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Evaluation of LOCA With Delayed Loop and Loop With Delayed LOCA Accident Scenarios

Technical Findings Related to GSI-171, "ESF Failure From LOOP Subsequent to LOCA"

Prepared by
G. Martinez-Guridi, P.K. Samanta, T-L. Chu, J. W. Yang

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ABSTRACT

Generic Safety Issue 171 (GSI-171), Engineered Safety Features (ESF) Failure from a Loss Of Offsite Power (LOOP) subsequent to a Loss Of Coolant Accident (LOCA), deals with an accident sequence in which a LOCA is followed by a LOOP. This issue was later broadened to include a LOOP followed by a LOCA. Plants are designed to handle a simultaneous LOCA and LOOP. In this report, we address the unique issues that are involved in LOCA with delayed LOOP (LOCA/LOOP) and LOOP with delayed LOCA (LOOP/LOCA) accident sequences, and determine that such sequences and the specific concerns raised as part of GSI-171 are not fully addressed in Individual Plant Examination (IPE) submittals. The determination is based on our review of selected IPE submittals. LOOP/LOCA accidents are addressed more fully by IPEs than are LOCA/LOOP ones. LOCA/LOOP accidents are analyzed further in this report by developing event-tree/fault-tree models to quantify their contributions to core-damage frequency (CDF) in a pressurized water reactor and a boiling water reactor (PWR and a BWR). Engineering evaluation and judgements are used during quantification to estimate the unique conditions that arise in a LOCA/LOOP accident. The results show that the CDF contribution of such an accident can be a dominant contributor to plant risk, although BWRs are less vulnerable than PWRs.

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Generic Safety Issue 171 (GSI-171), Engineered Safety Features (ESF) Failure from a Loss Of Offsite Power (LOOP) subsequent to a Loss Of Coolant Accident (LOCA), primarily addresses an accident in which a LOCA is followed by a LOOP (hereafter called LOCA/LOOP). It was later broadened to include LOOP followed by a LOCA (hereafter called LOOP/LOCA). This issue is concerned with nuclear power plants' (NPPs') ability to respond to a LOOP subsequent to a LOCA and vice-versa, since one of them occurring as a consequence of the other and delayed by few seconds or longer may result in unique conditions not analyzed previously. Several incidents that have occurred during operation of nuclear power plants, and anomalies noted while testing a plant response's to LOCA and LOOP have raised questions about the ability to respond to such accidents. NPPs are designed to properly respond to a simultaneous occurrence of LOCA and LOOP. The specific issues and concerns associated with LOCA/LOOP and LOOP/LOCA accidents are documented as part of GSI-171.

To address the issues and concerns raised as part of GSI-171, this report quantitatively analyzes the accident sequences based on the following tasks:

1) Analyses of LOCA/LOOP and LOOP/LOCA accident sequences considering the loading sequence in response to LOCA and LOOP and the plant's electrical distribution system, along with applicable protection features,

2) Review of Individual Plant Examination (IPE) submittals to identify the extent to which the GSI-171 concerns are addressed,

3) Development of a detailed model for quantifying the Core-Damage Frequency (CDF) contribution of a LOCA/LOOP accident in a NPP,

4) Development of estimates of LOCA/LOOP frequency based on past LOOP events and estimates of parameters representing the specific conditions during the progression of the accident, using a combination of operating experience data, modeling, engineering analyses and judgment, and

5) Quantification of the CDF contribution of a LOCA/LOOP accident for different plant groups based on a plant's design characteristics and sensitivity analyses of specific plant-vulnerabilities, assumptions in modeling, and variability in the estimated parameters.

The evaluation was carried out for a pressurized- and a boiling-water reactor (PWR and a BWR).

LOCA/LOOP Accidents

A review of the Individual Plant Examination (IPE) submittals indicated that these examinations do not model nor do they discuss the LOCA/LOOP scenarios postulated in GSI-171 along with the associated concerns. Some plants model the random occurrence of LOOP following a LOCA in the LOCA analysis, but these analyses do not provide any insight into the plant's response in the case of a LOCA/LOOP accident.

To address the LOCA/LOOP accident scenario, new event-tree models were developed analyzing the progression of events leading to a core-damage; these involved several issues and a unique combination of failure mechanisms not addressed in current Probabilistic Risk Assessments (PRAs). These issues and failure mechanisms included overloading of Emergency Diesel Generators (EDGs), non-recoverable damage to EDGs and

EXECUTIVE SUMMARY

Emergency Core Cooling System (ECCS) pump motors, lockout energization of circuit breakers due to their anti-pump circuits, lockup of load sequencers, and overloading of ECCS pumps. We used different design characteristics relating to loading the ECCS loads to offsite power, load-shedding, time delay before the circuit breaker of the EDG closes, and reloading the ECCS loads into EDGs to develop plant groups and quantify the CDF contribution for each of them. Sensitivity and uncertainty analyses addressed the major assumptions, variability in data, and specific plant vulnerabilities.

The results and insights relating to PWR plants can be summarized as follows:

1) The CDF contribution of a LOCA/LOOP accident varies by about two orders of magnitude (1.2×10^{-4}/yr to 2.8×10^{-6}/yr), depending on the design characteristics mentioned above.

2) Plants where block-loading to EDG following a LOOP takes place because load-shedding is not implemented, and block-loading to the offsite power is used are expected to have a high CDF contribution; plants where sequential loading to offsite power and the EDG are used, along with load-shedding, appear better equipped to handle this accident and are expected to have a low CDF contribution.

3) Some plants may have specific vulnerabilities. Examples relate to operation with switchyard undervoltage that may increase the probability of a delayed LOOP and overloading of pumps, specific design of load sequencers making lockup highly likely, settings in anti-pump circuits so increasing the likelihood of lockout. Such vulnerabilities further increase the CDF contributions of LOCA/LOOP accidents.

4) Sensitivity analyses show that the dominant contributors to CDF from a LOCA/LOOP accident are overloading of the EDG and lockout of the anti-pump circuits; thus, design features which avoid such failures will significantly reduce the CDF contribution. These contributors may be explored further to identify and evaluate conservatism in their evaluation, which is discussed in the study.

The results and insights relating to BWR plants can be summarized as follows:

1) Similar to PWR plants, the CDF contribution of a LOCA/LOOP accident can vary by orders of magnitude (3.1×10^{-5}/yr to 6.1×10^{-7}/yr), and depends on the design characteristics mentioned above.

2) The CDF impact of a LOCA/LOOP accident for a BWR plant is estimated to be about an order of magnitude lower than in PWRs, and thus, BWRs are less vulnerable to a LOCA/LOOP accident. For some older BWR plants, the CDF contribution can be higher, which was not quantified in this study.

3) Similar to PWRs, the most vulnerable plants are those that block-load to offsite power in response to a LOCA, and block-load to the EDG without load-shed in response to a LOOP. The relative impact for other design features is similar to that observed for PWRs.

4) Similar to PWR plants, EDG overloading and lockout of anti-pump circuits dominate the risk contributions, and these concerns can be addressed to further reduce CDF.

5) Plant-specific vulnerabilities similar to that of PWRs may exist for BWR plants, and, if present, CDF contributions will be higher.

LOOP/LOCA Accidents

In a LOOP/LOCA, during the transient subsequent to the LOOP, the pressure in the reactor coolant system (RCS) may reach the set point for the Power-Operated Relief Valves (PORVs) or Safety Relief Valves (SRVs) to open and these may subsequently fail to reclose, leading to a LOCA. IPEs generally model the LOOP/LOCA scenario, but may not address the GSI-171 issues. This study did not quantify the CDF contribution of a LOOP/LOCA considering the GSI-171 concerns, but Licensee Event Reports (LERs) were reviewed to develop estimates of the probabilities of PORVs and SRVs to open subsequent to a LOOP. These estimates are lower than the values used in the IPEs and PRAs reviewed in this study, and consequently, the LOOP/LOCA frequency is expected to be lower than that used in IPEs.

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LIST OF ACRONYMS

AC	AC Power
ADS	Automatic Depressurization System
AEOD	NRC's Office of Analysis and Evaluation of Operational Data
ANO	Arkansas Nuclear One
ANSI	American National Standards Institute
B&W	Babcock and Wilcox
BWR	Boiling Water Reactor
CCF	Common Cause Failure
CCWS	Component Cooling Water System
CD	Core Damage
CDF	Core Damage Frequency
CE	Combustion Engineering
CFR	Code of Federal Regulations
ECCS	Emergency Core Cooling System
EDG	Emergency Diesel Generator
EDS	Electrical Distribution System
ESF	Engineered Safety Features
ESFAS	Engineered Safety Features Actuation System
FSAR	Final Safety Analysis Report
GDC	General Design Criterion
GE	General Electric
GSI	Generic Safety Issue
HEP	Human Error Probability
HPCI	High Pressure Coolant Injection
HPCS	High Pressure Core Spray
HRA	Human Reliability Analysis
IEEE	Institute of Electrical and Electronic Engineers
IN	Information Notice
IPE	Individual Plant Examination
LER	Licensee Event Report
LOCA	Loss of Coolant Accident
LOOP	Loss of Offsite Power
LOCA/LOOP	LOCA with consequential or delayed LOOP
LOOP/LOCA	LOOP with consequential or delayed LOCA
LPCI	Low Pressure Coolant Injection System
LPCS	Low Pressure Core Spray System
LWR	Light-Water-Cooled Reactor
MOV	Motor Operated Valve
MSIV	Main Steam Isolation Valve
NPP	Nuclear Power Plant
NPRDS	Nuclear Power Reliability Data System
NRC	United States Nuclear Regulatory Commission

LIST OF ACRONYMS

NSAC	Nuclear Safety Analysis Center
NSSS	Nuclear Steam Supply System
NUBARG	Nuclear Utility Backfitting and Reform Group
NUDOCS	NRC's Nuclear Documents Database
PORV	Power-Operated Relief Valve
PRA	Probabilistic Risk Assessment
PWR	Pressurized Water Reactor
RBCCWS	Reactor Building Closed Cooling Water System
RCIC	Reactor Core Isolation Cooling System
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RES	NRC's Office of Nuclear Research
RPS	Reactor Protection System
SCSS	AEOD's Sequence Coding Search System
SGTR	Steam Generator Tube Rupture
SI	Safety Injection
SIS	Safety Injection Signal
SRV	Safety Relief Valve
US	United States
UV	Undervoltage
W	Westinghouse

1 INTRODUCTION

1.1 Background

Generic Safety Issue 171 (GSI-171), Engineered Safety Feature (ESF) Failure from a Loss Of Offsite Power (LOOP) subsequent to a Loss Of Coolant Accident (LOCA), primarily addresses an accident sequence in which a LOCA is followed by a delayed LOOP. This issue was initially identified by the United States Nuclear Regulatory Commission's (NRC's) Office of Nuclear Reactor Regulation (NRR) in NRC Information Notice (IN) 93-17, "Safety System Response to Loss of Coolant and Loss of Offsite Power" issued March 8, 1993 (NRC Info Notice 93-17). This IN was partly based on an identified deficiency in the Surry Power Station Emergency Diesel Generator (EDG) loading logic that could have overloaded the EDGs if a LOCA occurred followed by a LOOP before the Safety Injection Signal (SIS) was reset. The NRC subsequently learned from Nuclear Steam Supply System (NSSS) owners' group that other plants were not necessarily designed to respond properly to a LOCA followed by a delayed LOOP if the SIS was not reset. The IN 93-17 did not request any specific action by (nor information from) the licensee.

In response to the Nuclear Utility Backfitting and Reform Group's (NUBARG) request, NRC's Committee to Review Generic Requirements (CRGR) considered IN 93-17 and noted that "...the staff is considering the need for further generic action to determine if all power reactor licensees should be required to demonstrate the capability to withstand the LOCA/delayed LOOP sequence of concern..." (Letter from E.L. Jordan to D.F. Stenger and R.E. Helfrich, April 12, 1994). NRC IN 93-17, Rev. 1 was issued March 25, 1994.

A prioritization analysis was carried out by NRC's Office of Research (RES) and a HIGH priority ranking was given to the GSI-171 (Attachment to D.L. Morrison to L.C. Shao's Memorandum, June 16, 1995). This prioritization was further reviewed (Memorandum from M.A. Cunningham to C.Z. Serpan, October 18, 1995) and questions were raised about some assumptions made in the analysis. The GSI-171 Task Action Plan was developed. This report presents the study of the GSI-171 accident sequences for the operating power reactors, and the insights gained for addressing the concerns raised as part of this generic issue.

GSI-171 encompasses two scenarios in which a LOCA and a LOOP are not independent events, but the occurrence of one triggers some events that lead to the occurrence of the other; those events usually take some time to occur, and thus, there is usually a delay between the LOCA and the LOOP. The scenario in which the LOCA causes the LOOP is called either LOCA with consequential LOOP or LOCA with delayed LOOP; here we refer to it using the notation LOCA/LOOP. The other scenario in which the LOOP causes the LOCA is called LOOP with consequential LOCA or LOOP with delayed LOCA; we refer to it using the notation LOOP/LOCA.

1.2 Objectives

The objective of this study was to evaluate the LOCA with delayed LOOP (LOCA/LOOP) sequences in pressurized- and boiling-water reactors (PWRs and BWRs), addressing the issues raised as part of GSI-171 and the assumptions made in earlier evaluations. The following were the specific objectives of the study:

a) To analyze the LOCA/LOOP accidents in power reactors considering the loading sequences in response to accidents involving LOCA and LOOP, and the electrical distribution systems along with their applicable protective features;

b) To evaluate the Individual Plant

Examinations (IPEs) conducted as part of NRC's Generic Letter 88-20, and determine whether LOCA/LOOP accidents, as postulated in GSI-171, have been addressed;

c) To develop frequency estimates of LOCA/LOOP accidents considering the dependency of a subsequent LOOP on the LOCA that has occurred;

d) To develop models (event trees) to delineate accident sequences leading to core damage in a LOCA/LOOP, identifying the progression of events;

e) To develop approaches to estimate the probabilities of events identified as part of the event trees, particularly those involving unique failure conditions and mechanisms that may occur during a LOCA/LOOP accident but have not been considered in a conventional probabilistic risk assessment (PRA);

f) To quantify the core damage frequency (CDF) contributions for LOCA/LOOP accidents considering the different, relevant design features in a plant, and assess the sensitivity of the results to the assumptions influencing the evaluations.

In addition, since the GSI-171 also discusses a LOOP/LOCA scenario, i.e, a LOOP followed by a delayed LOCA, we include a discussion of these types of sequences, the adequacy of their modeling in IPEs, and estimates of their frequencies.

1.3 Scope

The scope of this study was to analyze LOCA/LOOP and LOOP/LOCA accidents addressed in CSI-171 and the vulnerabilities of nuclear power plants to such accidents:

(a) To review selected IPEs to determine whether these accident scenarios have been addressed;

(b) To estimate the likelihood of LOOP given LOCA, using the events that occurred at operating nuclear power plants, and similarly, the likelihood of LOCA given a LOOP, based on reviewing LOOP events; and

(c) To develop models to quantify the contributions to core-damage frequency associated with LOCA/LOOP accident scenarios.

The evaluations considered both a pressurized water reactor (PWR) and a boiling-water reactor (BWR).

It was recognized that because of differences in design characteristics the risk contribution of such accidents may vary from plant to plant, and an evaluation of a single plant might not reveal the resulting variations in risk impact. Accordingly, the scenario was modeled in a manner that would facilitate evaluation for different design characteristics. Because of the significant differences between PWRs and BWRs, they were considered separately. Quantitative analysis was conducted using data and other modeling features, as needed, from the following plants: Sequoyah (a PWR), and Peach Bottom (a BWR). These particular plants were chosen because their PRA models were available in the SAPHIRE computer code (Russell et al., 1994), not because of their vulnerability to GSI-171 issues.

The risk contribution was calculated at the level of core-damage frequency (CDF), i.e., an evaluation corresponding to a Level 1 PRA. During a LOCA/LOOP accident, the containment systems also can be adversely affected (NRC Info Notice 96-95), thus affecting the Level 2 and 3 results, but evaluation beyond CDF was not within the scope.

In quantifying the CDF contributions, probability estimates are given for different conditions in a LOCA/LOOP accident. The estimates ideally are based on detailed plant-specific information which, however, was not available for all cases during this study. In many of these cases, past operating-experience data either was not available or its compilation would have taken large resources, if at all possible. Thus, the scope of the evaluation involved the following:

a) using the information available in Final Safety Analysis Reports (FSARs), NRC Info Notices, Licensee Event Reports (LERs), and Individual Plant Examinations (IPEs) dealing with similar conditions; and

b) using engineering judgments to estimate the probabilities, based on the above information.

1.4 Outline of the Report

The report is organized as follows: Chapter 2 discusses the LOCA with delayed LOOP (LOCA/LOOP) and LOOP with delayed LOCA (LOOP/LOCA) accidents as defined in GSI-171; the unique conditions and failure mechanisms that may arise during such accidents are also summarized. Chapter 3 presents a review of the treatment of LOCA/LOOP accidents in the IPE submittals. Estimations of the frequency of LOCA/LOOP accidents are given in Chapter 4. LOOP/LOCA accidents are discussed in Chapter 5, including treatment of this type of accident in IPEs and an estimate of their frequency. Chapter 6 describes the event-tree models for LOCA/LOOP accident sequences. Chapter 7 presents the estimates for different conditions and parameters defined within the event trees. Chapter 8 discusses the CDF contributions of LOCA/LOOP accidents for a PWR and a BWR, as well as plant-specific vulnerabilities, and their impact on CDF contributions, along with sensitivity and uncertainty analyses. The summary and our conclusions are provided in Chapter 9. Appendix A contains the fault trees used for CDF quantification for LOCA/LOOP accident sequences.

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2 LOCA/LOOP AND LOOP/LOCA ACCIDENT SEQUENCES, ELECTRICAL DISTRIBUTION SYSTEMS, AND PROTECTIVE FEATURES

2.1 Description of GSI-171

GSI-171, "ESF failure from LOOP subsequent to LOCA", primarily deals with a LOOP *caused* by the LOCA event and Engineered Safety Features Actuation System (ESFAS) sequencing. Thus, the LOCA and subsequent LOOP would not be *independent* events. The loss of a large amount of electric-power generation, as might be precipitated by the trip of the unit with the LOCA, can cause instability in the transmission system grid, resulting in a total LOOP. The loss of generation from the LOCA-affected unit can also degrade voltage at the unit switchyard, resulting in actuation of degraded voltage protection and subsequent total LOOP. Plants that have no Technical Specifications (TS) upper setpoint limit on degraded voltage sensing, and have little margin between the setpoint and minimum operating grid voltage may be susceptible to this problem.

Besides problems with the transmission system grid, a LOOP may also occur because of problems with the plant's electrical-distribution system. In many plants, the main generator normally feeds the plant loads through a unit auxiliary transformer. When the reactor trips, the main generator often remains connected to the plant's electrical systems and high voltage switchyard until protective relaying transfers the power source from the main generator to an offsite source. If the transfer fails during ESFAS sequencing, the buses which provide power to ESF systems would become isolated from offsite power sources, and then the EDGs would be required to provide power.

When a LOCA occurs at a PWR, the ESFAS will be actuated by one of four automatic signals, or manually by operators' action if the plant operators detect the LOCA before the automatic signals respond. These are the four automatic signals:

1) Low Pressurizer Pressure

2) High Containment Pressure

3) High Steam Line Flow Rate Coincident with either Low Steam Line Pressure or Low-Low Average Temperature (T_{avg})

4) Steam Line High Differential Pressure.

The ESFAS will typically cause the following system responses:

1) Reactor trip initiated

2) Safety Injection Sequence initiated, i.e., emergency core-cooling system (ECCS) pumps started and aligned for cooling the core

3) Phase "A" containment isolation

4) Auxiliary feedwater initiated

5) Main feedwater isolated

6) EDG Startup

7) Auxiliary Cooling System Line-up (pumps started in essential service water and Component Cooling Water systems)

8) Control Room and Containment Ventilation Isolation.

The EDGs at most plants probably cannot handle simultaneous starting of all of the pumps and motors actuated by the ESFAS and, thus, it is necessary to sequence the startup of all ESFAS-actuated systems to prevent overloading the EDGs. There are similar system responses for LOCAs at BWRs.

It is possible that the EDGs could be damaged with no immediate possibility of recovery during this scenario if they attempt to re-energize the entire portion of the previously sequenced load without resequencing. Two utility reports identify another failure mechanism in which circuit-breaker protective devices lock out the circuit breaker to protect it from potential damage resulting from repeated opening and closing (referred to as "pumping"). The operators' actions required to reset the circuit breakers may be quite complicated and could result in a high probability of failure to recover. A third failure mechanism involves the lockup of timers in the accident load-sequencing logic which could result in the loss of all automatic accident-loading capability.

In addition to concerns about the electrical-power system and control system, the coolant systems may also be vulnerable to damage resulting from plant transients during ESF sequencing. Drain-back in coolant systems during power supply transients and switchovers, even assuming that the power is eventually restored, can result in the formation of voids in outlet piping that can lead to water hammer. Water hammer can damage pipes and pipe supports. Restarting a pump which has open outlet valves can require significantly more power than the pump motor was designed to draw during startup, which can exacerbate problems with the electrical power system.

Another potential GSI-171 scenario is a LOOP followed by a delayed LOCA (LOOP/LOCA). One possible scenario for this event is that a plant transient resulting from, or in, a LOOP causes a relief valve to lift which subsequently fails to fully reseat resulting in a loss of inventory and a LOCA initiation signal some time later. It is believed that more plants may be able to handle this event than the delayed LOOP event, even though they may not have been specifically designed for it. The reason for this judgment is that the LOOP/LOCA event does not necessarily require load-shedding and resequencing of loads on the diesel generators, and therefore, might avoid some of the problems associated with those actions identified above for the delayed LOOP event.

There are potential problems in a LOOP/LOCA event. If the LOOP loads have all completed loading on the diesel generators when the LOCA signal comes in, and the loading logic simply load-sequences the additional LOCA loads, the diesel generators may or may not be able to satisfactorily handle the additional loads on top of the already existing ones if this capability was not considered in the original design. If the LOCA loads begin sequencing onto the diesel generators in the middle of the LOOP sequence, the load-sequencing steps may overlap, and the diesel may stall or the generator voltage collapse in the attempt to pick up the excessively large, simultaneous starting load. In both the above examples, the logic associated with the load sequencing may fail to actuate or lockup if it has not been specifically designed to handle the LOOP/LOCA event. NRC IN 84-69 (August 29, 1984) and its supplement (February 24, 1986) also identify the potential that, in some designs, accident loads may not be automatically sequenced onto the diesel generators if the generators are already providing power to the safety buses, which would be the case for the LOOP/LOCA event.

