	Open	Operable	Off, isolated	Pumps operating from VCT water source only
<u>Compressed Air System Failures</u>													
11. Passive Failure of Instrument Air Header	Operable, probable trip	Closed	Operable, probable trip	Eventual failure of seals unless tripped	Operable	Operable	Open	Open	Operating at high speed	Operable	Operable	Operable	One Pump Injection, letdown isolated
12. Passive Failure of AFS Instrument Air Header "B"	Operable	Operable	Operable	Operable	Operable	Operable	Operable	Operable	Operable	Operable	Train B Initiated Control Valves open	Operable	Operable

TABLE 10. (Continued)

Initiating Failure	System/Component Response												
	Reactor Trip	ADV/TBV	Turbine Trip	RC Pumps	PRV's	MSIV's	MFW Reg. Valves	MFW Bypass Valves	MFW Pumps	MFIV	AFS	HPSI	CVCS
<u>Cooling Water System Failures</u>													
13. CCW Pump 11	Opera-ble, eventual trip	Operable	Opera-ble, eventual trip	Eventual failure of seal unless tripped	Operable	Operable	Operable	Operable	Operable	Operable	Operable	Operable	Operable
14. Closure of CCW CV-3822 or CV-3833	Opera-ble, eventual trip	Operable	Opera-ble, eventual trip	Eventual failure of seal unless tripped	Operable	Operable	Operable	Operable	Operable	Operable	Operable	Operable	Operable
15. Failure of Service Water Pump 11	Opera-ble, eventual trip	Even-tually closed on loss of In-strument Air	Opera-ble, eventual trip	Eventual isola-tion of CCW on loss of Instru-ment Air. Eventual seal failure unless tripped	Operable	Operable	Probably closed unless Instru-ment Air Pressure is lost prior to turbine trip	Operable until Instru-ment Air pressure is lost. Valves then will open	Operable	Operable	Operable	Operable	Operable until Instru-ment Air pressure is lost. Letdown then will be isolated

TABLE 10. (Continued)

Initiating Failure	System/Component Response												
	Reactor Trip	ADV/TBV	Turbine Trip	RC Pumps	PRV's	MSIV's	MFW Reg. Valves	MFW Bypass Valves	MFW Pumps	MFIV	AFS	HPSI	CVCS
16. Failure of Service Water CV-1637 or CV-1639	Operable, eventual trip	Eventually closed on loss of Instrument Air	Operable, eventual trip	Eventual isolation of CCW on loss of Instrument Air. Eventual seal failure unless tripped	Operable	Operable	Probably closed unless Instrument Air Pressure is lost prior to turbine trip	Operable until Instrument Air pressure is lost. Valves then will open	Operable	Operable	Operable	Operable	Operable until Instrument Air pressure is lost. Letdown then will be isolated

*Manual Control Available.
**Turbine will trip on low speed or other turbine related parameter.

subsequent analyses. The comparison of these frequencies with equivalent independently occurring event sequence frequencies will be used to evaluate the overall importance of support system failures.

Based on the system and component responses listed in Table 10, a brief description of the resulting plant transient and possible remedial actions available to the operator are presented in Table 11 for each of the sixteen postulated support system failures. In addition, an estimate of the potential severity has been made for each of the resulting transients. These responses to support systems failures are discussed below.

1. Electrical Systems Failures

Two postulated electrical systems failures resulted in a small LOCA coupled with a failure to automatically initiate HPSI. These coupled events are of potential importance to PTS sequences due to the lower reactor coolant system temperatures which result during the repressurization phase of the transient following delayed initiation of the LPSI and HPSI.

Transient 1 (Table 11) consisted of a coincident failure of vital buses Y01 and Y02. Failure of these buses would result in a spurious high pressurizer pressure signal which opens the two PRV's and would deenergize the two ESFAS actuation channels defeating SIAS actuation of HPSI. Following transient initiation, the operator can manually close the PRV's, start the HPSI or reenergize either of the vital buses. Recovery of either bus results in automatic closure of both PRV's and actuation of one HPSI and LPSI train.

Coincident failure of 4 KVAC safety buses 11 and 14, Transient 9, would result in termination of cooling water to the RC pump seals and would deenergize the HPSI pumps' and valves' motors. Coincident failure of MCC's 104R and 114R, Transient 10, also may result in an isolation of cooling water to the RC pump seals due to the loss of instrument air compressors' control power (120 VAC buses Y09 and Y10) and loss of power to the HPSI injection valves. Tripping the RC pumps effectively would prevent seal failure and the possibly resulting small LOCA. If the RC pumps were not tripped and seal failure occurred, recovery of one of the 4 KVAC buses or 480 V MCC's would be required for recovery from Transients 9 and 10, respectively.