2.2 LOCA With Delayed LOOP (LOCA/LOOP)

This section expands on the issues and concerns associated with a LOCA/LOOP accident.

2.2.1. Overload of EDGs

The Surry report (Virginia Electric and Power Company, May 1989), referenced in NRC IN 93-17 (March 8, 1993), describes a deficiency in the diesel generator's loading logic for the LOCA/-LOOP scenario that results in the generator attempting to pick up, simultaneously, the permanently connected loads plus any safety loads that were sequenced onto the offsite power system before the delayed LOOP signal. Such a problem might occur because a designer did not provide for a load-shed signal to previously sequenced loads following a LOCA because a simultaneous LOCA/LOOP would not require that capability. The safety significance of this deficiency depends on the amount of safety load that was energized prior to occurrence of the LOOP signal. If the LOOP signal comes in just a few seconds after the LOCA signal and before energization of the first sequenced load-step there is no significance because the diesel generator will pick up only the permanently connected loads that are normally energized when the diesel generator's breaker closes. If the LOOP signal comes in substantially later (e.g., more than 30 seconds after the LOCA signal), the diesel generator would have to pick up a large block of load, and could potentially trip off on overload or be damaged with no immediate possibility of recovery.

2.2.2. Block-load

For plants that start all LOCA loads simultaneously (one large load-block versus load-sequence) on offsite power, the worst-case scenario would occur any time the LOCA signal follows the LOOP signal. Block-loading to offsite power may also increase the likelihood of a consequential LOOP.

2.2.3 Non-Recoverable Damage to EDGs and ECCS Pump Motors

EDGs are generally designed to start automatically on a LOCA signal and remain running in standby if offsite power is available during a LOCA. Following a subsequent loss of offsite power, systems that are designed to respond automatically to a LOCA/LOOP will use a time delay or voltage-sensing relay to delay the closing of the diesel generator's output circuit breakers if the generators are up and running. The purpose of this feature is to allow the residual voltages of motors that had been running on the safety buses to decay to a sufficient value (approximately less than 25%) of their nominal voltage to avoid an out-of-phase transfer of the motors with the already running diesel generators. If systems are not specifically designed to respond to the LOCA/LOOP scenario they may not have this feature, and the diesel generator's circuit breakers will likely close immediately upon receiving the LOOP signal, creating the potential for an out-of-phase transfer. Substantial damage to the motor and diesel generator may occur as a result.

2.2.4. Lockout Energization of Safety Loads (Anti-pump Circuits)

Two utility reports (Clinton Power Station Unit 1, November 19, 1993, and Indian Point 3 Nuclear Power Plant, April 4, 1994) and NRC IN 88-75 (September 16, 1988) identify a problem involving the anti-pump circuits in circuit breakers that could result in the inability to automatically or manually reclose safety-related load breakers in designs that attempt to load-shed and reclose these circuit breakers given a LOCA/LOOP. The anti-pump circuits are intended to prevent the close/open pumping of a circuit breaker when both a close signal and open signal are simultaneously presented to the breaker, such as might occur if an operator attempts to close a breaker against a fault. Because of the time delays and permissives involved in resetting anti-pump circuits, the circuits can also lockout closing of circuit breakers in some anti-pump designs if a breaker is rapidly closed-opened-closed or opened-closed, even though the signals do not overlap. Such a series of close/open signals could occur in designs that attempt to load-shed and reclose circuit breakers given a LOCA/LOOP. Whether a breaker is locked out depends on the design of the particular anti-pump circuit and the timing of the LOOP signal. Because load-sequencing times on redundant trains of safety equipment are usually identical, the potential exists that redundant loads, such as safety injection pumps, could be locked out by their breakers in a LOCA/LOOP. Before reclosing a circuit breaker that has been locked out by an anti-pump circuit, the circuit must be reset by either removing the automatic close signal to the breaker, or de-energizing the control power to the anti-pump circuit. Neither of the actions required to do this are likely to be known by the operator.

2.2.5. Lockup of the Load Sequencers

An additional potential vulnerability associated with the LOCA/LOOP event involves the timers used in the load-sequencing logic. Typically, the timers must be reset at some point to reinitialize the timing circuits to restore the circuits to their original pre-event status. In plants that were not designed to accommodate a LOCA/LOOP event, these timers may require resetting by the operator at some point after load-sequencing, or may be automatically reset at some point following load-sequencing. In either case, the inability to reset the timers in the middle of an interrupted load-sequencer operation, such as one occurring during a LOCA/LOOP in plants that load sequence on both offsite and onsite power, could lockup the load sequencers, and lose all subsequent accident-loading capability.

2.2.6. Double Sequencing

The Palo Verde plant (January 5, 1995) discovered the potential for double-sequencing of safety-related equipment following a LOCA, which could delay injection. Following a LOCA and a successful fast bus transfer, the following sequence of events potentially could occur:

1) start of sequencing safety-related equipment onto the preferred offsite power,

2) load-shed due to the class 1E 4.16 kV undervoltage relays dropping out during sequencing onto offsite power, and failing to reset during the time delay (less than 90 percent for approximately 35 seconds),

3) isolation of the class 1E 4.16 kV bus from the offsite source,

4) closure of the EDG breaker, and

5) resequence of the equipment onto the EDG.

This double-sequencing has the net effect of delaying water-makeup injection into the reactor coolant system by more than half a minute after the safety injection signal.

2.2.7. Water Hammer

Water hammer is a concern because of the potential drainback associated with a pumped system when the system is de-energized and then re-energized with voids in the outlet piping. The resulting water hammer may damage the piping and its supports.

2.2.8. Pumps Tripping on Overload

Pumps may also require larger and more prolonged accelerating torques due to re-energization with outlet valves in the open versus closed position. This could result in a stalled pump motor or a more prolonged accelerating current, and potential tripping of the pump on overload. Tripping on overload also is a possibility in large air-conditioning chiller-pump motors that are re-energized before the system's pressures are equalized. In both cases, the large prolonged motor currents could degrade the electrical system beyond tripping just the associated motors.

2.3 LOOP With Delayed LOCA (LOOP/LOCA)

This section expands on the issues and concerns associated with a LOOP/LOCA accident.

2.3.1. EDG Overload

If the LOOP loads have all completed loading on the diesel generators when the LOCA signal comes in, and the loading logic simply load-sequences the additional LOCA loads, the diesel generators may or may not be able to satisfactorily handle the additional loads on top of the already existing ones if this capability was not considered in the original design.

2.3.2. Failure of Logic Associated with the Load Sequencing

If the LOCA loads begin sequencing onto the diesel generators in the middle of the LOOP sequence, the load-sequencing steps may overlap, and the diesel may stall or the generator's voltage collapse in the attempt to pick up the excessively large, simultaneous starting load. The logic associated with the load sequencing may fail to actuate, or may lockup if it has not been specifically designed to handle a LOOP/LOCA.

2.3.3. Accident Loads Not Automatically Sequenced onto the EDGs

NRC IN 84-69 (August 29, 1984) and its supplement (February 24, 1986) also identify the potential that, in some designs, accident loads may not be automatically sequenced onto the diesel generators if they are already providing power to the safety buses, which would be the case for the LOOP/LOCA event.

2.4 Electrical Distribution System

This section describes a typical electrical distribution system (EDS), the different schemes used to energize the ECCS pump motors, and gives an overview of the response of the EDS to three situations: LOOP, LOCA, and LOCA with a delayed LOOP.

2.4.1 Description

The reliability of the electrical supply to the electrical systems, and, in particular, to the onsite emergency safety buses (Class 1E buses) is an important consideration for safely operating a nuclear power plant, and in analyzing LOCA with delayed LOOP. The safety loads (pumps) required to mitigate a LOCA or a LOOP are energized from the 1E buses.

ANSI/IEEE Standard 308-1980 defines Class 1E as "The safety classification of the electric equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or are otherwise essential in preventing significant release of radioactive material to the environment."

Electric power systems in US NPPs are designed and operated to meet the requirements of GDC 17 of Appendix A to Part 50 of Title 10 of the Code of Federal Regulations (CFR). This criterion states, in part, "Electric power from the transmission network to the onsite electric distribution system (Class 1E buses) shall be supplied by two physically independent circuits... Each of these circuits shall be designed to be available in sufficient time following a loss of all onsite alternating current power supplies and the other offsite power circuit, to assure that specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded. One of these circuits shall be designed to be available within a few seconds following a loss-of-coolant accident to assure that core cooling, containment integrity, and other vital safety functions are maintained. Provisions shall be included to minimize the probability of losing electric power from any of the remaining supplies as a result of, or coincident with, the loss of power generated by the nuclear power unit, the loss of power from the transmission network, or the loss of power from the onsite electric power supplies."

During normal operation, the power for the Class 1E buses is from either of the following sources:

1) The main generator of the unit via a transformer, usually called the Auxiliary or Unit Transformer.

2) Offsite sources (switchyards, power lines) via one or more transformers typically referred to as the Startup Transformers or Service Transformers.

If power is lost from these sources, the Class 1E buses are supplied by the onsite emergency diesel generators (EDGs). There is typically one EDG for each 1E bus.

Figure 2.1 is a simplified design of the electrical distribution system of an operating NPP containing two 4.16 kV safety (1E) buses and 2 EDGs; the names of the components in the diagram, such as buses and circuit breakers, have been changed to clarify the discussion. The loads in the two 1E buses are very similar to each other. Therefore, our discussion refers to one of the 1E buses only, but it applies equally to the other, unless otherwise indicated. This plant is an example of the second type of power source for the Class 1E buses during normal operation. Power from the 345 kV switchyard is fed through Auxiliary Transformer 1 and circuit breaker CBNP1.

The offsite power sources to a NPP may be of three different types according to their electrical independence from each other (R.E. Battle, NUREG/CR-3992, Feb. 1985):

1) All offsite power sources are connected to the plant through one switchyard.

2) All offsite power sources are connected to the plant through two or more switchyards, and the switchyards are electrically connected.

3) All offsite power sources are connected to the plant through two or more switchyards or separate incoming transmission lines, but at least one of the AC sources is electrically independent of the others.

The plant in Figure 2.1 is an example of the first type in which the 345 kV switchyard is the only offsite power source to the plant.

The voltage in Bus 1 is monitored by undervoltage (UV) relays (27). If the voltage falls below a certain setpoint of the relays, then a transfer will be made from the normal offsite source to the EDG. To make this transfer, the UV relays send signals for circuit breaker CBNP1 to open, and circuit breaker CBDG1 to close.

2.4.2. Energization of ECCS Loads

There are two main schemes of energization of ECCS loads. In the first, the ECCS loads are energized sequentially by a sequencer that closes the circuit breakers of the ECCS loads in a certain sequence. In the second scheme, all ECCS loads are energized at once; this is called block-load.

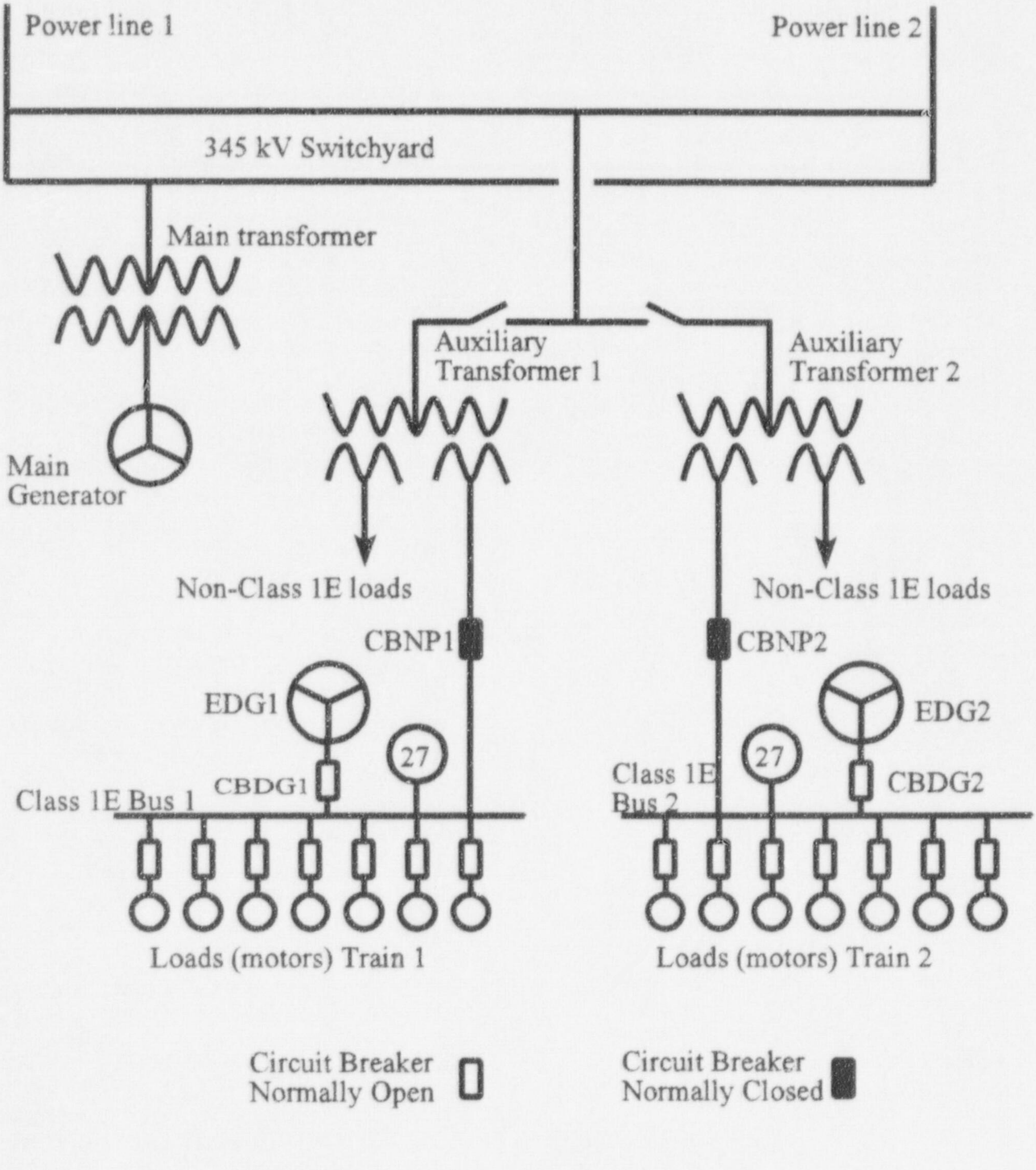


Figure 2.1 Simplified electrical distribution system

Table 2.1 Approximate time to core uncovery after a LOCA

Type of LOCA	Range in Size of LOCA (inches)	Approximate Time of Core Uncovery for an Average Size of LOCA
Large	6 - 29	2 minutes
Medium	2 - 6	16 minutes
Small	0.5 - 2	3 hours

When offsite power is available, the ECCS loads are either sequentially loaded or block-loaded, depending on the particular design of a plant. When offsite power is not available, i.e., there is a LOOP, the ECCS loads are energized by the EDGs. The energization scheme in this case is usually sequential. In BWRs 5 & 6, a diesel generator is dedicated for the High Pressure Core Spray system.

2.4.3. Response to LOOP

In the event of a LOOP, the EDG1 will be started, and, once it has reached its rated frequency and voltage, UV relays will signal the circuit breaker CBDG1 to close. The circuit breakers of the ECCS loads connected to the 1E bus also will receive a signal to close.

2.4.4 Response to LOCA

In the event of a LOCA, an SI signal will be generated some time after its onset, depending on the size of the LOCA. For a small LOCA, it may take up to 2 minutes until it is detected, and, therefore, for the SI signal to be generated. Medium and large LOCAs are detected almost immediately and, therefore, the SI signal is generated immediately after their onset.

In a LOCA, primary coolant is being lost through the break, the level of coolant is decreasing in the pressure vessel, and water makeup must be provided to the vessel; injection is carried out by the ECCS pumps. If there is no injection to the pressure vessel, the core will eventually uncover, overheat, and be damaged.

The larger the size of the LOCA, the faster the pressure vessel will lose water inventory, and the shorter the time to uncover the core. Usually, three sizes of LOCA are analyzed: Large, Medium, and Small. For our discussion, only a rough estimate of the time of core uncovery is needed; this time is given in Table 2.1.

The SI signal will cause the EDG1 to start automatically, but its circuit breaker will remain open. The ECCS loads are energized either using a sequencer or the block-load scheme. In particular, if offsite power is available when the LOCA occurs, some plants energize all ECCS loads (from offsite power) using the block-load scheme.

If offsite power is not available when the LOCA occurs, the ECCS loads are usually energized sequentially.

2.4.5 Response to LOCA and a Delayed LOOP

A LOCA will generate a SI signal, that, in turn, will cause a reactor trip. The loss of generation from the LOCA-affected unit can also degrade voltage at the unit switchyard, resulting in actuation of degraded voltage protection and subsequently, a total LOOP. Any of the three types of offsite power sources mentioned before may be affected in this scenario, but the first two are expected to be more susceptible since there is no electrically independent offsite power source to the plant.

Besides problems with the transmission system grid, a LOOP may also occur because of problems within the plant's electrical distribution system. In many plants, the main generator normally feeds the plant loads through a unit auxiliary transformer. When the reactor trips, protective relaying transfers the power source from the main generator to an offsite power source. If the transfer fails during the ESFAS sequencing, the 1E buses become isolated from sources of offsite power, and then, a transfer to the EDGs would be required.

2.5 Protective Features

Protective devices are used throughout the electrical distribution system. The devices protecting the EDGs and the ECCS pump motors from damage are discussed in this section, and shown in the single line diagram of Figure 2.2. The devices in Figure 2.2 are identified by their function number, which are defined in the standard IEEE C37.2-1991. Circuit breakers depicted with a rectangle with its function number, 52, provide a level of protection by isolating their corresponding equipment from a faulty condition. The circuit breakers are automatically controlled by relays; the relays are depicted with a circle with a function number. An exception is a circle with an "S" inside it, meaning a synchronizing device.

Some or all of the protective devices discussed here may already be installed in nuclear plants. Their configuration and settings in a particular design determine its susceptibility to a LOCA/LOOP. To find out if the configuration and settings are adequate, a systems study, on a plant-specific basis, would have to be carried out. Azarm et al. (July 1996) present such a study for the Susquehanna plant.

The protective devices are connected to the line current by an instrument transformer which transforms line current into values suitable for standard protective relays, and isolates the relays from line voltages. Since they are not essential for our purposes, the instrument transformers are not shown in the figures of this report. A definition of each of the devices in Figure 2.2 is included in the text below.

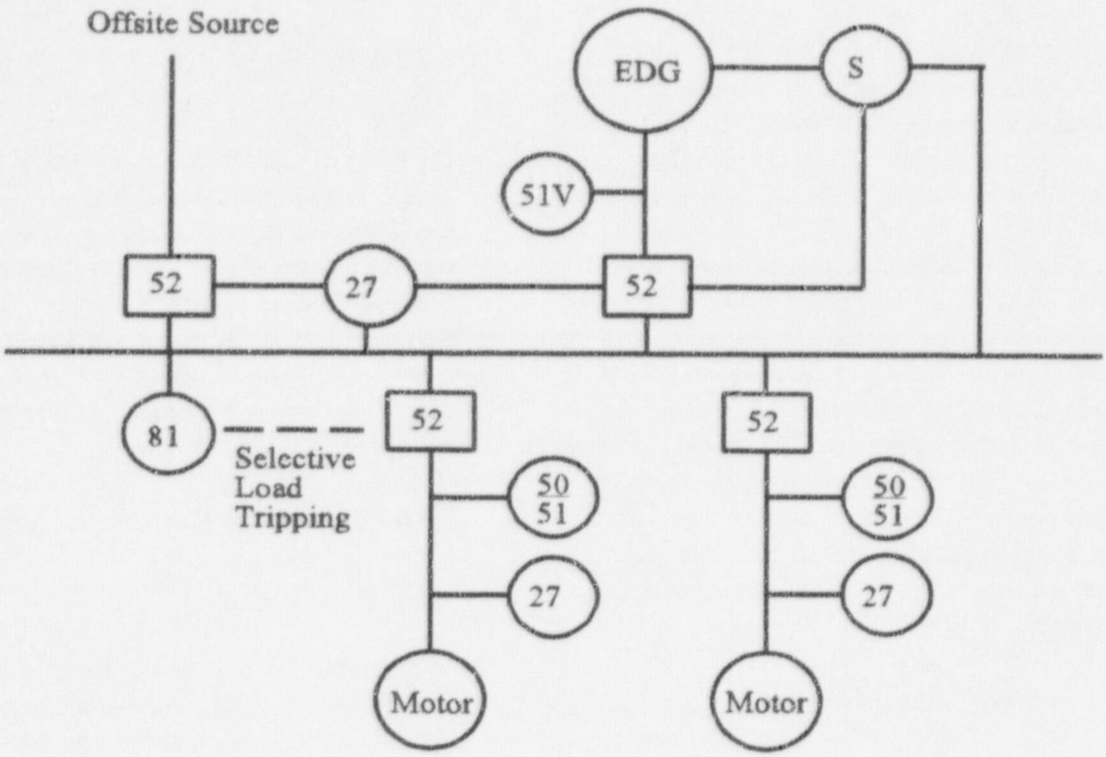
2.5.1 Protective Devices for an EDG

Out-of-Phase Transfer

Several protective devices may be used to prevent or mitigate an out-of-phase transfer; two of these types are a time-delay undervoltage relay and a synchronizing device. A voltage-restrained overcurrent relay mitigates the consequences of this kind of transfer.

A time-delay undervoltage relay, (27) in Figure 2.2, connected between the circuit breakers of the offsite power source and the EDG, is used to initiate a bus transfer from the offsite source to the EDG. The relay has a time delay to preclude out-of-synchronism closure.

A synchronizing relay, (S) in Figure 2.2, is a multifunction device that senses the differences in phase angle, voltage magnitude, and frequency of the sources on both sides of an incoming generator breaker; it initiates corrective signals to adjust the generator's frequency and voltage until the systems are in synchronism. The relay sends a signal to close the incoming source breaker before the generator comes into synchronism with the running system, so that when the breaker is closed the systems will be exactly synchronous. An in-phase monitor is another device ensuring an in-phase transfer.



S **Synchronizing device.** This is the only type of device that can protect the ECCS pump motors from damage due to an out-of-phase bus transfer. By ensuring that the bus transfer takes place synchronously, this device prevents damage. There are two different devices accomplishing this function:

- **Synchronizing relay.** A relay used to automatically close or supervise the closing of a circuit breaker whose function is to connect a generator to a system.
- **In-Phase Monitor.** An accessory on the transfer switch that measures the phase angle difference between two power sources. At the proper difference in phase angle between the sources, it initiates transfer.

27 **Undervoltage relay.** A relay that operates when its input voltage is less than a predetermined value.

50 **Instantaneous overcurrent relay.** A relay that functions instantaneously on an excessive value of current.

51 **AC time overcurrent relay.** A relay that functions when the ac input current exceeds a predetermined value, and in which the input current and operating time are inversely related through a substantial portion of the performance range.

51V **Voltage-restrained overcurrent relay.** A relay that protects the generator if a system fault has not been cleared after a sufficient delay has elapsed.

50/51 **Time-overcurrent with instantaneous relay.** A combination of relays 50 and 51.

52 **AC circuit breaker.** A device that is used to close and interrupt an ac power circuit under normal conditions, or to interrupt this circuit under fault or emergency conditions.

81 **Underfrequency relay.** A relay that responds to the frequency of an electrical quantity operating when the frequency or rate of change of frequency is below nominal frequency.

Figure 2.2 Protective devices for EDG and motors

If the transfer takes place out of synchronization, the EDG may be subjected to overcurrent. To protect against this, a voltage-restrained overcurrent relay is employed (51V in Figure 2.2).

Overload of EDG

As discussed in Subsection 2.4.2, the ECCS pump motors may be energized by a block-load. If so, it is very likely that the total load will exceed the available generation, i.e., the generation of the EDG. To avoid overloading an EDG two schemes are used, load-shedding and sequencing.

When there is an overload, the EDG begins to slow down and its frequency drops. An underfrequency relay, (81 in Figure 2.2), operates at a specific (preset) frequency below nominal to trip off a predetermined amount of load. More than one underfrequency relay may be used to permit several steps of load-shedding; this is represented in Figure 2.2 by "Selective Load Tripping".

The order of an energizing sequence should depend primarily on the safety importance of the loads, and on the capability of the EDG. For example, an EDG may able to simultaneously energize three relatively small, but safety-critical loads (a small block-load within the sequence), and then energize other loads sequentially. This type of approach was implemented by the Surry Nuclear Power Station on discovering a deficiency in the EDG's loading logic (Virginia Electric Power, May 1994). The sequence may be implemented by a time-undervoltage relay attached to each particular motor; see relay 27 attached to a motor in Figure 2.2. This relay inserts a precise time delay in the energizing sequence.

2.5.2 Protective Devices for a Motor

The two devices that prevent damage to an EDG, a time-delay undervoltage relay, and a synchronizing device (synchronizing relay or in-phase monitor), also prevent damage to the ECCS motors by precluding an out-of-phase transfer. The use of an in-phase monitor was proposed by Gill (1979) and IEEE Std. 242-1986 (1992), which allows the motor loads to be reconnected almost immediately and without excessive inrush current. Before transfer, the in-phase monitor samples the relative phase angle between the source supplying the motor and the source to which the transfer is being made. Once the two voltages are within the required phase angle and approaching zero phase-angle difference, the in-phase monitor signals a transfer switch to operate, and reconnection takes place when the two are almost in synchrony.

With this arrangement, rapid transfer is a definite asset. Also, it is not necessary to know the residual voltage profile of the motors. In most cases, it will probably be high, but it will also be almost in phase. Hence, there will be minimal electrical and mechanical shock to either the critical loads (ECCS motors) or the source to which it is being transferred (EDG). Furthermore, this transfer is accomplished without altering the EDG's speed.

Using the in-phase monitor does not require any special field adjustments or interwiring to the motors. For typical transfer switches with transfer times of 10 cycles (166 ms) or less, and for frequency differences between the sources of up to 2 Hz, the in-phase monitor will safely transfer motors.

If the transfer takes place out of synchronization, the ECCS pump motors may be subjected to overcurrent. To protect a motor from the ensuing thermal damage, a time-overcurrent with instantaneous relay is used, (50/51 in Figure 2.2). This relay may not protect the ECCS pump motors against mechanical damage due to an out-of-phase bus transfer; a synchronizing device (synchronizing relay or in-phase monitor), however, prevents such damage from happening.

3 TREATMENT OF LOCA/LOOP IN IPE SUBMITTALS

In this chapter, we present our review of Individual Plant Examinations (IPEs) conducted by the operating nuclear power plants and submitted to the Nuclear Regulatory Commission (NRC) as regards their treatment of the LOCA/LOOP accident scenarios and the associated issues discussed in the GSI-171, ESF failure from LOOP subsequent to LOCA. We discuss the objectives of the review, the approach, the assumptions in the review, and then summarize our findings. The findings primarily address whether the IPEs adequately treat such accident scenario including the issues and concerns raised as part of the GSI-171, and, if not, whether there is sufficient information in these submittals to analyze the issues.

3.1 Objectives of the Review

The impact of the LOCA/LOOP scenarios or how they may lead to core damage in a specific plant depends upon the protective features in the electrical system of the plant. The objectives of the review, which focused on GSI-171 issues, can be summarized as follows:

1) To identify the extent to which LOCA/LOOP scenarios are discussed or modeled in the IPEs, and whether the relevant GSI-171 issues are addressed.

2) To gather information on the protective devices in the plant which prevent damage to, or loss of, the emergency diesel generators (EDGs) and the emergency core cooling system (ECCS) pumps during a LOCA/LOOP accident; this was based on reviewing discussion of electrical systems in the IPE submittals.

3.2 Review Approach

The approach taken was to use the computerized IPE Data Base (Lehner et al., 1995) as far as possible and to supplement it with a review of individual submittals. The latter focussed only on sections of the submittals relevant to the items delineated in the objectives. It was known at the outset of the work that the LOCA/LOOP sequences usually are not modeled in Probabilistic Risk Assessments (PRAs) and only a detailed perusal of them can determine the extent to which GSI-171 issues are addressed and information on protective features is available. The computerized IPE Data Base provided a useful screening of the available information, and gave us general insights that were very applicable for reviewing individual submittals.

The review consisted of the following steps:

1) Using the computerized IPE Data Base to survey LOCA/LOOP sequences modeled in IPEs.

2) Using the results from this survey to obtain general insights on the sequences, their core-damage frequencies, and their contribution to total risk.

3) Reviewing selected IPE submittals to examine

   a) whether the LOCA/LOOP sequences are modeled, or discussed;

   b) whether the GSI-171 issues are addressed if those sequences are modeled or discussed; and

Table 3.1 List of IPE submittals individually reviewed

Plant	Plant Type	Vendor
Arkansas Nuclear One	PWR	B&W
Byron 1&2	PWR	W
Calvert Cliff 1&2	PWR	CE
Indian Point 2	PWR	W
McGuire 1&2	PWR	W
Millstone 3	PWR	W
Salem 1&2	PWR	W
San Onofre 2&3	PWR	CE
Sequoyah 1&2	PWR	W
Shearon Harris 1	PWR	W
South Texas 1&2	PWR	W
St. Lucie 1	PWR	CE
Surry 1&2	PWR	W
Zion 1&2	PWR	W
Grand Gulf 1	BWR 6	GE
Hope Creek	BWR 4	GE
Oyster Creek	BWR 2	GE
Peach Bottom 2&3	BWR 4	GE
Quad Cities 1&2	BWR 3	GE
Susquehanna 1&2	BWR 4	GE

c) what are the implications of GSI-171 issues on CDF, if the sequences are modeled.

4) Examining descriptions of electrical systems given in each IPE submittal to glean information about electric logic circuits and protective devices, and their modeling in the IPE.

The IPE Data Base contains information about 50 PWRs and 28 BWRs. However, out of these 78 IPEs, only 20 were individually reviewed. These 20 plants were selected by considerating all of the information in the Data Base; they are a reasonable representation of the different designs of operating nuclear plants. Table 3.1 lists the IPEs individually reviewed.

3.3 Assumptions in Reviewing the IPE Submittals

The review of the IPEs conducted specifically focussed on the GSI-171 issues. The assumptions discussed below apply, and should be considered in interpreting our conclusions.

1) The detailed review was conducted for 20 plants which reasonably cover the different designs and types. Therefore, the conclusions made are expected to apply, in general, to the remaining plants.

Table 3.2 LOCA/LOOP scenario given by IPE data base

Plant Name	Initiator	CDF/yr	% Total CDF
BWR			
Hope Creek	S1	$7.1x10^{-10}$	0.0
Millstone 1	S2	$3.2x10^{-7}$	2.9
Oyster Creek	S2	$9.5x10^{-9}$	0.2
Quad Cities 1&2	A	$5.5x10^{-9}$	0.5
PWR			
None			

A: Large LOCA, S1: Medium LOCA, S2: Small LOCA

2) To focus on the topics of interest to this study, the review covered only selected parts of the IPE submittals and did not extend to others i.e., the reviewers gathered relevant information from selected, applicable portions of the submittal rather than reviewing the entire document.

3) The review did not analyze the quality nor the validity of the information; only the relevant information was compiled and interpreted for applicability to the issues of concern.

4) The IPE submittals did not directly discuss protective features. Their presence was deduced from the discussions of electrical systems, which involved our interpretations and judgments. Any indication in the discussion pointing toward presence of any of the protective features was interpreted as the plant having that feature. At the same time, plants may have adequate protective features and have not mentioned them in their IPE submittals.

5) The review conducted and the conclusions presented are based on the IPEs submitted to the NRC. [illegible] backup information may be available at the utility which may contain relevant information. No effort was made to obtain such information nor any other separate analysis applicable to GSI-171 that may have been conducted by individual utilities. Also, Final Safety Analysis Reports (FSARs) contain additional information on electrical systems and protective features. In general, however, they do not contain the specifics needed to understand the GSI-171 issues. A review of the FSARs was not part of the evaluation presented in this chapter.

3.4 Details of The Review

In this section, we provide further details of our review. These discussions primarily relate to the individual reviews of the 20 IPEs.

3.4.1 LOCA/LOOP Scenario

Table 3.2 shows the CDF contributions of LOCA sequences with random occurrence of LOOP as modeled in IPEs, identified in the computerized IPE Data Base. The initiating event includes large, medium, and small LOCAs. All the LOCA sequences in the table lead to the loss of AC power system and some other support systems. Other sequences involve also the loss of EDG by reasons not related to the GSI-171 issues; therefore, they are not included in Table 3.2.

The review of 20 IPE submittals shows that only one plant (Susquehanna) had some discussion of GSI-171 issues, and six plants mention the LOCA/LOOP scenario but do not discuss issues relevant to G1-171. The results of the review are given in Table 3.3.

The Susquehanna IPE submittal states that "...when the LOCA event occurs and the reactor is successfully shutdown there is the possibility that the LOCA (with scram) could cause a grid instability and a loss of Offsite Power (LOOP) (probability of $1x10^{-3}$/demand) to occur." It further states that "...assuming the LOCA/LOOP does occur, in order for the diesel to successfully operate, the LOCA isolation scheme (at the 13.8kv level) and the LOCA load-shed scheme (at the 4160V level) must occur. The failure or partial failure of these schemes may result in additional loading on the diesels which could lead to diesel overload and subsequent diesel failure. Also, these LOCA scheme failure may lead to catastrophic equipment failure as a result of this equipment not being stripped off the AC power source it supplies." Despite the references to LOCA/LOOP scenario, there was no event tree with this initiating event in the IPE submittal.

Among the six plants which mention the LOCA/LOOP scenario, three plants (Hope Creek, Oyster Creek, and Quad Cities) performed analysis and appeared in the survey list (Table 3.1). The other three plants (Grand Gulf, Millstone 3, and Shearon Harris) have no LOCA/LOOP sequences identified in the IPE Data Base survey. (Millstone 1 was identified from the IPE Data Base, but was not individually reviewed.) For these plants, the loss of AC is included in the LOCA event trees to recognize that a random LOOP may occur after a LOCA event, but GSI-171 issues, such as out-of-phase bus transfer, are not addressed.

3.4.2. Protective Devices

The protective features applicable to the GSI-171 issues were reviewed for the 20 IPE submittals. The review focused on five protective features: Load-shedding/Load sequencing, Overcurrent Relay, Time Delay, Synchronization Relay, and Interlock. Only 11 plants provide some discussions on these, as shown in Table 3.4. Our discussion for each of these eleven plants follows:

Byron: The IPE submittal describes five automatic actions following an undervoltage on one or both of a unit's ESF buses. The five actions include the conditions and steps for the 4kV ESF bus trip, 4kV ESF load, start of diesel generator, close of the diesel generator output breaker, and the sequencing of the safe shutdown loads. It also describes the safety injection load 1) if the safety injection signal occurs concurrent with ESF bus undervoltage, and 2) if the ESF bus undervoltage does not exist. It is not clear whether the discussion is applicable to the LOCA/LOOP issues.

Grand Gulf: In the description of the Load-shedding and Sequencing System (LSSS), the IPE submittal states that the system initiates operation of the EDGs, selects and provides logic for the sequential loading of the vital buses to minimize stress on the diesel engine. Depending on the existing conditions (Pus Undervoltage, LOOP, and/or a LOCA), the automatic loading sequences can sequentially load the ESF bus with the appropriate equipment. It seems that the LSSS gives some protection against equipment damage.

Hope Creek: A description is given of the interlock between the normal offsite 4.16 kV Class 1E power supply breakers and the diesel generator supply breaker. It states that "...this interlock

Table 3.3 Summary of LOCA/LOOP modeling in IPE submittals

Plant	Not Discussed in the IPE	Mentioned in the IPE (GSI-171 Issues Not Addressed)	Some Discussion of GSI-171 Issue
Arkansas Nuclear One, Unit 1	X		
Byron	X		
Calvert Cliff	X		
Grand Gulf		X	
Hope Creek		X	
Indian Point 2	X		
McGuire 1&2	X		
Millstone 3		X	
Oyster Creek		X	
Peach Bottom	X		
Quad Cities 1&2		X	
Salem 1&2	X		
San Onofre 2&3	X		
Sequoyah 1&2	X		
Shearon Harris		X	
South Texas 1&2	X		
St. Lucie 1	X		
Surry 1&2	X		
Susquehanna			X
Zion	X		

prevents a diesel generator from being parallel to offsite power out of phase or with unmatched voltage." The interlock may provide protection against EDG damage.

Indian Point 2: Descriptions in the IPE submittal show that the electric power system is designed for three conditions when the offsite power is not available: Safety injection with no LOOP, Safety injection with LOOP, and LOOP with no safety injection. The second condition is defined by a coincident safety injection signal with the loss of offsite power. Upon receiving an automatic starting signal, the EDG output breakers will close automatically to load the EDG onto their associated 480V buses only under two conditions: Safety injection with LOOP, or LOOP with no safety injection. The system may be applicable to the LOCA/LOOP scenario, but no detailed information is available about protective features applicable to GSI-171 issues.

Oyster Creek: The emergency diesel generators are designed for "...a complete loss of offsite power and simultaneous loss-of-coolant accident (LOCA)." However, the description of the EDG operation does not indicate whether the GSI-171 issues are addressed.

Peach Bottom: The IPE states that undervoltage condition on the 4kV buses will send a signal to start the diesels. "Upon successful diesel st[illegible]

Table 3.4 Review of protective features discussed in IPEs

Plant	EPS Description Available*	Protective Features				
		Load-shed/ Load Seq.	Overcurrent Relay	Time Delay/ Load Seq.	Synchronization Relay	Interlock
ANO - 1	No					
[illegible]	Yes	Applicability for LOCA/delayed LOOP not clear	Applicability for LOCA/LOOP not clear	—	—	—
Calvert Cliff	No					
Grand Gulf	Yes	May provide protection to equip.	—	—	—	—
Hope Creek	Yes	—	—	—	—	May provide protection against EDG damage
Indian Point 2	Yes	Applicability for LOCA/LOOP not clear	—	—	—	—
Mc Guire 1&2	No					
Millstone 3	No					
Oyster Creek	Yes	—	—	—	—	—
Peach Bottom	Yes	Applicability for LOCA/LOOP not clear	—	—	—	—
Quad Cities 1&2	Yes	No dedicated load sequencer	—	Time delay present. May not provide protection against damage	—	—
Salem 1&2	No					

Table 3.4 Review of protective features discussed in IPEs (continued)

Plant	EPS Description Available*	Protective Features				
		Load-shed/ Load Seq.	Overcurrent Relay	Time Delay/ Load Seq.	Synchronization Relay	Interlock
San Onofre 2&3	Yes	Applicability for LOCA/LOOP not clear	—	—	—	—
Sequoyah 1&2	No					
Shearon Harris	Yes	May provide protection to equip.	—	—	—	—
South Texas Project 1&2	Yes	May provide protection to equip.	—	—	—	—
Surry 1&2	No					
Susquehanna	Yes	Applicability for LOCA/LOOP not clear	Provides protection against damage	—	—	—
Zion	No					

* Description was used to infer protective features; EPS: Electric Power System

breakers E-12, E-22, etc., will close such that the 4kV and the 480 V buses are supplied by the diesels and are loaded appropriately. The diesel loads are sequenced so that transients leading to diesel trips or damage are avoided." The description is insufficient to show its applicability for the LOCA/LOOP scenario.

Quad Cities 1&2: The plant has one dedicated EDG per unit and one shared EDG between the two units. The EDGs are designed to be "...capable of powering the largest postulated vital loads under postulated accident conditions" (i.e., LOCA coincident with a LOOP). The EDGs are also "...capable of supplying the necessary loads to bring the unit to safe shutdown following a loss of offsite power (without a coincident LOCA)." The loads and the safety bus power required to supply them are listed in the IPE submittals. There is no dedicated load sequencer.

San Onofre 2&3: The IPE submittal has a very brief description of the operation of EDG that does not address GSI-171 concerns. "If a SIAS is generated, the EDGs will automatically start regardless the availability of offsite power. In addition, the SIAS signal initiates load-shed of Non-Class 1E loads." "If no LOVS (loss of voltage signal) is present (the bus remains powered by offsite power), the EDG breaker will not close. If a SIAS and LOVS are both present, then the EDG breaker will close, and the Class 1E loads will be sequenced onto the bus at the appropriate times". The brief description does not address the GSI-171 issues.

Shearon Harris: The IPE submittal described the situation of "...combined undervoltage and SI Signals". Several conditions are considered: an undervoltage signal is received first (LOOP/LOCA), a SI signal is received first (LOCA/LOOP), and the receipt of a LOOP or SI signal when the EDG are running in test (a situation similar to that identified in NRC IN 84-69). Under these conditions, the automatic loading sequence follows "Program B", which is described in the IPE submittals.

South Texas Project 1&2: A brief description is given on the start of EDG and the EDG sequencer logic under two events: loss of offsite power and safety injection actuation. The description shows that there may be some protection against damage to the equipment. The GSI-171 issues are not addressed.

Susquehanna: The IPE submittal states that "...if both preferred and alternative startup buses become de-energized or other failures prevent offsite power supplies to the 4.16kV ESS buses, then the buses and the safety-related loads picked up automatically by the diesel generator assigned to that bus." This seems to imply that neither a time delay nor a synchronization device is used for the bus transfer from offsite sources to the EDGs. The IPE submittal also states that overcurrent-sensing relays are provided to prevent damage to the EDG and motors connected to the 4.16 kV ESS buses.

3.5 Insights from the Review

From our survey of the computerized IPE Data Base and individual reviews of 20 IPEs, we summarize our findings and conclusions for the objectives defined earlier.

1) The IPEs do not model nor do they discuss LOCA/LOOP, i.e., LOCA with consequential or delayed LOOP, along with the GSI-171 concerns relating to damage to EDGs and ECCS pumps, nor the loss of this equipment due to overloading, lockup of the load sequencer, and lockout energization of breakers. Some IPEs model random occurrence of LOOP following LOCA in the LOCA analysis, but these analyses do not address nor provide any insights into the plant's response in the case of the GSI-171 postulated scenarios.

2) The IPEs do not contain sufficient information to understand the protective devices that may be present in a plant to adequately respond to LOCA/LOOP sequences. Limited information shows that some plants may have protection against damage to the EDGs and ECCS pumps. Plant-specific information is needed for a complete knowledge about its protective features.

LOCA/LOOP Scenario

The survey of the computerized IPE Data Base showed that only four submittals (4 BWRs, 0 PWR) of the twenty studied modeled LOCA with random occurrence of LOOP. Further, only one submittal discussed GSI-171 issues. Six IPEs either modeled LOCA with a random occurrence of LOOP, or mentioned such a scenario. In general, IPEs do not recognize the GSI-171 LOCA/LOOP scenario.

Protective Devices

The evaluation of the protective devices was made by reviewing the description of the electric power system given in the IPE submittals (Table 3.4). Among the twenty submittals, elevan plants have some description which can be used to infer protective features, and nine have minimal or no description at all. The review focused on five protective features identified at the beginning of the review.

To summarize the information available in the IPEs on protective features:

1) Most IPE submittals do not provide a description of the electrical distribution system that can be used to understand the protective features.

2) The description that is given in a few IPEs does not directly address the protective features of concern in GSI-171.

3) Some plants may have features that may protect equipment against GSI-171 concerns.

4 FREQUENCY OF LOCA/LOOP ACCIDENTS

In a LOCA/LOOP accident scenario, as postulated in GSI-171, there is an increased likelihood of LOOP given a LOCA compared to a random occurrence of the LOOP in the same period. This increased likelihood can be due to a disturbance in the grid caused by the reactor trip which occurs after a LOCA, problems due to bus transfer, or due to the increased loads on the emergency buses in response to the LOCA.

The objective of this chapter is to estimate the initiating event frequency associated with the LOCA/LOOP accident scenarios. Since the frequency of LOCA and LOOP as independent events is known, this involves

a) establishing that there is an increased likelihood for LOOP given a LOCA, and

b) estimating the likelihood of LOOP given LOCA using the events that occurred at operating nuclear power plants.