TABLE 11. POTENTIAL IMPACT OF SUPPORT SYSTEMS FAILURES ON PTS SEQUENCE*

Initiating Failure	Description of Transient	Available Remedial Actions	Estimated Impact on PTS Sequences
Electrical System Failures			
1. Buses Y01 & Y02	Reactor trips and PRV's open creating a small LOCA. Turbine trips on low speed. ESFAS actuation channels fail resulting in failure to actuate HPSI, AFS or isolate steam generators. CVCS "fails" in the 3-pump injection mode. Main feedwater to steam generators regulated to 5%.	Operator may manually close PRV's or their isolation valves and start HPSI. Recovery of either vital bus results in automatic closure of PRV's and probable ESFAS actuation.	(a) With promptly instituted remedial actions, the impact of this transient on PTS sequences is considered negligible. (b) Without remedial actions, a coupled small LOCA and failure to automatically start HPSI will occur. Automatic initiation of CVCS injection moderates the effect of the HPSI initiation failure.
2. Other Double Vital Bus Failures	Reactor trips and PRV's open creating small LOCA. Turbine will trip on reactor trip or low speed depending on whether Y02 is available. At least one of two ESFAS actuation channels available.	Operator may manually close PRV's and recover vital buses.	A double vital bus failure is a cause of an "isolatable" small LOCA. The impact of this transient on PTS sequences is limited since it is not coupled to a failure to automatically initiate HPSI.

*Impact of support systems failures on PTS sequences will require a calculation of the frequency of the support system failures and the failures of the operator to take remedial actions. This calculation will be performed in subsequent analyses.

TABLE 11. (Continued)

Initiating Failure	Description of Transient	Available Remedial Actions	Estimated Impact on PTS Sequences
3. Buses Y01 & Y09	MFW regulating valve CV-1111 freezes in position and MFW pumps runback to minimum speed. Reactor and turbine trip on loss of feedwater flow and probable AFS actuation. 3-pump CVCS operation may be initiated depending on selection of pressurizer level instrument power.	Close MFIV MOV-4516 on indicated high steam generator level if required.	Negligible impact on PTS sequences.
4. Buses Y02 & Y10	MFW regulating valve CV-1121 freezes in position. 3-pump CVCS operation initiated. Reactor and turbine trip on high pressurizer level and steam generator 12 is overfed.	Close MFIV MOV-4517 (or trip MFW pumps) and regain control of CVCS.	(a) With promptly initiated remedial actions, the impact of this transient on PTS sequences is considered negligible. (b) Without remedial actions, a steam generator overfill transient will occur.
5. Panel C35 or C36 Deenergized	MFW regulating valve CV-1111 or CV-1121 freezes in position. Eventual reactor and turbine trip due to lack of feedwater control and subsequent overfeeding of steam generator 11 or 12.	Close associated MFIV MOV-4516 or MOV-4517 (or trip MFW pumps).	(a) With promptly initiated remedial actions, the impact of this transient on PTS sequences is considered negligible. (b) Without remedial actions, a steam generator overfill transient will occur.

TABLE 11. (Continued)

Initiating Failure	Description of Transient	Available Remedial Actions	Estimated Impact on PTS Sequences
6. 125 VDC Bus 11	Turbine and reactor trip after 30 sec. Service water and CCW isolated to "non-essential" components including air compressors RC pump seals. Eventual failure of RC pump seals occurs unless pumps are tripped. Long term operation of compressors without cooling water can lead to their failure. However, even if instrument air pressure is lost, MFW regulating valves remain closed.	Trip RC pumps on high controlled bleed-off temperature. If Unit 1 compressors must be tripped, align Unit 2 compressors to supply Unit 1 instrument air header.	(a) With promptly initiated remedial actions, the impact of this transient on PTS sequences is considered negligible. (b) Without remedial actions, a small LOCA due to RC pump seal failures would occur. The impact of this transient on PTS sequences is limited since the LOCA is not coupled to a failure to automatically initiate HPSI. (One HPSI train can be initiated automatically.)