4.1 Approach for Estimating LOCA/LOOP Frequency

There may be an increased likelihood of LOOP following LOCA, for the following reasons:

1) First, a LOCA will cause a reactor trip and a generator trip. In addition, the EDGs will start automatically, but will not be connected to the safety buses unless an undervoltage occurs at the buses. The loss of the main generator disturbs the offsite grid and can possibly lead to a loss of offsite power to the plant.

2) The reactor trip also will cause a fast transfer of power supply to those buses that normally receive their power from the main generator; this transfer is from the auxiliary transformer to the startup transformer (offsite power). Problems in the fast transfer could lead to a loss of power to the safety buses, and require that the EDGs be connected to the safety buses.

3) If the fast transfer is successful, those loads that were originally on the safety buses will continue to operate without interruption, and the ECCS loads will be loaded onto the safety buses. This addition of the ECCS loads can cause an undervoltage at the safety buses requiring that the EDGs be connected to the buses.

The first two causes can occur subsequent to a reactor trip, and all three causes can occur due to a LOCA. Reactor trips and ECCS-actuation were used as surrogates to estimate LOCA/LOOP frequency, based on the operating experience data. In this section, we discuss our approach, using experience data on reactor trips and safety injections, to estimate the likelihood of LOOP due to these three causes. The data on reactor trips provide an estimate of the likelihood of LOOP due to the first two causes, and data on safety injections give an estimate of the same likelihood due to the third cause.

For a perspective on the increased likelihood of LOOP following a LOCA compared to a random occurrence, the probability of a random occurrence of a LOOP in 24 hours mission time following a LOCA can be considered. In a typical PRA modeling of LOCAs, the subsequent LOOP is modeled as an independent event. This probability is calculated as the product of the LOOP frequency and the 24 hour mission time; using NUREG-1150 estimates, this value is about $2x10^{-4}$. The frequency of a simultaneous LOCA and LOOP is discussed further in Section 4.3.

4.1.1 Formula for Estimating LOCA/LOOP Frequency

The following formula was used to obtain a point estimate of the frequency of a LOCA/LOOP event:

Frequency of a LOCA/LOOP event = Frequency of a LOCA x Probability of LOOP given LOCA **(1)**

Considering the surrogate events, automatic reactor trips and ECCS actuations, we obtain a point estimate of this conditional probability:

Probability of LOOP given a LOCA ≅
Probability of LOOP given reactor trip +
Probability of LOOP given ECCS actuation **(2)**

The primary reason for choosing reactor trips and ECCS actuations as surrogates is that they challenge the electric power system at the plant in a way that approximates that presented by a LOCA. The initial response of the electric power system to a LOCA is a generator trip caused by the reactor trip which, in turn, was caused by the LOCA. Grid instability and the problems of bus transfer that may occur following a LOCA causing a LOOP are expected to be similar in an automatic reactor trip or scram. Thus, the probability of LOOP given an automatic reactor trip gives a portion of the probability of LOOP given a LOCA. As part of a LOCA, an ECCS-actuation signal or safety-injection signal will also be generated. This signal leads to the starting and loading of the ECCS components on the safety buses, and the starting of the emergency diesel generators that will be connected to the safety buses if an undervoltage occurs. Thus, the occurrence of possible undervoltage at the safety buses caused by actuation of the ECCS components and subsequent EDG connection can be determined via data from ECCS actuation events. Therefore, the probability of a safety-bus undervoltage, which contributes to the probability of a LOOP given a LOCA, is estimated by obtaining the probability of a LOOP given ECCS actuation. The probability of LOOP given a LOCA is obtained as a sum of the two terms, as expressed in equation 2, because the second term is the occurrence of LOOP due to the loading of ECCS equipment, and can happen even if a LOOP did not follow the reactor trip. The reactor trip or automatic reactor scram that results in a LOOP is herein called a Trip-LOOP event and the ECCS actuation that results in a safety-bus undervoltage and EDG connection is called an ECCS-LOOP event.

The terms in equation (2) can be estimated as:

$$\text{Probability of LOOP given a Reactor Trip} = \frac{\text{\# Trip-LOOP events}}{\text{\# Automatic Reactor Trip Events}} \qquad \textbf{(3)}$$

$$\text{Probability of LOOP given an ECCS Actuation} = \frac{\text{\# ECCS-LOOP events}}{\text{\# ECCS Actuations}} \qquad \textbf{(4)}$$

The confidence limits on the probability of LOOP given a LOCA are obtained as follows:

a) the confidence limits on each of the two terms contributing to the probability of LOOP given a LOCA are obtained by considering a binomial distribution because the data, number of failures in a given number of demands and the consideration that the probability is constant across these demands, correspond to such a distribution,

b) the confidence limit on the sum of the two terms is obtained by combining the limits on each.

In estimating the confidence limits, the following expressions are used. We use *p* as the probability being evaluated, f as the number of observations of the event, i.e., the numerator, and n as the number of demands, i.e., the denominator. The point estimate of p *is* f/n (see Chapter 5 of NUREG/CR-2300, PRA Procedures Guide, US Nuclear Regulatory Commission, January 1983).

The upper 100 (1 - α)% confidence limit on p is obtained by solving:

$$\alpha = \sum_{x=0}^{f} \binom{n}{x} p^{x} (1-p)^{n-x}$$

The lower 100 (1 - α)% confidence limit on p is obtained by solving:

$$\alpha = \sum_{x=f}^{n} \binom{x}{n} p^{x} (1-p)^{n-x}$$

We used the above expressions to obtain the 5th and 95th percentile confidence limits.

4.1.2 Data Sources and Analysis

The estimate of a LOOP probability given a LOCA, as formulated above, involves identifying

a) reactor trip events,

b) reactor trip events that caused LOOP, i.e., Trip-LOOP events,

c) ECCS actuations, and

d) ECCS actuations that caused LOOP, i.e., ECCS-LOOP events.

Reactor trip events were identified from the annual reports of NRC's Office for Analysis and Evaluation of Operation Data (AEOD). To identify the Trip-LOOP events, LOOP events over the same period were compiled and reviewed. The databases used to identify the LOOP events were NSAC-203 (1994), AEOD report E93-02 (1993), and the sequence coding search system (SCSS). Detailed descriptions of the events identified as Trip-LOOP events were obtained from the NRC's NUDOCS system. The "Nuclear Power Experience" database was also searched for additional descriptions, as needed, and to cross-check the Trip-LOOP events identified.

The number of ECCS actuations was obtained by searching the SCSS and reviewing the abstracts of the LERs. The ECCS-LOOP events were identified from reviewing the information in the SCSS.

Number of Reactor-trip Events

The number of reactor trips, i.e., automatic scrams was obtained from the AEOD annual report which has a year-by-year count for each of the vendor's designs. For the ten-year period 1984-1993, there were 1804 automatic scrams for PWRs and 813 for BWRs.

Number of Trip-LOOP Events

One hundred and seventy-one LOOP events were identified for the same period.

Twelve of them were in the Trip-LOOP category; they were identified by the following criteria:

1) A LOOP is an event that challenges at least one EDG. A partial LOOP is also counted.

2) The main generator must be initially online, so that bus transfers would be required.

3) The cause of a LOOP event must be independent of the cause of the reactor trip. Many LOOP events in the databases started with a problem in the electric

PLANT	VENDOR	DATE OF EVENT	DOCKET#/LER#	DATA SOURCE
PWR				
1. Byron	W	10/02/87	455/87-019	NSAC-203
2. Davis-Besse 1	B&W	08/21/87	346/87-011	AEOD/E-93-02
3. Indian Point 2	W	02/10/87	247/87-004	AEOD/E-93-02
4. Point Beach 2	W	03/29/89	301/89-002	NSAC-203
5. Robinson 2	W	01/28/86	261/86-005	NSAC-203
6. Robinson 2	W	02/13/88	261/88-005	AEOD/E-93-02
7. Zion 2	W	03/24/86	804/86-011	AEOD/E-93-02
BWR				
8. Brunswick 1	GE	09/13/86	325/86-024	AEOD/E-93-02
9. Dresden 2	GE	01/16/90	237/90-002	SCSS
10. Duane Arnold	GE	08/26/89	331/89-011	AEOD/E-93-02

power system that caused the reactor trip, and later, a LOOP. Such events were not considered because we were only interested in those LOOP events resulting from increased grid instability and problems in bus transfers subsequent to a reactor trip.

The above ten Trip-LOOP events were identified, broken down into 3 for BWRs and 7 for PWRs. Most of these events involved problems in bus transfers; only one involved loss of the grid.

Number of ECCS Actuations

To determine the relevant, automatic ECCS actuations, the LER events in the SCSS database were searched and 100 ECCS actuations for PWRs and 18 for BWRs were identified.

The following criteria were used to identify the ECCS actuation events:

1) The main generator must be initially online, so that bus transfers would be required after the reactor trip.

2) A safety injection that takes place subsequent to a reactor trip is counted as a relevant safety injection because starting and loading the ECCS components onto the safety bus is the same as if a LOCA occurred.

3) For BWRs, actuation of the RCIC and HPCI is not considered a relevant safety injection because these pumps are not AC-driven and their actuation will not challenge the AC power system. This criterion eliminated many potential events that were identified in the LER search. Actuation of RCIC and HPCS at a plant with HPCS is a relevant safety injection because the HPCS is AC-driven.

Number of ECCS-LOOP Events

The 118 ECCS actuations found were reviewed to identify those resulting in a LOOP. Out of the 100 ECCS actuations for PWRs, one event at Salem (LER #86-007) was identified as an ECCS-LOOP event. Similarly, for the 18 BWR events, one event at River Bend (LER #88-018) was considered an ECCS-LOOP applicable to the GI-171 accident scenario, even though the loading of the ECCS onto the safety bus may not have caused the LOOP.

4.2 Estimate of LOCA/LOOP Frequency

Based on analyses of events occurring at operating nuclear power plants over 10 years (1984-1993), an estimate of probability of LOOP given LOCA was obtained. This estimate is combined with the LOCA frequency given in a PRA to obtain the LOCA/LOOP frequency.

Table 4.1 presents the results of the data analyses and point estimates of the probabilities of a LOOP given a LOCA for PWRs and BWRs; Table 4.2 gives the confidence limits on these estimated probabilities. The results were based on formulas given in Section 4.1.1. Using the point estimates and the LOCA frequency given in PRAs, the point estimates for LOCA/LOOP frequency are given in Table 4.3, together with the frequency associated with each type of LOCA in a LOCA/LOOP scenario which can be used to quantify the corresponding event trees to obtain the associated CDF contribution. The uncertainty in the CDF estimates also can be appropriately obtained following standard PRA practices. The probability of LOOP given a LOCA is assumed to remain the same for different types of LOCA.

The main findings of the data analyses estimating the probability of a LOOP given a LOCA, in Tables 4.1 and 4.2, are summarized as follows:

1) The estimated probability of a LOOP given a LOCA is 6.0×10^{-2} and 1.4×10^{-2} for BWR and PWR plants, respectively.

2) These point estimates are significantly higher (approximately, by factors of 70 and 300) than that obtained if a LOOP is considered a random event; the ranges are comparable or lower than some estimated previously for prioritization of GI-171.

The estimates are averages over the population of plants and may vary significantly for a specific plant depending on its vulnerability. An example of such a situation was found at the Palo Verde plant (1994) before an administrative control was implemented.

4.3 Frequency of a Simultaneous LOCA and LOOP

To analyze the likelihood of a LOOP occurring coincidentally with a LOCA, we analyzed the plant's response to a LOCA. A LOCA invokes several events that may cause switchyard undervoltage and grid instability, which, in turn, may cause a LOOP:

1) The plant trip associated with the LOCA may degrade the voltage on the safety buses due to the loss of generation to the grid (switchyard),

2) Large safety motors will be started on the safety buses. If the energization scheme from offsite power is a block-load, then the voltage of the switchyard may be further degraded,

3) In some cases, non-safety loads are transferred to a transformer fed from the switchyard.

Table 4.1 Point estimate of LOOP probability given LOCA

A. Probability of LOOP given reactor trip

Plant Type	# Trip-Loop Events	# Trips	Conditional Probability of LOOP (Grid Disturbance, Failure during bus transfer)
BWR	3	813	$3.7x10^{-3}$
PWR	7	1804	$3.9x10^{-3}$
Total	10	2617	$3.8x10^{-3}$

B. Probability of LOOP given ECCS actuations

Plant Type	# ECCS-LOOP Events	# ECCS Actuations	Conditional Probability of LOOP (Safety-Bus undervoltage)
BWR	1	18	$5.6x10^{-2}$
PWR	1	100	$1.0x10^{-2}$
Total	2	118	$1.7x10^{-2}$

C. Probability of LOOP given LOCA

Plant Type	A	B	Probability of LOOP Given LOCA (A+B)
BWR	$3.7x10^{-3}$	$5.6x10^{-2}$	$6.0x10^{-2}$
PWR	$3.9x10^{-3}$	$1.0x10^{-2}$	$1.4x10^{-2}$
Total	$3.8x10^{-3}$	$1.7x10^{-2}$	$2.1x10^{-2}$

Table 4.2 Confidence limits for LOOP probability given LOCA

Plant Type	Probability of LOOP Given LOCA		
	5%	Point Estimate	95%
BWR	$4.5x10^{-3}$	$6.0x10^{-2}$	$2.5x10^{-1}$
PWR	$2.7x10^{-3}$	$1.4x10^{-2}$	$5.5x10^{-2}$
Total	$5.7x10^{-3}$	$2.1x10^{-2}$	$6.0x10^{-2}$

Table 4.3 LOCA/LOOP frequency calculation

A. **PWR**

	Frequency of LOCA (/yr)					Probability of LOOP Given LOCA	Frequency of LOCA/LOOP (/yr)
	Sequoyah		Salem	Surry			
	IPE	1150	IPE	IPE	1150		Based on 1150 LOCA Frequency
A	$2.0x10^{-4}$	$5.0x10^{-4}$	$5.0x10^{-4}$	$2.0x10^{-4}$	$5.0x10^{-4}$		$7x10^{-6}$
S1	$4.6x10^{-4}$	$1.0x10^{-3}$	$1.0x10^{-3}$	$1.0x10^{-3}$	$1.0x10^{-3}$	$1.4x10^{-2}$	$1.4x10^{-5}$
S2	$4.9x10^{-3}$ + (non-isolable) $1.5x10^{-2}$ (isolable)	$1.0x10^{-3}$	$2.0x10^{-2}$	$2.1x10^{-2}$	$1.0x10^{-3}$		$1.4x10^{-5}$

B. **BWR**

	Frequency of LOCA (/yr)					Probability of LOOP Given LOCA	Frequency of LOCA/LOOP (/yr)
	Peach Bottom		Fitzpatrick	Grand Gulf			Based on 1150 Peach Bottom LOCA Frequency
	IPE	1150	IPE	IPE	1150		
A	$4.1x10^{-4}$	$1.0x10^{-4}$	$1.0x10^{-4}$	$1.0x10^{-4}$	$3.0x10^{-4}$		$6.0x10^{-6}$
S1	$2.0x10^{-3}$	$3.0x10^{-4}$	$3.0x10^{-4}$	$3.0x10^{-4}$	$8.0x10^{-4}$	$6.0x10^{-2}$	$1.8x10^{-5}$
S2	$1.0x10^{-2}$	$3.0x10^{-3}$	$3.0x10^{-3}$	$1.0x10^{-3}$	$3.0x10^{-3}$		$1.8x10^{-4}$

A: Large LOCA
S1: Medium LOCA
S2: Small LOCA

Note: Very small LOCAs are not included. For these LOCAs, it is estimated that more than 3 hours will be available for recovery actions and the CDF contribution, which is of interest, will be negligible.

In addition, for plants that experience switchyard undervoltage for a significant fraction of operating time, as did the Palo Verde Nuclear Power Station before administrative controls were implemented, the three conditions above may exacerbate the undervoltage at the emergency buses.

The voltage at the emergency buses is monitored by undervoltage relays which transfer the power source of these buses from the switchyard to the EDGs when the voltage has dropped enough. This transfer is signaled by the undervoltage relays at a pre-set time that is a function of the drop in voltage. In general terms, if the voltage at the emergency buses has dropped substantially, then the transfer will be *fast*, but if not, then the undervoltage relays will exercise delays to "ride" temporary disturbances and avoid spurious transfers. For example, the report from the Surry plant on EDG undervoltage during a LOCA/LOOP scenario states that if the voltage at the emergency buses drops below 75%, then the transfer will take place in 2 seconds, but if the voltage is between 75% and 90% and a Safety Injection Signal (SIS) is present, then the transfer will take 7 seconds; that is, a LOOP signal due to degraded voltage on the safety buses from a LOCA will take about 2 to 7 seconds.

When a LOCA occurs, the reactor and the turbine are tripped, but the main generators in both BWRs and PWRs are not necessarily tripped at the same time, but only after certain conditions have been met. Therefore, a period lasting at least several seconds, running from the moment when the reactor and turbine are tripped to when the main generator is finally tripped, also will introduce a delay for the potential switchyard undervoltage and grid instability, and consequently, for the undervoltage relays to sense the undervoltage and initiate the transfer of the power source of the emergency buses. This time is expected to be about several seconds, and may even be 10 to 30 seconds.

Thus, there are two types of delay before a LOOP occurs after a LOCA, i.e., the period after the LOCA (reactor and turbine trip) when the main generator is finally tripped (at least several seconds), and the delay of the undervoltage relays depending on the severity of the voltage drop (again, at least several seconds). In addition, these two types do not completely overlap because the delay related to the undervoltage relays will probably start timing-out some time during the delay related to the main generator trip, or even after this latter is completed. Therefore, to some extent, it is likely that the two delays will result in a total longer delay. Accordingly, we can expect that a consequential LOOP will occur at least several seconds after the LOCA.

LOOP events were reviewed to obtain a) an estimate of the conditional probability of LOOP given LOCA, and b) a distribution of timing of LOOP following LOCA (see Chapter 7). Of the 12 LOOP events (10 following reactor trip and 2 following ECCS activations), the timing of LOOP following the triggering event could be directly determined from the description of the event for 5 of them, and ranged from 34 seconds to 5 minutes. In other cases, the estimate of this time is based on the analysis of such an event discussed above. In one case, River Bend 1, LER 458/88-018, less than 5 seconds is estimated, but this event initiated with a generator trip and this estimate represents the timing of LOOP following this trip.

Based on the plant's design characteristics relating to LOCA and LOOP, and review of the LOOP events that occurred at nuclear power plants, we conclude that the likelihood of a consequential LOOP occurring coincidentally with a LOCA can neither be supported from engineering evaluation nor from analyses of past experience data. For practical purposes by a simultaneous LOCA/LOOP, or LOCA coincident with a LOOP, we can assume a LOOP occurring within 1 second following LOCA. But, as discussed above, even if the definition of a simultaneous LOCA/LOOP is extended to include a consequential LOOP occurring within 5 seconds, the likelihood remains negligible.

The other possibility is a random LOOP occurring within 1 to 5 seconds following a LOCA. Such probabilities are known to be very small (of the order of 10^{-9} to 10^{-8} assuming a 0.1/yr frequency of a LOOP). Accordingly, the likelihood of a simultaneous LOCA and a LOOP is very small, although a reliable quantitative estimate is difficult to obtain without detailed analyses of a plant's design and its response characteristics following a LOCA. Based on the estimate of the conditional probability of a delayed LOOP following a LOCA obtained earlier, it can be stated that the likelihood of a simultaneous LOOP is several orders of magnitude lower.

4.4 Summary of Results and Insights

The probability of LOOP given a LOCA, as postulated in GI-171, was estimated using automatic reactor scram and ECCS actuations as surrogate events for a LOCA. Operating experience data relating to reactor trips, ECCS actuations, and LOOP events over ten years (1984 to 1993) were reviewed to obtain estimates for PWRs and BWRs; these estimates are averages over the population of each type. The main findings are as follows (also see Table 4.4):

1) The point estimates for probability of LOOP given LOCA for BWRs and PWRs are, respectively, 6.0×10^{-2} and 1.4×10^{-2}, while the comparable probability of random occurrence of a LOOP given LOCA is approximately 2×10^{-4}.

2) There is an increased likelihood of LOOP given a LOCA compared to a random occurrence of LOOP; the estimates obtained for PWRs and BWRs are higher than a random occurrence probability by factors of approximately 70 and 300, respectively, but the range is comparable to, or less than, some previous estimates used for prioritization of GI-171.

The average estimates obtained here can be significantly different for a specific plant where there is a specific vulnerability to such an event. An example was at the Palo Verde plant (1994) before an administrative control was implemented. Also, although ten years of data were evaluated, relatively small numbers of conditional LOOP events were observed which were used to obtain the estimates.

An analysis of simultaneous occurrence of LOCA and LOOP was also conducted. From reviewing plant design characteristics relating to LOCA and LOOP, and of LOOP events that occurred at NPPs, we judge that the likelihood of a simultaneous LOCA and LOOP is very small.

Table 4.4 Comparison of estimates of probability of LOOP given LOCA

	Reference Study	Probability of LOOP given LOCA
1.	NUREG- 1150, IPEs (random occurrence of LOOP given LOCA)	$2 \times 10^{-4*}$
2.	GI-171 Prioritization Evaluation (NRC Memorandum, June 1995) (dependent LOOP probability)	1×10^{-3} to 3×10^{-1}
3.	Reevaluation of GI-171 Prioritization (NRC Memorandum, Oct. 1995) (dependent LOOP probability)	3×10^{-3} to 3×10^{-1}
4.	This study (operating experience, reactor trip, and ECCS actuations as surrogates to LOCA)	$1.4 \times 10^{-2\dagger}$ (3×10^{-3} to 6×10^{-2})†† $6 \times 10^{-2\dagger}$ (5×10^{-3} to 2.5×10^{-2})†† $2 \times 10^{-2\dagger}$ (6×10^{-3} to 6×10^{-2})

† point estimate, †† 5th and 95th percentile confidence limits

* This value assumes LOOP occurred over 24 hours. For a duration of 1 minute, the value is about 10^{-7}.

5 LOOP/LOCA ACCIDENT SEQUENCES

As stated in Chapter 2, GSI-171 addresses LOOP/LOCA, i.e., LOOP with consequential or delayed LOCA, in addition to LOCA/LOOP accident sequences. In a LOOP/LOCA, during the transient subsequent to the LOOP, the RCS pressure may reach the set point for the PORVs or SRVs to open and these may subsequently fail to reclose, leading to a LOCA.