TABLE 11. (Continued)

Initiating Failure	Description of Transient	Available Remedial Actions	Estimated Impact on PTS Sequences
7. 125 VDC Bus 21	Service water and CCW isolated to "non-essential" components including air compressors and RC pump seals. Reactor and turbine expected to trip due to loss of cooling water to turbine components. Eventual failure of RC pump seals occurs unless pumps are tripped. Long term operation of compressors without cooling water can lead to their failure. However, even if instrument air pressure is lost, MFW regulating valves remain closed.	Trip RC pumps on high controlled bleed-off temperature. If Unit 1 compressors must be tripped, align Unit 2 compressors to supply Unit 1 instrument air header.	(a) With promptly initiated remedial actions, the impact of this transient on PTS sequences is considered negligible. (b) Without remedial actions, a small LOCA due to RC pump seal failures would occur. The impact of this transient on PTS sequences is limited since the LOCA is not coupled to a failure to automatically initiate HPSI. (One HPSI train can be initiated automatically.)

TABLE 11. (Continued)

Initiating Failure	Description of Transient	Available Remedial Actions	Estimated Impact on PTS Sequences
8. 4 KVAC Bus 11	Service water pump 11 and operating CCW pump stop terminating flow to air compressors and RC pump seals. Reactor and turbine expected to trip due to loss of cooling water to turbine components. Eventual failure of RC pump seals occurs unless pumps are tripped. Long term operation of compressors without cooling water can lead to their failure. However, even if instrument air pressure is lost, MFW regulating valves remain closed.	Start CCW pump 12 and locally open valves to supply service water from heat exchanger 12 to train 11 components. Trip RC pumps if the transient results in high controlled bleed-off temperature.	(a) With promptly initiated remedial actions, the impact of this transient on PTS sequences is considered negligible. (b) Without remedial actions, a small LOCA due to RC pump seal failures would occur. The impact of this transient on PTS sequences is limited since the LOCA is not coupled to a failure to automatically initiate HPSI. (One HPSI train can be initiated automatically.)
9. 4 KVAC Buses 11 & 12	Reactor and turbine trip on reduced feedwater flow or other causes. CCW lost to RC pump seals which are presumed to be running. Seal failure will result if RC pumps are not tripped. Auxiliary feedwater initiated but HPSI and CVCS are deenergized. (Loss of 4 KVAC buses initiated by loss of 500 KV bus is of less interest to PTS since RC pumps are deenergized and pump seal failure is not coupled directly to loss of CCW.)	Trip RC pumps on high controlled bleed-off temperature. Restore power to one or both 4 KVAC buses.	(a) With promptly initiated remedial actions, the impact of this transient on PTS sequences is considered negligible. (b) Without remedial actions, a coupled small LOCA due to RC pump seal failures and a loss of HPSI and LPSI injection capacity would occur until power was restored.

TABLE 11. (Continued)

Initiating Failure	Description of Transient	Available Remedial Actions	Estimated Impact on PTS Sequences
10. 480 VAC MCC 104R & 114R	Reactor and turbine trip on reduced feedwater flow. Letdown flow isolated and 3-pump CVCS injection initiated. Sources of water to VTC and Chg. pumps remain isolated and HPSI discharge valves remain closed. Loss of control power to instrument air compressors may result in a loss of instrument air pressure and isolation of CCW to the RC pumps. Seal failure will occur if RC pumps are not tripped. Feedwater bypass valves will open resulting in increasing steam generator levels. (Loss of MCC's due to loss of 4 KV bused discussed in transient 9, above).	Restore power to one or both MCC's or align unit 2 air compressors to unit 1 instrument air header. If unsuccessful, trip RC pumps on high bleed-off temperature and trip MFW pumps on high steam generator level. Trip or deenergize Chg. pumps prior to draining VTC. If RC pump seal failure occurs prior to restoration of electric power, open HPSI discharge valves manually, if possible.	(a) With promptly initiated remedial actions, the impact of this transient on PTS sequences is considered negligible. (b) Without remedial actions, a coupled small LOCA due to RC pump seal failures and a loss of HPSI and LPSI injection capacity would occur until power was restored or the HPSI/LPSI injection valves were opened manually.
<u>Compressed Air System Failures</u>			
11. Passive Failure of Instrument Air Header	Both MFW regulating valves freeze in position and bypass valves open. CCW and service water to "non-essential" components including RC pump seals isolated. Following expected reactor and turbine trip, both steam generators overfed and loss of CCW to RC pump seals will result in a small LOCA unless RC pumps are tripped.	Trip RC pumps on high controlled bleedoff temperature and close MFIV's on high steam generator level.	(a) With promptly initiated remedial actions, the impact of this transient on PTS sequences is considered negligible. (b) Without remedial actions, a coupled small LOCA due to RC pump seal failures and a steam generator overfill transient would occur.

TABLE 11. (Continued)

Initiating Failure	Description of Transient	Available Remedial Actions	Estimated Impact on PTS Sequences
12. Passive Failure of AFS Instrument Air Header "B"	AFS Train B operation initiated with control valves open. Failure not expected to depressurize main instrument air header due to available compressor capacity.	Close operable isolation valves in AFS injection paths to both steam generators.	Assuming the main instrument air header remains pressurized, the impact of this transient on PTS sequences is considered negligible.
Cooling Water System Failures			
13. CCW Pump 11	CCW flow to RC pump seals, CEDM's and letdown heat exchanger stops. RC pump seal failure will result if CCW flow not restored or RC pumps tripped.	Start CCW pump 13 or 12. Trip RC pumps on high controlled bleed-off temperature if CCW flow cannot be restored.	(a) With promptly initiated remedial actions, the impact of this transient on PTS sequences is considered negligible. (b) Without remedial actions, a small LOCA due to RC pump seal failures would occur. The impact of this transient on PTS sequences is limited since the LOCA is not coupled to a failure to automatically initiate HPSI.

TABLE 11. (Continued)

Initiating Failure	Description of Transient	Available Remedial Actions	Estimated Impact on PTS Sequences
14. Closure of CCW Valve CV-3832 or CV-3833	CCW flow to RC pump seals and CEDM's stops. RC pump seal failure will result if CCW flow not restored or RC pumps tripped.	Trip RC pumps if CCW isolation valves cannot be rapidly opened.	(a) With promptly initiated remedial actions, the impact of this transient on PTS sequences is considered negligible. (b) Without remedial actions, a small LOCA due to RC pump seal failures would occur. The impact of this transient on PTS sequences is limited since the LOCA is not coupled to a failure to automatically initiate HPSI.

TABLE 11. (Continued)

Initiating Failure	Description of Transient	Available Remedial Actions	Estimated Impact on PTS Sequences
15. Service Water Pump 11	Service water flow to air compressors and turbine components stop. Turbine and reactor trip expected, unless service water flow restored. Long term operation of the air compressors without service water may lead to compressor failure and loss of instrument air pressure (unless alternate compressors are aligned). In the event of loss of instrument air pressure, CCW flow is isolated from the RC pump seals, however, steam generator overfeeding would not occur (regulating valves are closed).	Start service water pump 13 or open valves in connecting piping from heat exchanger 12. If cooling water to air compressors cannot be maintained, align Unit 2 compressors to Unit 1 instrument air header. If CCW flow to RC pumps is isolated on loss of instrument air pressure, trip RC pumps.	(a) With promptly initiated remedial actions, the impact of this transient on PTS sequences is considered negligible. (b) Without remedial actions, a small LOCA due to RC pump seal failures would occur. The impact of this transient on PTS sequences is limited since the LOCA is not coupled to a failure to automatically initiate HPSI.

TABLE 11. (Continued)

Initiating Failure	Description of Transient	Available Remedial Actions	Estimated Impact on PTS Sequences
16. Closure of Service Water Valve CV-1637 or CV-1639	See Item 15 above, Service Water Pump 11	Locally reopen isolation valve if possible. If valve cannot be reopened, align Unit 2 compressors to Unit 1 instrument air header and trip Unit 1 compressors to prevent damage. If CCW flow to RC pumps is isolated on loss of instrument air pressure, trip RC pumps.	(a) With promptly initiated remedial actions, the impact of this transient on PTS sequences is considered negligible. (b) Without remedial actions, a small LOCA due to RC pump seal failures would occur. The impact of this transient on PTS sequences is limited since the LOCA is not coupled to a failure to automatically initiate HPSI.

The three double bus failure transients are judged to be very unlikely. However, the combined frequency of the double bus failures and failures of the operator to take remedial actions should be estimated and compared to the independent frequencies of a small LOCA and HPSI failure to evaluate the significance of transients 1, 9 and 10 to PTS.

Other electrical systems failures (Transients 6, 7 and 8) would result in termination of cooling water to the RC pumps as shown in Table 11. However, they would not result in coincident loss of HPSI and therefore are considered less significant. Also, failure of control power to the MFW regulating valves (Transients 4 and 5) would result in a potential overfill of one steam generator. However, other coincident, coupled events adverse to PTS were not identified.