In this chapter, we discuss the treatment of LOOP/LOCA sequences in the IPE submittals including the adequacy of addressing the GSI-171 issues relating to LOOP/LOCA, and our estimates of their frequency based on operating events at nuclear power plants, as well as on a review of existing PRA models. The IPE submittals were reviewed in the same way as discussed for LOCA/LOOP scenarios in Chapter 3; the assumptions stated there also apply here.

5.1 Treatment of LOOP/LOCA Accidents in IPE Submittals

The survey of the IPE Data Base (Lehner et al., 1995) shows that many plants have significant sequences involving the LOOP/LOCA scenario in the Level-1 PRA analysis; Table 5.1 summarizes the survey results.

The review of the 20 IPE submittals showed that all plants have modeled the LOOP/LOCA scenario, but the GSI-171 issues (i.e., EDG overload, load sequencing logic) are not addressed in any of them.

The IPEs do not have sufficient information on the timing of the LOCA occurrence. However, from other sources, such as FSARs, it appears that for PWRs the LOCA is likely to occur after LOOP sequencing is completed. Under this situation, as discussed in GSI-171, EDG overloading is of concern. For BWRs, stuck-open SRV/ADS can occur immediately after the closure of main steam isolation valve (MSIV). Thus, both EDG overloading and sequencing issues apply to BWRs.

The EDG capacity and loading (sequential or block) are not given in either the IPE Data Base (Lehner et al., 1995) nor in IPE submittals. A few IPE submittals have a brief description of EDG loading sequence which is insufficient to address the GSI-171 issues for this accident scenario.

For PWRs, there are two types of LOCA: the stuck-open power-operated relief valves (PORVs) or safety relief valves (SRVs) (opening and subsequent failure to reclose of the pressurizer

Table 5.1 LOOP/LOCA sequences modeled in IPE submittals

	PWR	BWR
No. of plants with significant sequences	21	9
Range of CDF, 1/yr	$3.6x10^{-9}$ to $4.7x10^{-5}$	$6.5x10^{-9}$ to $3.5x10^{-7}$
Contribution to total CDF	0.01% to 15 %	0.05% to 4.8%
No. of plants with CDF>$1.0x10^{-6}$	15	0
Type of LOCA (No. of plants)	RCP seal LOCA (15)[†] PORV stuck-open (3) SRV stuck-open (3)	SRV stuck-open (9) SRV and ADS valves stuck-open (2)

[†] SBO sequences are not included as they are not relevant for this study.

valves), and reactor coolant pump (RCP) seal LOCA (the failure of the systems that provide cooling for the RCP seals and loss of cooling through the seals). For BWRs, the type of LOCA are the stuck-open SRVs and automatic depressurization system (ADS) valves. Depending on the number of valves failing to reclose, the size of LOCA can vary from small to medium, or even large for BWRs. The size of LOCA will determine the time to core damage and time available for any recovery action.

The IPE Data Base contained 21 PWRs and 9 BWRs with significant sequences (i.e., appearing in the top 100 sequences of the IPE) involving the LOOP/LOCA sequences. Table 5.2 shows the results of the survey; the LOOP events do not include the SBO scenario. The contributions to CDF are higher than 10% for four plants (Turkey Point, Summer, Diablo Canyon, and Watts Bar) of all the PWR plants. For BWRs, the CDFs are relatively low and only two plants (Fitzpatrick and Oyster Creek) have contributions to CDF more than 4%. The CDF contributions can be interpreted to indicate that the LOOP/LOCA event plays an important role, especially for PWRs, on core damage based on the IPE modeling which does not address the GSI-171 issues. The risk is expected to be higher if the GSI-171 issues are modeled.

Timing of the LOCA occurrence (i.e., before, during, or after the occurrence of LOOP) is relevant for the GSI-171 issues, but is not provided in the IPEs. However, for PWRs, the LOCA event is likely to occur after the LOOP sequencing is completed, as discussed below:

1) RCP seal LOCA: During normal operation, seal-injection flow is supplied by the Chemical and Volume Control System (CVCS) and thermal barrier cooling is provided by the Component Cooling System (CCS). Seal LOCA can occur by overheating when both CVCS and CCS are lost to the RCP. Overheating of the seal is expected to require a longer time than the LOOP sequencing. Among the 20 IPE submittals reviewed, only one plant (McGuire) briefly stated that seal damage is assumed to occur 15 minutes after the loss of cooling.

2) Stuck-open PORV or SRV: The PORV or SRV is challenged due to pressurization as a result of imbalance of power generation and heat removal by coolant flow in the reactor vessel. The LOOP-induced reactor trip will cause the RCP to coast down. The RCS pressure is likely to decrease by the rapid reduction of decay power and slow pump coast-down. A pressure increase to challenge the PORV/SRV could occur after the loss of heat removal from the secondary side of the steam generator.

Among the 14 PWR IPE submittals reviewed, only the back-end analysis of the Surry plant shows that RCS pressure would challenge the PORV at about two hours after the initiation of the accident for a SBO event with the loss of AFWs. This time delay is much longer than that of the LOOP sequencing.

For BWRs, the closing of the Main Steam Isolation Valves (MSIV) after the initiation of LOOP accident will lead to a pressurization in the reactor vessel, which can immediately challenge the SRVs. The opening and the closing of several groups of SRVs follow a cyclic behavior. Stuck-open SRVs could occur at any time before the ADS is actuated. The timing of opening the SRV is not given in IPE submittals but is given in many FSARs. For example, in the FSAR of Hope Creek plant, the first opening of the SRV was about 2 seconds after a loss of AC power accident.

Table 5.2 LOOP/LOCA scenario given in IPE data base

Plant Name	LOCA Type	CDF Contribution(/yr)	Total CDF(/yr) (Internal Event)	% Total CDF (Internal Event)
BWR				
Oyster Creek	Stuck-open SRV	1.85×10^{-7}	3.9×10^{-6}	4.75
Fitzpatrick	Stuck-open SRV	8.81×10^{-8}	1.9×10^{-6}	4.64
Brunswick 1&2	Stuck-open SRV	3.46×10^{-7}	2.7×10^{-5}	1.28
Hatch 1	Stuck-open SRV, ADS	2.70×10^{-7}	2.2×10^{-5}	1.23
Browns Ferry 2	Stuck-open SRV	3.52×10^{-7}	4.8×10^{-5}	0.73
Perry 1	Stuck-open SRV	7.24×10^{-8}	1.3×10^{-5}	0.56
Fermi 2	Stuck-open SRV	8.32×10^{-9}	5.7×10^{-6}	0.15
Nine Mile Point 1	Stuck-open SRV	6.53×10^{-9}	5.5×10^{-6}	0.12
River Bend	Stuck-open SRV, ADS	8.56×10^{-9}	1.6×10^{-5}	0.05
PWR				
Diablo Canyon 1&2	Stuck-open PORV	1.33×10^{-5}	8.8×10^{-5}	15.11
Turkey Point 3&4	RCP seal LOCA	4.69×10^{-5}	3.7×10^{-4}	12.68
Summer	RCP seal LOCA	2.11×10^{-5}	2.0×10^{-4}	10.55
Watts Bar 1&2	RCP seal LOCA	8.1×10^{-6}	8.0×10^{-5}	10.09
Beaver Valley 2	RCP seal LOCA	1.86×10^{-5}	1.9×10^{-4}	9.77
Haddem Neck	Stuck-open SRV	1.58×10^{-5}	1.9×10^{-4}	8.29
Beaver Valley 1	RCP seal LOCA	1.68×10^{-5}	2.1×10^{-4}	8.01
Callaway	RCP seal LOCA	3.87×10^{-6}	5.9×10^{-5}	6.56
Prairie Island 1&2	RCP seal LOCA	2.05×10^{-6}	5.1×10^{-5}	4.02
Wolf Creek	RCP seal LOCA	1.31×10^{-6}	4.2×10^{-5}	3.12
Seabrook	RCP seal LOCA	1.63×10^{-6}	6.6×10^{-5}	2.47
McGuire 1&2	RCP seal LOCA	8.80×10^{-7}	4.0×10^{-5}	2.20
Kewaunee	RCP seal LOCA	1.23×10^{-6}	6.7×10^{-5}	1.84
Point Beach 1&2	RCP seal LOCA	1.64×10^{-6}	1.2×10^{-4}	1.37
Palo Verde 1,2&3	RCP seal LOCA	9.13×10^{-7}	9.0×10^{-5}	1.01
Sequoyah 1&2	RCP seal LOCA	1.68×10^{-6}	1.7×10^{-4}	0.99
H.B. Robinson 2	Stuck-open SRV	2.28×10^{-6}	3.2×10^{-4}	0.71
Calvert Cliffs 1&2	Stuck-open PORV	5.24×10^{-7}	2.4×10^{-4}	0.22
TMI 1	RCP seal LOCA	8.53×10^{-8}	4.5×10^{-5}	0.19
St. Lucie 2	Stuck-open PORV	4.04×10^{-8}	2.6×10^{-5}	0.16
San Onofre 2&3	Stuck-open SRV	3.60×10^{-9}	3.0×10^{-5}	0.01

From the above discussion, it appears that only EDG overloading is of concern to PWRs, but both overloading and sequencing logic apply to BWRs. These data are summarized as follows:

1) IPEs generally model the LOOP/LOCA scenario but do not address GSI-171 issues.

2) For PWRs, EDG overloading can be of concern, and if it is likely, then the risk contribution will be higher than that estimated in the IPEs.

3) For BWRs, both EDG overloading and sequencing should be considered.

5.2 Estimate of LOOP/LOCA Frequency

Two ways of estimating LOOP/LOCA frequency were used. First, the PRAs, including some IPEs, were reviewed to determine the frequency estimates provided therein for such an event. Second, LERs were reviewed to identify actual occurrences of events in which PORVs and SRVs opened subsequent to a LOOP. PWRs and BWRs were considered separately.

5.2.1 Estimate Based on Existing PRA Models

In a LOOP event-tree for a PWR, two types of LOCAs are typically modeled, a stuck-open PORV and a RCP-seal LOCA. During the transient subsequent to a LOOP initiating event, the RCS pressure may reach the set point for the PORVs to open. Once opened, the PORVs may fail to re-close leading to a LOCA. A seal LOCA could occur subsequent to a LOOP if cooling to the seal is lost. In many PRAs and IPEs, a station blackout is the dominant cause of loss of RCP seal cooling and, since then the EDGs are already failed, such scenarios are not relevant to GSI-171. A loss of seal cooling may occur due to causes other than a station blackout. However, the frequency of these scenarios is very low, of the order of $1.x10^{-5}$ or less, and therefore only the stuck-open PORV scenario is of interest here.

Table 5.3, below, summarizes the estimates of LOOP-stuck-open PORV frequency documented in different PRAs and IPEs for PWRs.

In the LOOP event-tree of a PRA for a BWR, the model typically accounts for stuck-open safety relief valves. The PRAs reviewed for this study

Table 5.3 Frequency of a LOOP followed by a stuck-open PORV

PRA/IPE	Initiating Event (LOOP) Frequency (/yr)	Conditional Probability of Stuck-Open PORV	Frequency of LOOP Followed by Stuck-Open PORV (/yr)
Sequoyah-1150	$9.1x10^{-2}$	$2.7x10^{-3}$	$2.5x10^{-4}$
Salem-IPE	$6.0x10^{-2}$	$2.0x10^{-3}$	$1.2x10^{-4}$
Surry-1150	$7.7x10^{-2}$	$2.6x10^{-3}$	$2.0x10^{-4}$

Table 5.4 Frequency of stuck-open SRVs used in NUREG-1150 study of Peach Bottom

Frequency of LOOP (/yr)	Number of Stuck-Open SRVs	Conditional Probability of Stuck-Open SRVs	Frequency of LOOP Followed by Stuck-Open SRV (/yr)
0.079	1-small LOCA	9.6×10^{-2}	7.6×10^{-3}
	2-medium LOCA	2.0×10^{-3}	1.6×10^{-4}
	3-large LOCA	2.0×10^{-4}	1.6×10^{-5}

include the Peach Bottom 1150 model, Peach Bottom IPE, Grand Gulf 1150 model, Grand Gulf IPE, and Fitzpatrick IPE. Stuck-open SRVs are modeled in very similar way in these analyses; however, quantitative information for calculating the frequency was only available for the NUREG-1150 model of Peach Bottom; the quantitative results from which are presented in Table 5.4.

5.2.2 Estimate Based on Review of Operating Experience

The table below shows eight potential LOOP-LOCA events, i.e., those that are initiated with a LOOP and lead to the opening of a PORV or SRV, found in the 10 year-history of operating experience: The conditional probability of an opening of a PORV or SRV, given a LOOP, can be written as: #LOOP events leading to SRV or PORV opening/#LOOP events. The total number of LOOP events occurring between 1984 and 1993 was 120 (81 from NSAC/203 [April 1994], 29 additional events from AEOD/E93-02 [March 1993], and 10 more from the search of LERs). Of these, 77 are for PWRs and the remaining 43 for BWRs. Based on this data, the conditional probabilities are 3/77=0.0390 for PWRs, and 5/43=0.116 for BWRs. For all the plants combined, the conditional probability is 8/120=0.067.

The frequency of open PORV or SRV following a LOOP is the product of the frequency of LOOP and the conditional probability of an opening of a PORV or SRV given a LOOP. This frequency also can be estimated as the ratio of the number of open PORV or SRV events and the number of years of plant operation.

The challenges to PORVs or SRVs during a LOOP event based on operating experience can be multiplied with a conditional probability that a valve would stick open, as used in PRAs, to obtain the frequency of a stuck-open PORV or SRV subsequent to a LOOP.

Plant	Vendor	Date of Event	Docket#/LER#	Data
<u>PWR</u>				
Diablo Canyon 2	W	07/17/88	323/88-008	SCSS
Robinson	W		261/88-005	AEOD/E-93-02
Salem 2	W	08/26/86	311/86-007	AEOD/E-93-02
<u>BWR</u>				
Brunswick 2	GE	06/17/89	324/89-009	AEOD/E-93-02
LaSalle 1	GE	09/14/93	373/93-015	SCSS
Pilgrim 1	GE	09/10/93	293/93-022	SCSS
Susquehanna 1	GE	07/31/91	387/91-008	SCSS
Susquehanna 1	GE	07/26/84	388/84-013	SCSS

Table 5.5 Comparison of frequency estimates based on operating experience with those based on PRA models

	Generic Operating Experience					PRA Model
	Number of Open PORV Events Following a LOOP	Number of Years the Plants Were Critical	Frequency of Open PORV or SRV following a LOOP (/yr)	Conditional Probability that a PORV/SRV Sticks Open	Frequency of Stuck-Open PORV/ SRV (/yr)	Frequency of Stuck-Open PORV/SRV (/yr)
PWRs	3	504.28	$6.0x10^{-3}$	$2.6x10^{-3}$ (Surry, Sequence Q-T1)	$1.5x10^{-5}$	$2.0x10^{-4}$ (Surry, NUREG-1150)
BWRs	5	228.78	$2.2x10^{-2}$	$9.6x10^{-2}$ (Peach Bottom, Sequence P1)	$2.1x10^{-3}$	$7.6x10^{-3}$ (Peach Bottom, NUREG-1150)

5.2.3 Summary of LOOP/LOCA Results and Comparison of the Two Estimate Methods

Table 5.5 shows the results based on operating experience and compares them with the estimate based on PRA models. The numbers of years that the PWRs and BWRs were critical during the 1984-1993 period were obtained from the AEOD annual report.

5.3 Summary Insights and Results on LOOP/LOCA Accidents

A review of the IPE submittals indicate that LOOP/LOCA sequences are modeled in these evaluations and the associated core-damage frequency (CDF) contributions can be greater than $1.0x10^{-5}$. Fifteen PWRs have sequences with a CDF contribution greater than $1.0x10^{-6}$, with the highest contribution being $4.7x10^{-5}$. However, these models do not address GSI-171 concerns relating to EDG overloading, nor failure of the logic associated with load sequencer in such a sequence.

Some IPEs and some PRAs completed as part of the NUREG-1150 study were reviewed to obtain the frequency estimates used for such an event. LERs were reviewed to obtain estimates for PORVs or SRVs to open subsequent to a LOOP. These estimates then were multiplied by the probability that the valve will be stuck or fail to close to give an assessment for the stuck/open PORV or SRV, i.e., a small LOCA. The findings can be summarized as follows:

1) The estimates for stuck/open PORV or SRV subsequent to a LOOP, based on review of operating experience, are lower than those used in IPEs or other PRAs reviewed for this study.

2) The LOOP/LOCA frequency used in the IPEs or PRAs appears to be conservative.

6 MODELING LOCA/LOOP ACCIDENT SEQUENCES

6.1 Specific Modeling Needs, Objectives, and Assumptions

Modeling a LOCA/LOOP accident entails addressing the unique issues that may be involved. The specific ways in which the safety systems may respond or fail were discussed as part of the GSI-171, and are summarized in Chapter 2. These issues and concerns have evolved over the years, and are based on incidents that have occurred at different plants. A LOCA/LOOP accident is modeled using event trees, as routinely done in PRAs, to define the progression of events and paths that lead to core damage.

The following are the objectives in this modeling:

a) to address various conditions that occur in a LOCA/LOOP accident, considering the timing involved and plant's design characteristics; this includes addressing the issues raised in GSI-171,

b) to consider a large, medium, and small LOCA as is done in a typical PRA, and,

c) to include differences in PWRs and BWRs taking into account the characteristics of their safety systems and responses to such an accident.

Since there are some similarities in plant designs related to the response to LOCA and LOOP events, while at the same time, there are differences between a PWR and a BWR, then, from plant to plant, we proceeded to model in the following way:

a) develop a general event tree considering the occurrence of a LOCA, the EDG's response, and delayed occurrence of LOOP, detailing issues and concerns about the safety-system's performance,

b) consider the specific features of PWR and BWR plants and modify the model accordingly to obtain general ones for both,

c) consider the different LOCA sizes and the plant's response, and modifying the event tree for quantifying the CDF contribution for each LOCA size; the probabilities for the operator's recovery actions differ for different LOCA sizes and are considered in the quantification, and

d) develop groupings of plants based on their design characteristics relating to load-sequencing and load-shedding features, and obtain the corresponding CDF contribution for each group.

The basic assumptions in the development of event tree are as follows:

1) GSI-171 encompasses many issues and concerns about a LOCA with a delayed LOOP accident that have evolved over the years, based on incidents at specific sites. Although corrective measures have been taken at such sites, questions remain about the applicability of the issues to other plants. Also, some issues are based on the analysis of some designs and the characteristics of the plant's response. To understand a plant's vulnerabilities to one or more of these issues, information is needed beyond that available in IPEs or FSARs. At present, no determination has been made about which issues apply to which group of plants. Conceivably, only a part of the issues apply to some plants. However, we model those issues that may have strong implication on the risk contribution since plants and issues have not yet been matched.

2) Modeling the accident sequences covers plants that may have most or all of the vulnerabilities to those that have the essential protective features. A plant vulnerable to some issues will lie in between. Modeling the vulnerabilities and the quantified risk contribution, discussed in Chapter 8, does not imply any distribution of the vulnerabilities of operating nuclear power plants.

3) The specific conditions that may occur during the progression of events, e.g., damage to the EDG or the ECCS pump motors, EDG trip, lockup of sequencers, are defined from evaluations of postulated conditions and those stated in GSI-171. Later, judgements are used to estimate these probabilities, based on this information; the process is discussed for each case. Plant-specific data can refine and tailor these estimates for individual applications.

4) The event tree proposed to model a LOCA/LOOP accident encompasses different design features relating to ECCS loading to offsite power, load-shedding following LOOP, the energization scheme to the EDG (block-loading or sequential), and the delay in connecting the EDG to the bus. The model addresses various combinations of these features, which later are used to group the plants (Chapter 8) and quantify the CDF contribution. We did not identify how current operating plants are distributed among these groups, nor do we know if there is one operating plant belonging to each of the groups. The event-tree model considers these combinations, and facilitates the quantification of CDF for each plant group discussed in Chapter 8.

6.2 Development and Descriptions of Event Trees

6.2.1 Headings of the Top-Level LOCA/LOOP Event Tree

The following is an overview of the sequence of events that take place in a LOCA with a delayed LOOP scenario:

1) The design of most nuclear power plants ensures that when a LOCA occurs the EDGs start.

2) When a LOOP occurs later, the circuit breaker of each running EDG closes to the emergency bus, and then GSI-171 concerns may affect the plant's safety.

This top-level sequence of events is modeled by the event tree of Figure 6.1. Below, we describe the headings in the event tree and briefly outline each sequence.

LOCA. This is the initiating event, and can be any of the initiating events for three sizes of LOCA, large, medium, and small, analyzed by this study.

SEQOFP. When the LOCA occurs, offsite power is available and the LOCA loads are energized by offsite sources. Then, some plants block-load the LOCA loads, while others use a sequencing scheme of energization. Some evidence suggests that the plants that block-load the LOCA loads to the offsite sources are more likely to experience a delayed LOOP than those that sequence the loads because block-loading may cause a voltage transient which, in turn, may initiate a LOOP.