2. Compressed Air System Failures

One compressed air system failure, a passive failure of the instrument air header, Transient 11, has been identified as potentially significant to PTS. Depressurization of the instrument air header would result in both MFW regulating valves freezing in position prior to turbine trip (open) and isolation of CCW flow to the RC pump seals and service water flow to the turbine building equipment. The turbine and reactor are expected to trip on loss of cooling water to the generator or turbine resulting in overfeeding both steam generators. The steam generator overfeed may be terminated by the operator by closing the MFW isolation valves or tripping the MFW pumps. In addition to terminating the overfeed, MFW pumps and condensate pump trip is required due to loss of service water to the pump bearing coolers.

As discussed above, loss of CCW to the RC pump seals could result in seal failure, a coincident coupled small LOCA. The operator must trip the RC pumps on high controlled bleed-off temperature to prevent seal damage and possible failure.

The frequency of the postulated passive failure and failure of the operator to take appropriate remedial action should be estimated and compared to the

frequency of coincident independent small LOCA and steam generator overfeed events to evaluate the significance of transient 11 to PTS.

The other compressed air system failure considered was a passive failure of an AFS instrument air header. This transient may result in the spurious initiation of one AFS train; however, a coupled impact on the main instrument air system is believed to be very unlikely due to the large compressor capacity available.

Other support system failures would result in loss of air compressors due to loss of electric power or compressor cooling water (Transients 6, 7, 8, 9, 15 and 16). However, in each case, instrument air pressure would be lost after the MFW regulating valves had closed in response to turbine trip. This action eliminates the coupling of a steam generator overfeed with other PTS adverse responses.

3. Cooling Water System Failures

Cooling water system failure considered to be significant to PTS were not identified. Failure of the operating CCW pump (Transient 13) or closure of a CCW containment isolation valve (Transient 14) result in a loss of CCW to the RC pump seals. However, additional, coupled responses adverse to PTS were not identified. Prior to tripping the RC pumps to protect the pump seals following a CCW failure, the operator has the option of starting a standby CCW pump or reopening an inadvertently closed isolation valve. Other support system failures which could lead to loss of CCW have been identified in Transients 6, 7, 8, 9 and 11.

Loss of service water pump 11 or closure of an isolation valve (Transients 15 and 16) would lead to loss of cooling water to the air compressors, and turbine components. The operator has several remedial actions possible including initiating flow from service water heat exchanger 12 to service water train 11 or reopening an inadvertently closed isolation valve. In the event air compressor cooling water cannot be restored, the operator has the option of aligning the Unit 2 air compressors to the Unit 1 instrument air header prior to Unit 1 compressor failures (or manual trip).

If service water is not restored, a turbine and reactor trip is expected prior to loss of instrument air pressure. This results in the MFW regulating valves closing and preventing a coupled steam generator overfeed with other PTS adverse events.

Other support system failures which would result in a loss of service water flow to the air compressors have been identified in Transients 6, 7, 8, 9 and 11.

6.0 REFERENCES

1. Memorandum from D. L. Selby (ORNL) to Distribution, November 22, 1983.

2. Letter Report from J. W. Minarick to D. L. Selby, "PTS Initiating Event Frequency and Branch Probability Screening Estimates - Calvert Cliffs Nuclear Power Station," October 7, 1983.

3. At this level of evaluation, the events/systems eliminated were passive and no response to support system failure was considered possible.

4. The source of design information used to obtain these summary results is identified in the individual system/component design discussions rather than on Table 3 for convenience.

5. Calvert Cliffs Nuclear Power Plants 1 and 2 updated Final Safety Analysis Report (FSAR), Chapter 7.

6. FSAR, Chapter 9.

7. "Significant Components Affecting PTS Sequences - Table 1," C. Yoder (BGE).

8. "Calvert Cliffs Schematic Diagram, Turbine Steam Dump and Bypass Controls," 61-061E, Rev. 8.

9. "Calvert Cliffs Piping and Instrument Diagram, Main Steam and Reheat, Unit 1, 60-225-E, Rev. 25.

10. Calvert Cliffs Schematic Diagram, Turbine Auxiliaries, Turbine Alarms and Trips, 1E-74.

11. Calvert Cliffs Reactor Auxiliaries, Pressurizer Relief 1ERV-402 and 1ERV-404, 61-075-B, Rev. 3.

12. FSAR, Chapter 4.