This heading models these two energization schemes of LOCA loads with offsite power available: block-loading, and sequential. Using this heading, the risk at a particular plant with either energization scheme can be evaluated; sequences 1

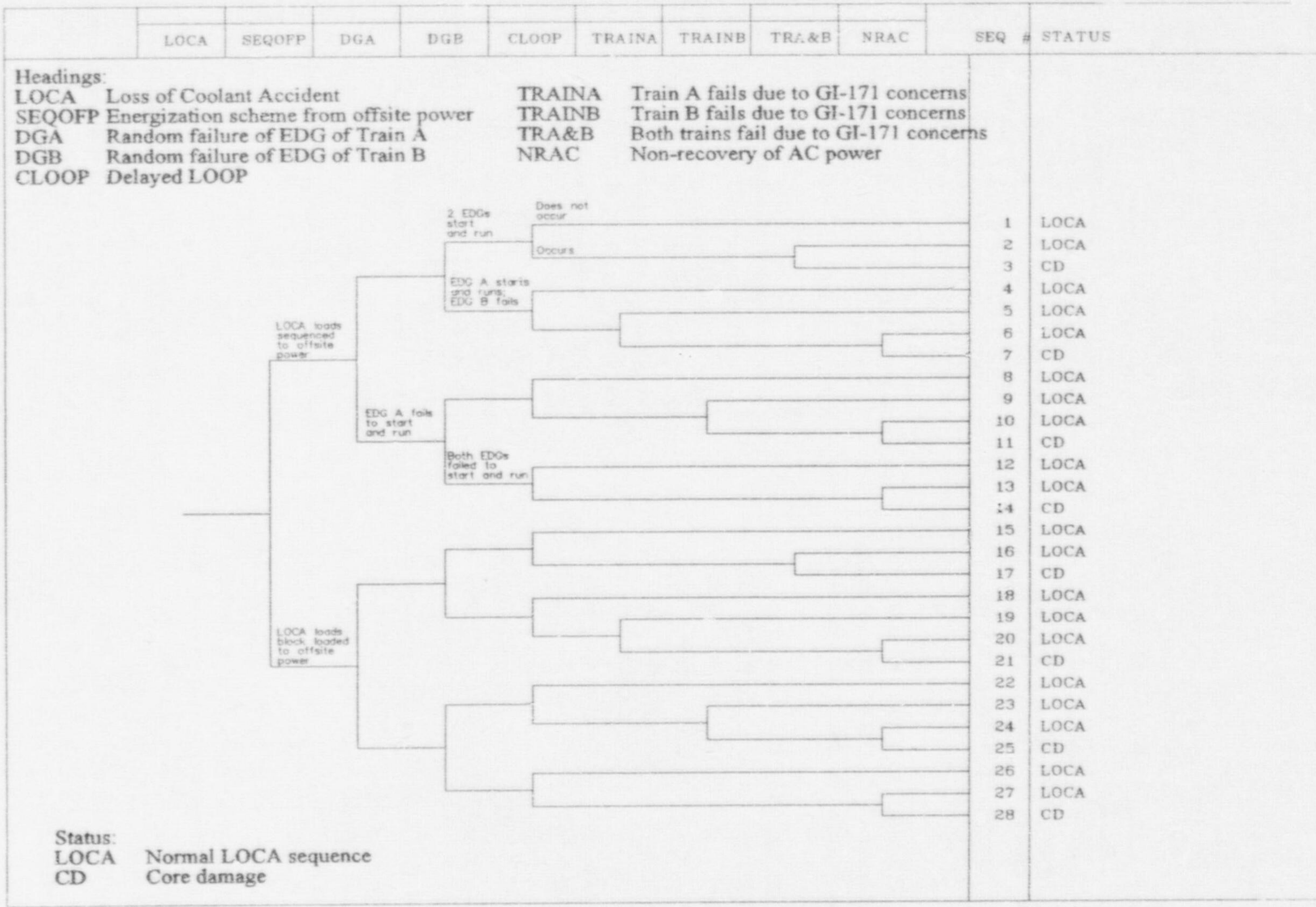


Figure 6.1 Top-level modeling of LOCA/LOOP scenario

to 14 only apply to plants with a sequential scheme, while sequences 15 to 28 only apply to plants with a block-loading scheme.

DGA and DGB. These two headings model the possibility that the EDG of train A and that the EDG of train B may fail to start and run, respectively. As shown in Figure 6.1, there are three possible types of outcomes after these two headings have been evaluated: both EDGs successfully start and run, one EDG successfully starts and runs while the other fails to do so, or both EDGs fail.

CLOOP. This is the probability that a delayed LOOP will occur after a LOCA; this probability was estimated earlier in Chapter 4 of this report.

TRAINA and TRAINB. If one train is not available because its corresponding EDG failed to start and run, then only the other train needs to be affected by GSI-171 concerns for both to be unable to cope with the severe demands of a LOCA and a LOOP. If the EDG of train A successfully starts and runs, then TRAINA evaluates the probability that the train A will fail due to GSI-171 concerns. Similarly, if the EDG of train B successfully starts and runs, then TRAINB evaluates the probability that the train B will fail due to GSI-171 concerns.

TRA&B. If the EDGs of both trains successfully start and run for their mission times, then both trains must be affected by GSI-171 concerns for core damage to occur.

NRAC. If one or both of the EDGs fail to start and run, then recovery of AC may be attempted before the core is damaged. Since core damage occurs within a few minutes after the onset of a large or medium LOCA, the probability of successfully recovering AC is very small. On the other hand, several hours are available after the onset of a small LOCA to recover AC. This heading evaluates the probability of failing to recover AC.

6.2.2 Sequences of the Top-Level LOCA/LOOP Event Tree

The top-level event tree (Figure 6.1) has 28 accident sequences whose outcome is either LOCA or core damage (CD); the outcome is shown in the column headed "STATUS". If the plant's mitigating systems and recovery actions fail to cope with the occurrence of GSI-171 concerns or the EDGs fail randomly, then the outcome is CD; otherwise, it is LOCA. In the latter case, the CDF contribution has been evaluated already by the traditional LOCA evaluations which usually assume that there are no failures related to a delayed LOOP, such as EDG overload.

As discussed under the SEQOFP heading, sequences 1 to 14 only apply to a plant with a sequential energization scheme to offsite power sources, while sequences 15 to 28 only apply to a plant with a block-loading energization scheme to offsite power sources. Therefore, each corresponding pair of sequences, such as 1 and 15, 2 and 16, and so on are identical except that the first (such as sequence 1) corresponds to a plant with a sequential energization scheme, and the second (such as sequence 15) to one with a block-loading energization scheme. Therefore, in the following description of the first 14 sequences, the corresponding information for a plant with a block-loading energization scheme is shown in parentheses.

Sequence 1 (15). A LOCA occurs and the LOCA loads are sequenced (block-loaded) to offsite power sources. Both EDGs start and run, and a delayed LOOP does not occur. Outcome: LOCA.

Sequence 2 (16). A LOCA occurs and the LOCA loads are sequenced (block-loaded) to offsite power sources. Both EDGs start and run, and a delayed LOOP occurs, but both trains survive the GSI-171 concerns. Outcome: LOCA.

Sequence 3 (17). A LOCA occurs and the LOCA loads are sequenced (block-loaded) to offsite power sources. Both EDGs start and run, and a delayed LOOP occurs, but both trains fail due to GSI-171 concerns. Outcome: Core damage.

Sequence 4 (18). A LOCA occurs and the LOCA loads are sequenced (block-loaded) to offsite power sources. EDG A starts and runs, but EDG B fails. A delayed LOOP does not occur. Outcome: LOCA.

Sequence 5 (19). A LOCA occurs and the LOCA loads are sequenced (block-loaded) to offsite power sources. EDG A starts and runs, but EDG B fails. A delayed LOOP occurs, but train A survives the GSI-171 concerns. Outcome: LOCA.

Sequence 6 (20). A LOCA occurs and the LOCA loads are sequenced (block-loaded) to offsite power sources. EDG A starts and runs, but EDG B fails. A delayed LOOP occurs, and train A fails due to GSI-171 concerns; however, AC is recovered and the plant avoids core damage by using the train that was not affected by GSI-171 concerns. Outcome: LOCA.

Sequence 7 (21). A LOCA occurs and the LOCA loads are sequenced (block-loaded) to offsite power sources. EDG A starts and runs, but EDG B fails. A delayed LOOP occurs, and train A fails due to GSI-171 concerns. AC is not recovered and the core is damaged because one train failed due to GSI-171 concerns and the other does not have AC power supply. Outcome: Core damage.

Sequence 8 (22). A LOCA occurs and the LOCA loads are sequenced (block-loaded) to offsite power sources. EDG A fails to start and run, but EDG B succeeds. A delayed LOOP does not occur. Outcome: LOCA.

Sequence 9 (23). A LOCA occurs and the LOCA loads are sequenced (block-loaded) to offsite power sources. EDG A fails to start and run, but EDG B succeeds. A delayed LOOP occurs, but train B survives the GSI-171 concerns. Outcome: LOCA.

Sequence 10 (24). A LOCA occurs and the LOCA loads are sequenced (block-loaded) to offsite power sources. EDG A fails to start and run, but EDG B succeeds. A delayed LOOP occurs, and train B fails due to GSI-171 concerns; however, AC is recovered and the plant avoids core damage by using the train that was not affected by GSI-171 concerns. Outcome: LOCA.

Sequence 11 (25). A LOCA occurs and the LOCA loads are sequenced (block-loaded) to offsite power sources. EDG A fails to start and run, but EDG B succeeds. A delayed LOOP occurs, and train B fails due to GSI-171 concerns. AC is not recovered and the core is damaged because one train failed due to GSI-171 concerns and the other does not have AC power supply. Outcome: Core damage.

Sequence 12 (26). A LOCA occurs and the LOCA loads are sequenced (block-loaded) to offsite power sources. Both EDGs fail to start and run, but a delayed LOOP does not occur. Outcome: LOCA.

Sequence 13 (27). A LOCA occurs and the LOCA loads are sequenced (block-loaded) to offsite power sources. Both EDGs fail to start and run, and a delayed LOOP occurs. However, AC is recovered and the plant avoids core damage by using both trains. Outcome: LOCA.

Sequence 14 (28). A LOCA occurs and the LOCA loads are sequenced (block-loaded) to offsite power sources. Both EDGs fail to start and run, a delayed LOOP occurs, and AC is not recovered. The plant experiences a LOCA and a station blackout. Outcome: Core damage.

6.2.3 Modeling of LOCA/LOOP Accident Sequences

Figure 6.2 represents a detailed modeling of LOCA/LOOP accident sequences addressing GSI-171 issues and concerns. When a delayed LOOP occurs after a LOCA, the circuit breaker of each EDG will receive a signal to close, which may cause one or both safety trains to fail.

Below, we describe the headings in this event tree and briefly outline the accident sequences.

6.2.3.1 Headings of the Detailed LOCA/LOOP Event Tree

The first three headings in the event tree of Figure 6.2 (LOCA, SEQOFP, CLOOP) are also present in the event tree of Figure 6.1. Both event trees were developed in this way to ensure that a sequence that started with certain conditions in the event tree of Figure 6.1 would continue with the same conditions in that of Figure 6.2. For example, if a sequence in Figure 6.1 started with a LOCA (LOCA initiating event), the LOCA loads block-loaded to offsite power sources (SEQOFP heading), and a delayed LOOP occurred (CLOOP heading), then the sequences of the event tree of Figure 6.2 that apply to these conditions are 22 to 28 only. LOCA, SEQOFP, and CLOOP headings were described earlier; the remainder are described below.

LOPBES. If a plant employs the sequential energization scheme to energize the LOCA loads from offsite power sources, and then a delayed LOOP occurs, it may occur during LOCA sequencing as opposed to after it is complete. As indicated in the event tree of Figure 6.2, the lower branch means a LOOP that occurs during LOCA sequencing, and the upper branch represents a LOOP that occurs after completing LOCA sequencing.

This heading is evaluated because we assume that the sequencers could only lock up if a LOOP occurred during LOCA sequencing, and, therefore, LOOP sequencing is attempted during the LOCA sequencing.

LDSD. When a LOOP occurs, some plants shed the load before the EDGs are connected to the emergency buses, i.e., before the circuit breakers of the EDGs close. This heading evaluates whether a plant has implemented a load-shedding scheme, and whether it is successful.

TIMDEL. When a LOOP occurs, some plants apply a time delay before the EDGs are connected to the emergency buses, i.e., before the circuit breakers of the EDGs close. This heading evaluates whether a plant has implemented a time delay, and whether it is successful.

DAMAGE. If the load-shedding scheme and the time delay evaluated in the two previous headings fail or are not implemented, or there is a combination of [illegible], then an out-of-phase connection could take place when the circuit breakers of the EDGs close to their respective emergency buses, leading to the non-recoverable damage of the safety loads. This heading evaluates the probability that such damage will occur.

EXLODG. If the LOCA loads are sequenced to offsite power, a delayed LOOP occurs during the LOCA sequencing, and the load-shed is not implemented or fails, then, when the circuit breaker of an EDG closes, the EDG may be overloaded in excess of its capacity. If the EDGs are overloaded, the plant's staff may succeed in restoring them to service. This heading evaluates the probability that an EDG overload will occur, and that the associated recovery actions will fail.

RE-SEQ. After successfully shedding the load, the safety loads will be re-energized by the EDGs. Similar to the energization schemes from offsite power sources, energization from the EDGs will be either sequential or block-loading. Assuming that

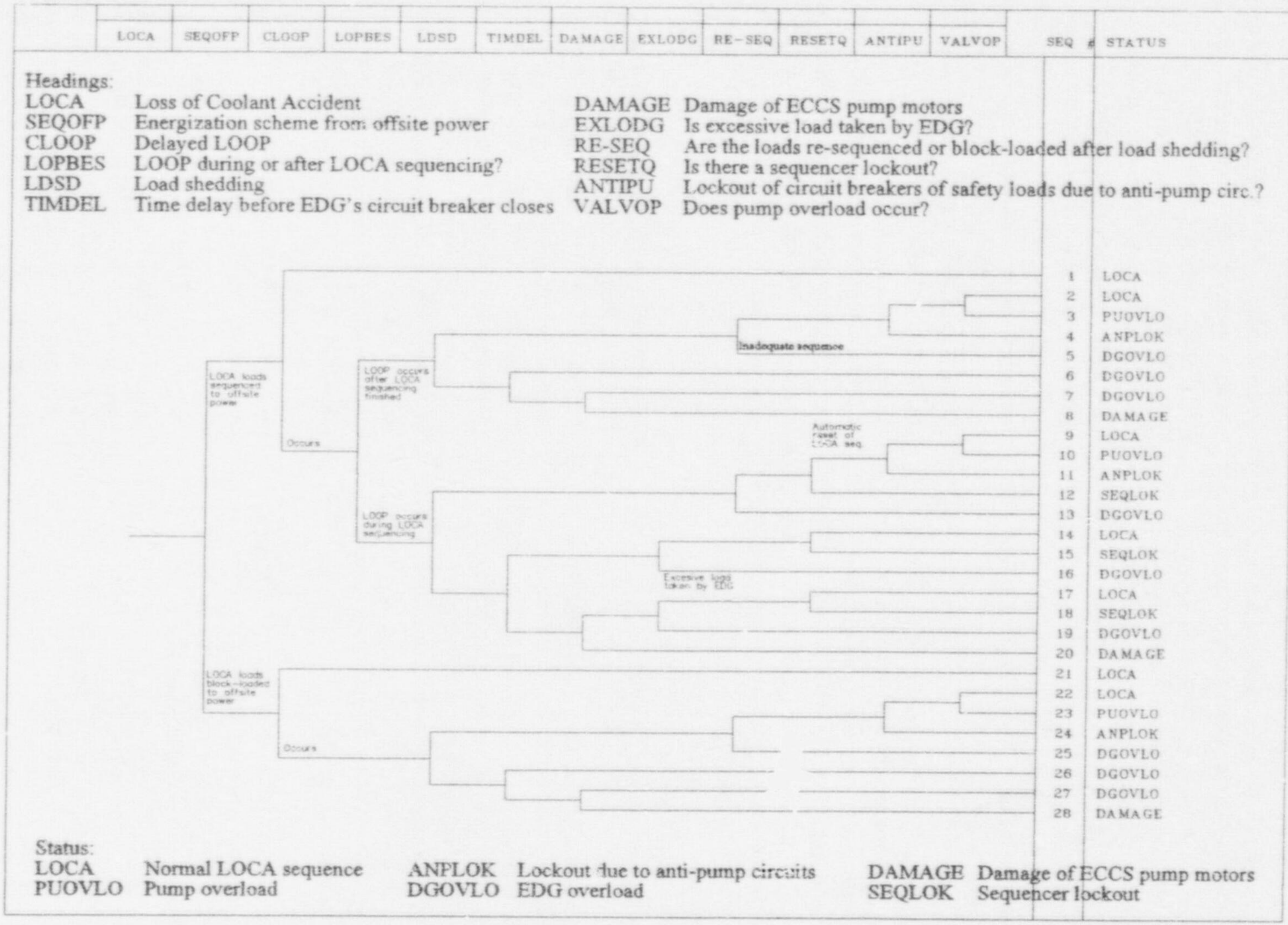


Figure 6.2 Detailed modeling of GSI-171 concerns

the latter is employed, the EDGs will be overloaded. A particular plant has either a sequential or block-loading energization scheme. If it employs the former, the upper branch is used in the event tree; the lower branch is used for the latter. A plant may be block-loading to the EDGs because it was not specifically designed to cope with a LOCA with a delayed LOOP. If the EDGs are overloaded, the plant's staff may succeed in restoring them to service. This heading includes the probability that the recovery actions after an EDG overload will fail.

RESETQ. If the LOOP occurs during the LOCA sequencing, the sequencers may be locked out. On the other hand, we assume that if the LOCA sequencing is reset when the LOOP occurs, then the sequencing will re-initialize, and the sequencers would not be locked out. However, if they are, the plant's staff actions may successfully re-sequence the safety loads. This heading evaluates the probability that sequencer lockout occurs, and that the associated recovery actions fail.

ANTIPU. If load-shedding was successful, some circuit breakers of the safety loads may receive signals to open and to close within a few seconds of each other, causing their anti-pump circuits to lockout. The plant's staff successful recovery actions may re-energize the safety loads. This heading evaluates the probability that the circuit breakers are locked out by the anti-pump circuits, and that recovery actions fail.

VALVOP. If the load was shed successfully, some pumps of the safety systems may become overloaded. This heading evaluates the probability that the pumps are overloaded, and that recovery actions fail.

6.2.3.2. Sequences of the Detailed LOCA/LOOP Event Tree

The detailed LOCA/LOOP event tree shown in Figure 6.2 has 28 accident sequences whose outcome is either LOCA or one of the five GSI-171 concerns modeled by this study: non-recoverable pump overload (PUOVLO), non-recoverable lockout of circuit breakers due to anti-pump circuits (ANPLOK), non-recoverable EDG overload (DGOVLO), non-recoverable damage (DAMAGE), and non-recoverable lockout of sequencers (SEQLOK). These outcomes are non-recoverable because the corresponding recovery actions were evaluated as part of the relevant headings of the event tree; these outcomes are shown in the column heading "STATUS". If the plant's mitigating systems and recovery actions failed to cope with the conditions leading to one of the GSI-171 concerns, then the outcome is core damage due to one of the concerns; otherwise, it is LOCA. In the latter case, the CDF contribution already has been evaluated by the traditional LOCA evaluations which usually assume that there are no failures related to a delayed LOOP, such as an overload on the EDG.

In sequences 1 to 20, the plant is designed such that the LOCA loads are sequenced to offsite power. Sequences 1 to 20 of Figure 6.2 leading to core damage due to one of the GSI-171 concerns , such as sequences 3, 4, and 5, will contribute to sequences 3, 7, 11, and 14 of Figure 6.1, whose outcome is core damage. Chapter 8 presents the transformation of the sequences of Figure 6.2 to fault trees to evaluate such contribution. The assessment of probabilities for quantifying the sequences is presented in Chapter 7.

Sequence 1. A LOCA occurs, but a delayed LOOP does not occur. Outcome: LOCA.

Sequence 2. A LOCA occurs, a delayed LOOP occurs after the LOCA sequencing is finished, the safety loads are re-sequenced to the EDG, there is no lockout of circuit breakers due to their anti-pump circuits, and the pumps are not overloaded. Outcome: LOCA.

Sequence 3. A LOCA occurs, a delayed LOOP occurs after the LOCA sequencing is finished, the safety loads are re-sequenced to the EDG, there is no lockout of circuit breakers due to their anti-pump circuits, but the pumps are overloaded and recovery actions fail. Outcome: Non-recoverable pump overload on the pumps.

Sequence 4. A LOCA occurs, a delayed LOOP occurs after the LOCA sequencing is finished, the safety loads are re-sequenced to the EDG, but the circuit breakers are locked out by their anti-pump circuits, and recovery actions fail. Outcome: Non-recoverable lockout of circuit breakers due to anti-pump circuits.

Sequence 5. A LOCA occurs, a delayed LOOP occurs after the LOCA sequencing is finished, but the safety loads are not adequately sequenced to the EDG, overloading it, and the recovery actions fail. Outcome: Non-recoverable EDG overload.

Sequence 6. A LOCA occurs, and a delayed LOOP occurs after the LOCA sequencing is finished. Load-shedding fails or is not implemented, but the time delay to close the EDG's circuit breaker prevents its non-recoverable damage. However, since all the safety loads are connected "at once" to the EDG, they are effectively block-loaded, so overloading it; the associated recovery actions fail. Outcome: Non-recoverable EDG overload.

Sequence 7. A LOCA occurs, and a delayed LOOP occurs after the LOCA sequencing is finished. Both load-shedding and the time delay to close the EDG's circuit breaker fail or are not implemented. The power source is transferred from an offsite source to the EDG at a random electrical angle, but the safety loads do not suffer non-recoverable damage. However, since all the safety loads are connected "at once" to the EDG, they are effectively block-loaded to it, and overload it; the recovery actions fail. Outcome: Non-recoverable EDG overload.

Sequence 8. A LOCA occurs, and a delayed LOOP occurs after the LOCA sequencing is finished. Both load-shedding and the time delay to close the EDG's circuit breaker fail or are not implemented. Power is transferred from an offsite source to the EDG at a random electrical angle, and the safety loads are damaged non-recoverable. Outcome: Non-recoverable damage of ECCS pump motors.

Sequence 9. A LOCA occurs, a delayed LOOP occurs during LOCA sequencing, the safety loads are re-sequenced to the EDG, there is no lockout of sequencers, nor of circuit breakers due to their anti-pump circuits; the pumps are not overloaded. Outcome: LOCA.

Sequence 10. A LOCA occurs, a delayed LOOP occurs during the LOCA sequencing, the safety loads are re-sequenced to the EDG, there is no lockout of sequencers, nor of circuit breakers due to their anti-pump circuits. However, the pumps are overloaded and recovery actions fail. Outcome: Non-recoverable pump overload.

Sequence 11. A LOCA occurs followed by a delayed LOOP during LOCA sequencing, and the safety loads are re-sequenced to the EDG. There is no lockout of sequencers, but the circuit breakers are locked out due to their anti-pump circuits, and recovery actions fail. Outcome: Non-recoverable lockout of circuit breakers due to anti-pump circuits.

Sequence 12. A LOCA occurs with a delayed LOOP during LOCA sequencing, and the safety loads are re-sequenced to the EDG. Since the LOOP occurs during LOCA sequencing, there is a lockout of sequencers, and recovery actions fail. Outcome: Non-recoverable lockout of sequencers.

Sequence 13. A LOCA occurs, a delayed LOOP occurs during LOCA sequencing, but the safety loads are not adequately sequenced to the EDG, causing it to become overloaded; recovery actions fail. Outcome: Non-recoverable EDG overload.

Sequence 14. A LOCA occurs followed by a delayed LOOP during LOCA sequencing; load-shedding fails or is not implemented, but the time delay to close the EDG's circuit breaker prevents non-recoverable damage. All the safety loads that were energized before the LOOP are connected "at once" to the EDG, but it is not overloaded. Since the LOCA sequencing is reset when the LOOP occurs, the sequencers are not locked out. Outcome: LOCA.

Sequence 15. A LOCA occurs with a delayed LOOP during LOCA sequencing, load-shedding fails or is not implemented, but the time delay to close the EDG's circuit breaker prevents its non-recoverable damage. All the safety loads that were energized before the LOOP are connected "at once" to the EDG, but it is not overloaded. Since the LOCA sequencing fails to reset when the LOOP occurs, the sequencers are locked out. Outcome: Non-recoverable lockout of sequencers.

Sequence 16. A LOCA occurs then a delayed LOOP during LOCA sequencing. Load-shedding fails or is not implemented, but the time delay to close the EDG's circuit breaker prevents non-recoverable damage. All the safety loads that were energized before the LOOP are connected "at once" to the EDG, which is overloaded, and the associated recovery actions fail. Outcome: Non-recoverable EDG overload.

Sequence 17. A LOCA occurs followed by a delayed LOOP during LOCA sequencing. Both load-shedding and the time delay to close the EDG's circuit breaker fail or are not implemented The power source is transferred from an offsite source to the EDG at a random electrical angle, but the safety loads are not damaged non-recoverable. All the safety loads that were energized before the LOOP are connected "at once" to the EDG, but it is not overloaded. Since the LOCA sequencing is reset when the LOOP occurs, the sequencers are not locked out. Outcome: LOCA.

Sequence 18. A LOCA occurs, and a delayed LOOP takes place during LOCA sequencing. Both load-shedding and the time delay to close the EDG's circuit breaker fail or are not implemented. The power source is transferred from an offsite source to the EDG at a random electrical angle, but the safety loads are not damaged non-recoverably. All the safety loads that were energized before the LOOP are connected at once to the EDG, but it is not overloaded. Since the LOCA sequencing fails to reset when the LOOP occurs, the sequencers are locked out. Outcome: Non-recoverable lockout of sequencers.

Sequence 19. A LOCA occurs followed by a delayed LOOP during LOCA sequencing. Both load-shedding and the time delay to close the EDG's circuit breaker fail or are not implemented. The power source is transferred from an offsite source to the EDG at a random electrical angle, but the safety loads are not damaged non-recoverably. All the safety loads that were energized before the LOOP are connected at once to the EDG and overloaded it, and recovery actions fail. Outcome: Non-recoverable EDG overload.

Sequence 20. A LOCA occurs with a delayed LOOP during the LOCA sequencing. Both load-shedding and the time delay to close the EDG's circuit breaker fail or are not implemented. The power source is transferred from an offsite source to the EDG at a random electrical angle, and the safety loads are non-recoverably damaged. Outcome: Non-recoverable damage of ECCS pump motors.

In sequences 21 to 28, the plant is designed so that the LOCA loads are block-loaded to offsite power. Sequences 21 to 28 of Figure 6.2 leading to core damage due to one of the GSI-171 concerns , i.e., sequences 23 to 28, will contribute to sequences 17, 21, 25, and 28 of Figure 6.1, whose outcome is core damage. As mentioned earlier, Chapter 8 presents the transformation of the sequences of Figure 6.2 to fault trees to evaluate such contribution, and the assessment of probabilities for quantifying the sequences is presented in Chapter 7.

Sequence 21. A LOCA occurs, but there is no delayed LOOP. Outcome: LOCA.

Sequence 22. A LOCA occurs, then a delayed LOOP. The safety loads are re-sequenced to the EDG, there is no lockout of circuit breakers due to their anti-pump circuits, and there is no overloading of the pumps. Outcome: LOCA.

Sequence 23. A LOCA followed by a delayed LOOP occur, the safety loads are re-sequenced to the EDG, and there is no lockout of circuit breakers by their anti-pump circuits; however, the pumps are overloaded, and associated recovery actions fail. Outcome: Non-recoverable pump overload.

Sequence 24. A LOCA and then a delayed LOOP occur, the safety loads are re-sequenced to the EDG, but the circuit breakers are locked out by their anti-pump circuits; the recovery actions fail. Outcome: Non-recoverable lockout of circuit breakers due to anti-pump circuits.

Sequence 25. A LOCA occurs, but the plant is designed such that the LOCA loads are block-loaded to offsite power. A delayed LOOP follows, but the safety loads are not adequately sequenced to the EDG, overloading it, and the associated recovery actions fail. Outcome: Non-recoverable EDG overload.

Sequence 26. A LOCA with a delayed LOOP occurs. Load-shedding fails or is not implemented, but the time delay to close the EDG's circuit breaker prevents non-recoverable damage. However, since all the safety loads are connected "at once" to the EDG, they are effectively block-loaded on to it, causing its overload; the recovery actions fail. Outcome: Non-recoverable EDG overload.

Sequence 27. A LOCA occurs, and then a delayed LOOP. Both load-shedding and the time delay to close the EDG's circuit breaker fail or are not implemented. The power source is transferred from an offsite source to the EDG at a random electrical angle, but the safety loads are not damaged non-recoverably. However, since all the safety loads are connected "at once" to the EDG, they are effectively block-loaded on to it, and overload it; the associated recovery actions fail. Outcome: Non-recoverable EDG overload.

Sequence 28. A LOCA occurs, after which a delayed LOOP occurs. Both load-shedding and the time delay to close the EDG's circuit breaker fail or are not implemented. The power source is transferred from an offsite source to the EDG at a random electrical angle, and the safety loads are damaged non-recoverably. Outcome: Non-recoverable damage of ECCS pump motors.

6.3 PWR LOCA/LOOP Accident Sequence Modeling

When a LOCA occurs at a typical pressurized water reactor (PWR), the Engineered Safety Features Actuation System (ESFAS) will be actuated by one of four automatic signals, or manually by the plant's operators if they detect the LOCA before the automatic signals respond. These four automatic signals are

1) Low Pressurizer Pressure

2) High Containment Pressure

3) High Steam-Line Flow Rate Coincident with either Low Steam-Line Pressure or Low-Low T_{avg}

4) Steam-Line High Differential Pressure.

The ESFAS will typically cause the following system responses:

1) Reactor trip initiated

2) Safety Injection Sequence initiated, i.e.,emergency core-cooling systems (ECCS) pumps started and aligned for cooling the core

3) Phase "A" containment isolation

4) Auxiliary feedwater initiated

5) Main feedwater isolated

6) Emergency EDG Startup

7) Auxiliary Cooling System Line-up (pumps started in essential service water and Component Cooling Water systems)

8) Control Room and Containment Ventilation Isolation.

The event tree discussed in Section 6.2.2 essentially applies to a PWR plant. The status presented in Figure 6.2 except for LOCA, i.e., PUOVLO, ANPLOK, DGOVLO, DAMAGE, SEQLOK, implies that the core will be damaged since no other system in a PWR can prevent it happening at that stage. The accident sequences resulting for that tree are used to quantify the CDF for a PWR, as discussed in Chapter 8.

In the model, we assume that the plant has two very similar but physically and electrically separated trains, A and B, each having an emergency (1E) bus, an emergency diesel generator (EDG), and associated safety loads. In principle, GSI-171 concerns can affect either one of the two trains independently, or both due to a common-cause failure (CCF) of the second train given failure of the first train. For example, in case of non-recoverable damage to the ECCS pump motors due to an out-of-phase bus transfer to a running EDG, the circuit breaker of the EDG of one train will receive a signal to close essentially at the same time as the EDG in the other train, and each EDG will be connected to the decaying voltage of very similar, or even identical, pump motors. In practice, some difference may exist, and the probability of impact on the second train may not be 1 but highly likely, which is handled as a common-cause failure. Accordingly, the modeling incorporates both independent (i.e., affecting only one train) and CCF (i.e., affecting both trains) due to failure mechanisms discussed in the event-tree model.

When a LOCA/LOOP happens, the EDGs of both trains should start and run. Most GSI-171 concerns occur given that the EDG associated with an emergency bus is running; for example, the ECCS pump motors are damaged non-recoverably due to an out-of-phase bus transfer to a running EDG. On the other hand, if one or both of the EDGs fails to start and run, then the corresponding train will not be affected by GSI-171 concerns but will be unavailable to respond to the severe demands of both a LOCA and a LOOP. For example, if both EDGs fail to start and run, then a LOCA with a delayed Station Blackout (SBO) would lead to core damage unless offsite power or the EDGs are recovered before such damage occurs.

Therefore, the risk model incorporates the possibility that one or both of the EDGs fail to start and run, that one or both of the trains are impacted by GSI-171 concerns, and all the combinations of these possibilities, such as one train unavailable due to its associated EDG failing to start and run, and the other failing due to a GSI-171 concern.

6.4 BWR LOCA/LOOP Accident Sequence Modeling

In this section, we discuss the BWR-specific ECC system designs that are relevant to GSI-171. The logic models discussed in Section 6.3 for PWRs were modified to account for the BWR's specific features. A plant that has the same reactor-core isolation cooling (RCIC) and high-pressure coolant injection (HPCI) systems as Peach Bottom, but has 2 trains instead of 4 in the low-pressure coolant injection (LPCI) system and low-pressure core spray (LPCS) system was used to quantify accident sequences.

Due to variations in the design of the ECC systems at BWRs, their susceptibility to GSI-171 issues varies significantly. The following describes three types of BWR designs and their effects on the risk significance of GSI-171.

1) Many BWRs, e.g., Peach Bottom, have a reactor core isolation cooling system (RCIC) and high pressure coolant injection system (HPCI) that are independent of AC power. These systems are not affected by GSI-171 issues, and can be used to mitigate small and medium LOCAs and delay or prevent challenges to the low pressure systems, e.g., low pressure coolant injection (LPCI) and low pressure core spray (LPCS). Consequently, this type of BWRs is not as vulnerable to the GSI-171 issues associated with these types of LOCAs as the PWRs. Since this type of BWR is the most representative of the BWR population in the United States, it was selected as the plant to be analyzed in detail.

2) Unlike Peach Bottom, a few older BWRs, e.g., Millstone 1, do not have a RCIC and a HPCI. Instead, Millstone 1 has an isolation condenser and uses one operating mode of the feedwater system to automatically provide inventory makeup. These plants do not have AC-independent ECC systems and are probably more vulnerable to GSI-171 than are BWRs similar to Peach Bottom.

3) Newer BWRs, i.e., BWR 5 and 6, have a RCIC but not HPCI. Instead, they have a high pressure core spray system (HPCS) which depends on AC power and has a dedicated diesel generator. The RCIC system can mitigate a small LOCA and reduce the vulnerability of this type of BWRs to the apposite GSI-171 issues. The HPCS system can be used to mitigate medium LOCAs. Because it depends on AC power, its operation may be affected by GSI-171. However, it has its own dedicated diesel generator, so probably it is less likely to be affected by some GSI-171 issues, such as overloading of diesel generators.

Susceptibility of a Plant Similar to Peach Bottom to GSI-171 Issues

We analyzed a plant with a design similar to that of Peach Bottom. In addition to the fact that RCIC and HPCI systems are independent of AC power, the following control logic and set points of Peach Bottom systems are important.

RPS	low vessel level (538 inches) or high drywell pressure (2 psig)
RCIC	low vessel level, delivers rated flow in 30 seconds, steam supply isolation at 50 psig
HPCI	low vessel level or high drywell pressure, steam supply line isolation at 100 psig

ADS low-low vessel level (378 inches) and high drywell pressure and at least one RHR pump or two LPCS pumps are running. Starts with a 2 minutes delay, does not depend on AC.

LPCS low-low vessel level or low reactor pressure (450 psig) and high drywell pressure. Pumps are started with 13- and 23-seconds delay if normal power is available; if not, they start in 6 seconds.

LPCI same actuation logic as LPCS; if normal AC power is available, the pumps are started with 2- and 8-seconds delay. If normal AC power is not available, the four pumps start simultaneously. The valves in the injection lines will not open unless the reactor pressure is low.

EDG starts on loss of offsite power, low vessel level, or high drywell pressure, and is connected to the bus when the generator voltage and frequency are established, bus voltage is zero, and all bus loads are tripped.

The following discussion summarizes the responses of the plant to different size LOCAs as they are related to the GSI-171 issues. The only ECC systems susceptible to the issues are the LPCI and LPCS systems. The issues are applicable if a consequential LOOP occurs when or after these systems are actuated.

Small LOCA: Given a small LOCA, the level in the vessel will decrease to the set point that automatically actuates the RCIC, HPCI, and the diesel generators. At this level, the LPCI and LPCS will not be started. As long as either the RCIC or the HPCI operates successfully, the loss of inventory is compensated for, and the level will not reach the set point for the low pressure systems. If a LOOP occurs, the diesel generators will be connected to the emergency buses, and the operation of RCIC and HPCI will not be affected. Therefore, GSI-171 can potentially affect a small LOCA only if both the RCIC and HPCI fail randomly. Assuming that they both fail randomly, the level in the vessel will have to decrease to the set point to automatically start the low pressure systems and pose a challenge to them. The capacity of RCIC at Peach Bottom is 600 gpm and the volume of the reactor vessel between the low and low-low level set points is approximately 22,000 gallons. Therefore, it would take approximately 37 minutes for the level to drop to the latter. The distribution of the time when a consequential LOOP occurs after a LOCA (discussed in Section 7.2) demonstrates that the LOOP most likely would occur before the low pressure systems are actuated. As a result, the challenge to the low pressure systems becomes that of a design basis accident and does not need to be considered. Hence, the impact of GSI-171 issues is insignificant for small LOCAs.

Medium LOCA: In a medium LOCA, similar to a small LOCA, the RCIC, HPCI, and diesel generators are automatically started as the level in the vessel reaches the low mark. The RCIC system has insufficient capacity to mitigate a medium LOCA, but the HPCI system does. The operation of the HPCI should maintain the vessel level such that the low pressure systems are not challenged right away. The HPCI system has a capacity of approximately 5000 gpm. If it fails randomly, it takes approximately 4.4 minutes for the level to reach the set point for automatically actuating the low pressure systems, and GSI-171 issues become applicable if a LOOP occurs when the low pressure systems are being started or after they are started. This is the scenario that was quantified for a medium LOCA to assess the impact of GSI-171. The probability of HPCI system failure is assumed to be 0.1. Using the distribution of the time when a consequential LOOP occurs, discussed in Section 7.2, the probability that a LOOP event occurs more than 4.4 minutes after the initiating event is 0.18. These probabilities, 0.1 and 0.18, are used to quantify the risk impact of GSI-171.

Large LOCAs: Given a large LOCA, all ECC systems will be actuated almost instantaneously, and all GSI-171 issues are applicable. The same logic model as that for a PWR can be used to assess their impacts.

Modification of Logic Models Developed for PWRs

The following modifications are made to the logic models for PWRs discussed in Section 6.3, so that they can be used to quantify the risk impact of GSI-171 for BWRs:

1) The frequencies of LOCAs estimated in NUREG-1150 for Peach Bottom were used.

2) The conditional probability of a consequential LOOP estimated in Section 4.2 for a BWR was used.

3) Small LOCAs were screened out.

4) For a medium LOCA, the only scenario in which GSI-171 is relevant is the case in which the HPCI fails.

5) Quantification of the top events in the event tree is the same as that of a PWR, except for that representing the event that the LOOP occurs during LOCA sequencing in a medium LOCA. Given that the LOOP occurs after 4.4 minutes, the probability of the event is assumed to be 0.1.

In addition to the assumptions discussed in Section 6.3 for PWRs, the following assumptions were made in the logic model for BWRs:

1) The plant being analyzed is similar to Peach Bottom in terms of the type of ECCS systems. However, it has only two trains which is more representative of the BWR population than Peach Bottom with four trains. It is assumed that failure of both trains leads to core damage.

2) It is assumed that in a medium LOCA with the HPCI operating successfully, the vessel pressure remains higher than the 450 psig set point below which the low pressure systems are actuated automatically. HPCI can continue operating long enough so that if there is a consequential LOOP, it occurs before the low pressure systems are actuated.

7 ESTIMATION OF PROBABILITIES FOR QUANTIFYING THE LOCA/LOOP EVENT TREE

7.1 Approach and Assumptions

The LOCA/LOOP event trees developed to quantify the CDF associated with such an accident, discussed in the previous chapter, contain several branches or events whose probabilities are not available in conventional PRAs nor in the reliability databases. The estimation of these probabilities are discussed here:

a) initiating frequency for a LOCA/LOOP event,

b) conditions specific to the event,

c) recovery actions taken by the operator.

The initiating frequency for a LOCA/LOOP event is estimated separately in Chapter 4 using data from operating experience.

Items b) and c) are connected in the sense that the operator's recovery actions relate to the specific conditions being evaluated as part of the event trees. Item c), applicable operator recovery actions, is analyzed in Section 7.8 after our discussion of the estimation of probabilities of the following conditions unique to the event tree:

(a) LOOP occurring during or after LOCA sequencing,

(b) non-recoverable damage to equipment,

(c) overloading of EDGs,

(d) lockup of sequencers,

(e) lockout energization of circuit breakers (anti-pump circuits), and

(f) overloading of ECCS pumps.

Water hammer is not within the scope of this project.

The assumptions used in defining the approaches are given next. Further assumptions applicable to each item are part of the respective discussions.

1) The specific conditions being modeled only apply to plants with certain design and operating characteristics, as discussed for each item below. Based on NRC information notices, and utility/LER reports collected as part of the GSI-171 issue, we assume that each of the conditions may apply to some of the plants. No plant-specific evaluation was made.

2) Our estimations of probabilities involve aspects whose evaluation may use detailed plant-specific information. Such evaluations were not expected to be available during this study, and accordingly, the approaches do not extend to those levels where such details are necessary.

3) Engineering judgements were used to estimate many parameters because either there are no data to estimate them or appropriate models to evaluate them. In general, some margin of conservatism should be used in such estimates.

7.2 LOOP as a Function of Time Following LOCA

The timing of the LOOP following a LOCA has critical significance to the progression of events leading to core damage in an accident sequence. Some issues relevant to GSI-171 apply if the LOOP occurred during the sequencing of the LOCA loads, whereas others are relevant if the LOOP followed it. To obtain the probability of LOOP occuring during or after a LOCA, we obtain the probability distribution of a LOOP occurring as a function of time following a LOCA. Such a distribution also was useful in estimating probabilities of other conditions, as will become evident from the following discussions.

The probability distribution of LOOP with time following a LOCA is based on our review of the operating experience data on LOOP events. The data collected in estimating the probability of LOOP given a LOCA was used. Similar to the previous analysis, since there are no data on LOCA events, automatic reactor trip and ECCS actuation events were substituted.

The process used is as follows:

1) review the identified events leading to LOOP following an automatic reactor trip or ECCS actuation to delineate the time of LOOP following the triggering event. Table 7.1 lists the events and the timing of LOOP,

2) obtain a distribution of the times of LOOP occurrence, and

3) obtain estimates of probability with time and use them to assess the probability of LOOP during and after LOCA sequencing.

Simple numerical estimates at different time-steps were obtained, rather than fitting a rigorous statistical distribution. The results are considered adequate for our purpose.

The assumptions in the process are as follows:

1) For some events, as noted in the table, precise timing of the occurrence of the LOOP was not stated in any of the descriptions. In those cases, the descriptions were carefully reviewed to judge the time of the LOOP's occurrence.

2) Similar to the analysis of the frequency of LOOP given a LOCA, surrogate events were used to obtain estimates. The impact of LOCA events may be somewhat different and may change the estimated probabilities.

3) The sample of events used to obtain the estimates was limited but considered reasonable.

4) Formal statistical distribution analysis and uncertainty propagation was not undertaken.

Table 7.2 gives the results of the evaluation. It groups the events in order of increasing times following the triggering event, and then, gives estimates of cumulative probability for the increasing time-steps.

Assuming that the sequencing of LOCA loads takes approximately 60 sec., the probability of LOOP occurring during, and subsequent to, LOCA load sequencing are obtained as:

P(LOOP occurs during LOCA load sequencing) = 0.73

P(LOOP occurs after completion of LOCA load sequencing) = 0.27

7.3 Non-Recoverable Damage to EDGs and ECCS Pumps

During a LOCA/LOOP accident, a bus transfer may take place resulting in out-of-phase connection of a running EDG to the ECCS pumps; this could damage the EDGs, or ECCS pump motors, or both. Such a condition may happen when LOCA loads loaded on to the bus in response to a LOCA

Table 7.1 Timing of LOOP following reactor trip and ECCS actuation events

Plant	Vendor	Date of Event	Docket#/LER#	Time of LOOP after Triggering Event	Trains Affected	Was LOOP a result of block-loading?
Reactor Trip - LOOP Events						
1. Byron	W	10/02/87	455/87-019	15 min.	2[4]	No
2. Robinson 2	W	01/28/86	261/86-005	61 sec.	2	No
3. Point Beach 2	W	03/29/89	301/89-002	10 sec.[1]	2	No
4. Indian Point 2	W	02/10/87	247/87-004	30 sec.[2]	2	No
5. Zion 2	W	03/24/86	304/86-011	30 sec.[2]	1	No
6. Brunswick 1	GE	09/13/86	325/86-024	30 sec.[2]	2	No
7. Davis-Besse 1	B&W	08/21/87	346/87-011	34 sec.	1	No
8. Duane Arnold	GE	08/26/89	331/89-011	5 min.	1	No
9. Robinson 2	W	02/13/88	261/88-005	---[3]	2	---
10. Dresden 2	GE	01/16/90	237/90-002	2 min. 45 sec.	2	No
ECCS Actuation - LOOP Events						
11. Salem	W	08/26/86	311/86-007	30 sec.[2]	2	Yes
12. River Bend 1	GE	08/25/88	458/88-018	Less than 5 sec.[5]	1	No

1. Undervoltage relays transferred the safety loads to EDGs. Timing of LOOP depends on the time delay of these relays, which is probably somewhat greater than 10 seconds.
2. No exact timing of start of EDGs is provided in LER. On the other hand, there appears to be a time delay before the generator is tripped following the turbine trip. We assume that for both PWRs and BWRs this delay is 30 seconds, and that the LOOP occurs immediately after the turbine trip.
3. EDGs were started as part of SI sequence; offsite power was supplied to both emergency buses throughout the event. Since no LOOP occurred, no time of LOOP after triggering event was obtained. Therefore, this event was not used to assess the time distribution of LOOP events.
4. Number of events with two trains affected = 8; with one train affected = 4.
5. No exact timing of start of EDG is provided in LER.

Table 7.2 Time and cummulative probability distribution of LOOP events

Number of Events	Cumulative Number of Events	Time of LOOP after Triggering Event t(sec.)	P(Time of LOOP after Triggering Event =< t)
1	1	5 or less	0.091
1	2	10	0.18
5	7	30 - 34	0.64
1	8	61	0.73
1	9	165	0.82
1	10	300	0.91
1	11	900	1.0

are not shed and there is no time delay before connecting the EDG to the bus.

The probability of non-recoverable damage to EDG and ECCS pumps was evaluated earlier by Azarm et al. (1996). Based on specific data, damage to the EDGs is not expected, i.e., the probability is zero, and the calculated probability of damage to ECCS pump motors is 0.27. Although a plant-specific evaluation is needed to estimate the probability of damage to equipment in a particular plant, for our purposes, these calculated values are used to assess the core-damage frequency for a LOCA/LOOP accident. So, the probability of non-recoverable damage to an EDG and an ECCS pump is:

P (DAMAGE) = 0, for an EDG
= 0.27, for an ECCS pump motor.

The probability of failure of the redundant ECCS pump motor, given failure of the first pump, is considered similiar to common-cause failure because the identical redundant pump experiences the same sequence of events. This probability is estimated to be 0.5 based on engineering judgment since no data are available:

$P_{2/1}$ (DAMAGE) = 0.5, for ECCS pump

where $P_{2/1}$ signifies the probability of failure of the second component, given the failure of the first.

7.4 EDG Overloading and Loss of ECCS Pumps

During a LOCA/LOOP sequence the EDG may be overloaded and trip in trying to pick up the safety loads. Overloading may happen during a sequence of events in which block-loading of already energized loads takes place, or when steps in the sequence of loading to EDGs are inconsistent with its capability. NRC Info Notice 92-53 (July, 1992) addresses EDG overloading due to simultaneous addition of significant load onto the EDG.

The specific scenarios relating to block-loading can be summarized as follows:

The specific scenarios relating to block-loading can be summarized as follows:

1) Following a LOCA, a LOOP occurs during LOCA load sequencing. In this case, some loads already have been energized, while some have not. The sequencer may be locked out and the EDG will attempt to pick up the already energized load (block-loading), causing an overload.

2) A LOOP occurs after the LOCA load sequencing is completed. In this case, all ECCS loads have been energized, and if they are not shed they may be unintentionally block-loaded to the EDG causing overloading.

3) A LOOP occurs following block-loading of the LOCA loads and the EDG attempts to block-load the energized loads.

When the load-shedding is successful, a sequential scheme of energization to the EDG is ususally employed. The sequence of energization, i.e., the delay between the energization of one load and the next may be inadequate because the steps in the sequence need to be consistent with the capability of the EDG to avoid an overloading. Miller and Roeltger (1993) studied this concern and stated that, "...the problem is that when a large motor is first connected to an EDG, its output frequency and voltage may drop substantially...and the EDG becomes unrecoverably overloaded." In a LOCA/LOOP sequence of events, such a situation is possible which contributes to EDG overloading; here it is called inadequate sequencing.

The probability of EDG overloading depends on the following factors:

1) the timing of the delayed LOOP following a LOCA,

2) the plant-specific loading scheme for a LOCA with normal off-site power available: block or sequential,

3) the plant's ability to provide a signal to load-shed previous loads energized following a LOCA, and

4) the plant's ability to reset the timers, automatically or manually, used in the load-sequencer logic during interrupted load sequencing.

A review of the FSARs and IPEs for some plants indicates the following:

1) Most plants we reviewed are designed to start the loads sequentially for a LOCA event with normal off-site power available. Only a few plants use the block-loading scheme that has a higher probability of overloading the EDG.

2) The ability for load-shedding that is needed in a LOCA/LOOP event is not indicated nor clear in most IPEs and FSARs. Plants with a load-shedding ability, similar to that developed in Surry (Virginia Electric and Power Company, 1989), can considerably reduce the probability of an EDG overload, particularly those with block loading.

3) Several plants can reset the sequential timers, automatically or manually. For a delayed LOOP occurring before LOCA loading is complete, the failure to reset the timers is high if an operator must do this (it takes about 60 seconds).

Thus, we can state that the probability of overloading the EDG is conditional on plant-specific features. For our evaluation, we delineate specific conditions and use engineering judgments to estimate the probabilities.

7.4.1 Estimation of Probability of EDG Overloading

The conditions under which the probability of EDG overloading is to be evaluated are as follows:

1. LOOP occurs during LOCA sequencing

(a) EXLODG1: when LOCA loads are shed, but EDG sequencing is inadequate,

(b) EXLODG2: when LOCA loads are not shed, and block-loading of the EDG follows,

2. LOOP occurs after LOCA sequencing is completed

(a) EXLODG3: when loads are shed, but the EDG sequencing is inadequate,

(b) EXLODG4: when loads are not shed, resulting in block-loading to the EDG,

3. Block-loading of LOCA loads

(a) EXLODG5: when loads are shed, but the EDG sequencing is inadequate,

(b) EXLODG6: when loads are not shed, and the EDG is block-loaded.

The overloading of the EDG depends on its capacity, the steps in the sequencing process, and the size of the load being placed on it. The probability of overloading depends on the specific EDG and requires a plant-specific evaluation. Such information was not available and so plant-specific evaluations were not made. Estimates of the probability of overloading the EDG were obtained using engineering judgments based on a review of analyses made at a particular plant site, and Licensee Event Reports addressing related situations.

Surry nuclear power station had a design where an EDG would pick up the safety injection loads simultaneously (i.e., block-loading) in a LOCA/LOOP scenario. Analysis of Surry's EDG design and capacity (Virginia Electric and Power Company, 1989) showed that the EDG would be overloaded and trip. The plant subsequently modified EDG loading for such a situation, avoiding block-loading and consequent overloading. However, this analysis indicates the problem associated with EDG block-loading and the potential for overloading it.

To estimate the probability of EDG overloading, the following engineering judgments were used:

(a) if the loading of EDG in a LOCA/LOOP scenario follows the same process as that for a routine LOOP-initiating event, then the likelihood of overloading is negligible.

(b) if the EDG is not normally block-loaded, but in a LOCA/LOOP scenario will be, then we assume that the EDG will be overloaded. In many plants, the EDG's capacity is very large, and even under block-loading, it may not trip. From that consideration, this assumption may be conservative.

(c) when a portion of the loads are block-loaded, as opposed to the total loads after a LOCA, there is less likelihood of overloading the EDG.

Using the above judgments, the six conditions for EDG overloading defined earlier were analyzed and the probabilities estimated. In making these estimates, judgments were made about the relative likelihood in different conditions, and the estimates scaled accordingly.

When the LOOP occurs following LOCA sequencing, and the loads are not shed causing a non-intentional block-loading, as discussed in item 2.a) and b), EDG overloading is considered to have the following probabilities:

P(EXLODG3) = 0.5
P(EXLODG4) = 1

P(EXLODG3) is applicable to designs where loads are shed but steps in sequencing are inconsistent with the EDG's capability; P(EXLODG4) applies when the loads are not shed.

Similar to the above discussion, for plants where LOCA loads are block-loaded to off-site power, and if load-shedding does not take place, it is assumed that the EDG will be overloaded.

P(EXLODG6) = 1.0

For plants where load-shedding takes place, but the sequencing is inadequate, then:

P(EXLODG5) = 0.5

This probability is assumed to be uniformly distributed between 0.2 and 0.8.

When LOOP occurs during LOCA sequencing, then EDG overloading depends on several factors: the portion of the LOCA load that is already loaded, load-shedding of the LOCA loads, and functioning of the EDG sequencer. When the LOCA loads are shed, but the sequencing is inadequate, then the EDG will be overloaded. If the LOOP occurs during the first 3 to 5 sec, and loading has not started, then usually the sequencer will handle the delayed LOOP in a manner similar to that of a simultaneous LOOP. The probability of EDG overloading is the same as that of a LOOP occuring during the remaining period of LOCA sequencing, assuming that the sequencer will lock-up due to interference.

P(EXLODG1) = probability of LOOP occurring between 3 to 60 sec.
$\simeq$ 0.5.

This probability is assumed to be uniformly distributed between 0.2 and 0.8.

When loads are not shed, then the EDG becomes overloaded because of non-intentional block-loading. If the LOOP occurs during the later stages of the sequencing, then a large portion of the LOCA load has already been loaded and overloading is more likely. To estimate this probability, we divided the time for LOCA sequencing into two periods: 0 to 30 sec, and 31 to 60 sec. We consider that there is a 50 percent chance of overloading during the first period, but such an overloading will occur during the remaining period.

P(EXLODG2) = 0.75 x 0.5 + 0.25 x 1
= 0.6

For this case, a uniform distribution and a range of 0.3 to 0.9 is assumed.

7.4.2. Common-Cause Failure of EDG Due to Overloading

Under the conditions defined, EDG overloading is considered very likely because in all cases some type of block loading takes place. Since the redundant EDGs typically are of the same design and capacity, given the failure of the first EDG, overloading of the redundant EDGs is considered a certainty. Accordingly, the probability of failure of redundant EDGs due to overloading is considered as 1. This may be conservative for cases designated as EXLODG1 and EXLODG2.

7.5 Lockup of Load Sequencers

The lockup of load sequencers may take place when the timer during the LOCA load-sequencing receives another signal for sequencing due to the occurrence of a LOOP. Some plants may automatically reset the timer used in the load-sequencing logic, thereby preventing such a lockup; an operator may have to reset the timer on receiving a LOOP signal in plants without automatic reset.

As modeled in the event tree, lockup of the load sequencer takes place when LOOP occurs during LOCA sequencing, and is applicable for plants which do not have an automatic reset in the timer. No estimate of the probability of such a lockup was available nor was any database searched to identify such failures and estimate this probability. Such a lockup is considered fairly likely, and based on expert judgment, it was estimated as:

$$P(RESETQ) = 0.1$$

The probability of operator succeeding in resetting the sequencer after a lockup is included in the human reliability analysis (in Section 7.8) and is part of our quantification. A lognormal distribution, and an error factor of 3 is assumed.

The sequencer for the redundant train is of the same design and experiences the same sequence of events. A common-cause failure of the redundant train is likely and is modeled as the probability of failure of the second train due to failure of the first train in a sequencer lockup:

$$P_{2/1}(RESETQ) = 0.5$$

Again, the estimate is based on expert judgments and not on an analysis of data relating to multiple failure of sequencers.

It can also be argued that lockup of load sequences is very design-specific, i.e., depending on the way in which the sequencers are designed in a plant they will either lock up or not. To address such considerations, sensitivity evaluations are presented in Section 8.5 where P(RESETQ) is assigned 1 and 0.

7.6 Lockout Energization of Circuit Breakers Due to Anti-pump Circuits

This issue involves loss of capability to either automatically or manually (from the control room) close the circuit breakers of the diesel generator or safety injection pump output because of design characteristics involving the breaker's anti-pump circuitry. During a LOCA/LOOP accident, such a condition may potentially arise, disabling the EDGs and/or ECCS pumps. Here, we analyze such failures, discuss under what event progressions they are likely, and, based on an evaluation of previous failures, estimate the likelihood of such events during a LOCA/LOOP sequence.

The anti-pump circuitry is designed to prevent the circuit breaker cycling between the closed and tripped (open) positions with concurrent automatic close and automatic trip signals. The anti-pump circuitry prevents repeated attempts to close the breaker under valid trip (fault) conditions. In a LOCA/LOOP scenario, concurrent signals for automatic close and automatic trip might be present, and as a result, the breaker would trip and lock out in the tripped position, so preventing its reclosure (because of seal-in of the anti-pump circuit) even though a valid standing closure signal is present and no fault condition exists. The sequence of events for ECCS pumps and EDGs differ, and they are discussed separately.

ECCS Pumps Circuit Breaker Lockout

In a LOCA/LOOP scenario, the ECCS pumps are started in response to the Safety Injection (SI) signal due to the LOCA. When a delayed LOOP occurs, the ECCS loads are shed which trips the pumps. The pump breaker's closing circuits are usually designed so that the closing spring begins recharging after the breaker is tripped. During this recharging period, if another signal to close the breaker is received, i.e., to restart the pump, the design of the anti-pump circuit will lock out the breaker and prevent the pump from starting. Since the ECCS pump breakers will receive a signal to close, as part of the LOOP, there is the likelihood of a lockout of their anti-pump circuit.

EDG Circuit Breaker Lockout

In a LOCA/LOOP scenario, the EDGs are started in response to the SI signal. When a delayed LOOP occurs, the EDG is not expected to trip, i.e., the EDG's circuit-breaker does not get a trip signal. Since the EDG has already received the start signal, it may have reached the rated speed and frequency and may be ready to pick up the loads. Thus, in this sequence, the EDG's circuit breakers do not experience concurrent close and trip signals and an anti-pump circuit lock-out is not feasible. The likelihood of lockout of the EDG's circuit breaker in the trip position is considered negligible. Lockout of the EDG's circuit breaker is feasible in LOOP/LOCA accidents which can be considered in quantifying those accident sequences.

In the following discussions, we focus on estimating the probabilities for lockout of the ECCS pump's circuit breakers in a LOCA/LOOP accident sequence.

7.6.1. Probabilities of ECCS Pump Failures Due to Lockout of Anti-pump Circuits

As discussed earlier, and presented in the event tree, the lockout of anti-pump circuits of the ECCS pumps can happen in the following situations:

(a) LOCA followed by delayed LOOP after LOCA sequencing is completed, where loads are shed and pumps are re-sequenced,

(b) LOCA followed by delayed LOOP during LOCA sequencing, where loads are shed and pumps are re-sequenced, and

(c) LOCA followed by delayed LOOP in block-loading, where loads are shed and pumps are sequenced back.

The estimation of probabilities of ECCS pump failures is discussed for each situation below.

Essentially, the probability of the ECCS pumps failing due to anti-pump circuit lockout, P(ANTIPU), depends on two time parameters:

1) The time following a trip signal to the circuit breaker during which another signal to close causes a lockout (T_{TC}).

2) The time following a LOOP signal when the ECCS circuit breaker will receive a signal to close (T_{RS}).

When,

$$T_{TC} \geq T_{RS}, \; P(ANTIPU) \rightarrow 1.$$
$$T_{TC} < T_{RS}, \; P(ANTIPU) \rightarrow 0.$$

In general, these two time parameters, T_{TC} and T_{RS}, are plant-specific. For our evaluation, we reviewed NRC Info Notices, and some LERs and FSAR descriptions on load-sequencing and timing to obtain a general understanding of them. We then made probability estimates using engineering judgments.

Our review of the documents relating to lockout of the anti-pump circuits reveals that T_{TC} is about 2 to 6 seconds, implying that when these circuit breakers receive a signal to close within 2 to 6 secs following a trip signal, they will lockup in the trip position. The loading sequences and the timing given in FSARs were reviewed for four plants to obtain a value for T_{RS}; for both PWRs and BWRs, the start signal for the ECCS pump is received within 3 to 10 seconds.

a) LOCA Followed by Delayed LOOP After Completion of LOCA Sequencing

In such situations, the ECCS pumps have started and the LOOP signal will cause a load-shed, sending a trip signal to the ECCS pumps and a signal to re-sequence, as defined in the plant's sequencing logic.

T_{RC} and T_{RS} are of such magnitude that there is significant likelihood that they overlap, causing the anti-pump circuit to lockout the breakers. From the times defined above, an engineering judgment is made that:

$$P(ANTIPU) = 0.1$$

For some plants, T_{TC} is greater than T_{RS}, and consequently P(ANTIPU) will be higher. Also, for some plants, T_{RS} may be just beyond T_{TC} when this probability will be lower. Considering these, and assuming a lognormal distribution, an error factor of 3 is estimated, i.e., P(ANTIPU) is within 0.03 to 0.3.

b) LOCA Followed by Delayed LOOP During LOCA Sequencing

When a delayed LOOP occurs during LOCA sequencing, then the lockout of the anti-pump circuit depends on whether or not the LOOP occurred before the startup of the pump. If the LOOP occurred before the pumps were started by the LOCA signal, then the breakers will not experience both trip and close signals within the short time tolerance and a lockout cannot happen. However, if the LOOP occurred after the pumps were started, then the situation is very similar to that discussed above. To estimate the probability under these conditions, we consider the likelihood of LOOP occurring before and following the startup of the pumps during LOCA sequencing.

If LOOP occurs during the first 15 secs. then P(ANTIPU) is negligible, but if it occurs during the next 45 secs. then P(ANTIPU) is 0.1, as estimated above. However, the probability of LOOP occurring during the first 15 secs. is approx. 0.3, and during the remaining time it is 0.4, i.e., the likelihood of LOOP during the last 45 secs. of the sequencing is approximately one half of the overall likelihood of LOOP occurring during this period, then,

$$P(ANTIPU) = 0.05$$

and we assume a similar error factor of 3, as used previously.

LOCA Followed By Delayed LOOP in Block Loading

In a block loading, the situation is very similar to case (a) discussed earlier where P(ANTIPU) depends on two time parameters. The same probability estimates are used as those in case (a) i.e.:

$$P(ANTIPU) = 0.1$$

with an error factor of 3.

7.6.2. Common Cause Failure (CCF) of ECCS Pumps Due to Lockout of Anti-pump Circuits

The failure of the redundant ECCS pumps due to the lockout of the anti-pump circuits is estimated using engineering judgments, based on our review of the referenced material. No CCF data for such situations are available.

In general, the CCF of the redundant pump is likely because it is started at approximately the same time as the first pump. For block-loading, essentially all ECCS pumps are started together, and, given the lockout of the first pump, the lockout of the redundant pump is a certainty:

$$P_{2/1}\ (ANTIPU) = 1 \text{ (For block-loading)}$$

For sequential loading, the redundant pump may be started shortly after the first pump. Therefore, the CCF is expected to be slightly less likely than the block-loading case, and we estimate:

$$P_{2/1}\ (ANTIPU) = 0.5 \text{ (For sequential loading)}$$

7.7 ECCS Pump Overloading

During a LOCA/LOOP event, pumps may require large, more prolonged accelerating torques due to re-energization with the outlet valves in the open versus the closed position. In response to the safety injection (SI) signal generated for a LOCA, pumps in the ECC systems are started, but a delayed LOOP will cause them to trip as part of the load-shed, and then to restart due to the sustained SI signal. The outlet valves are opened when the pumps are first started and are expected to remain open when the pumps are tripped. The pumps are then restarted with the valves in the open position. The open outlet valve may reduce the back pressure, so that the total dynamic head is lower than the pump's rated value; this could overload the pump.

This scenario depends on plant-specific systems, control logic, and may also be affected by operating procedures. To quantify the CDF contribution in a LOCA/LOOP scenario, we examined the possibility of overloading the ECCS and its pump-cooling system, referred to as the Component Cooling Water System (CCWS) for PWRs, and the Reactor Building Closed Cooling Water System (RBCCWS) for BWRs.

Estimation of Probability for the Overloading the Pump

The probability of overloading the pump is estimated using engineering judgments since no operating experience data were available. The estimates are obtained separately for PWR and BWR plants, considering the general characteristics of the plant's response in such accidents.

The estimate of probability of overloading is based on following:

(a) review of the design characteristics of the ECCS and its pump cooling system as given in FSARs and IPEs for selected plants, and then considering the applicability of the pump's overloading in the scenario being analyzed,

(b) qualitative evaluation of the back pressure experienced by pumps for different sizes of LOCA, and

(c) consideration of the differences in the operating and design characteristics of PWRs and BWRs.

ECCS Pump Overloading

For ECCS, the status of the outlet valves before the pumps are started after receiving the safety-injection signal depends on the type of system. For PWRs, each ECCS pump discharges through a check valve and a normally open MOV in series, as illustrated in the Westinghouse PWR Information Manual. Thus, the issue of "...re-energization with outlet valves in the open position" is not applicable to PWR ECCS pumps. (For some PWR designs, this may not be the case.) For BWRs, the outlet valves of ECCS pumps are normally closed before they are started. During a LOCA/LOOP, the outlet valves are likely to remain open when the pumps are re-energized after the delayed LOOP occurs. Thus, there may be a likelihood of requiring large and more prolonged accelerating torques, overloading the pump and causing a trip. However, from reviewing selected plants, we noted that the pumps are designed for a large variation in back pressure covering different break sizes during a LOCA event. The variation of pressures, regardless of the valves' status, is expected to be handled by the pump. Therefore, overloading of the ECCS pumps during a LOCA/LOOP event is considered to have a small likelihood for BWRs with a probability of 1.0x10^{-3}.

P(VALVOP) = not applicable for PWRs
P(VALVOP) = 1.0x10^{-3} for BWRs

Considering the subjectivity involved in arriving at this value and the variations in pump designs that affect the ability to withstand back pressure, an error factor of 10 is assumed.

However, for plants that experience switchyard undervoltage, as did the Palo Verde nuclear power station earlier, the likelihood of pump overloading is expected to be significantly higher than that estimated above.

If the voltages are low enough, they cause the undervoltage relays of the emergency bus to trip and begin timing out until they finally trip the bus from offsite power and transfer the loads to the EDGs. While the relays are timing out (delays are about 10 - 35 seconds), the motors of the safety loads attempt to start on very low voltages; some may even stall for a time, especially motor-operated valves (MOVs). This could cause excessively long acceleration times with substantial heating of the motors; overload relays could trip as a result. If the relays do not trip, the pre-heated motors must then undergo another start on the EDGs, which further increases their heating. Continuous-duty motors are not usually designed for quick successive starts, and MOVs typically require a higher starting-voltage, so both types of motors are at risk (thermal damage or overload trip) during this scenario.

When the switchyard is experiencing undervoltage due to such factors, then there is a relatively high chance that the motors of the safety loads will be overloaded and trip. Following this reasoning and for the purpose of this sensitivity study, we assigned a probability of 0.1 for pump overload given undervoltage.

Since the emergency buses are initially connected to offsite power (switchyard), then the undervoltage conditions will affect all the emergency buses of the plant. Therefore, there is a high potential for a *common cause failure* of the motors of the safety loads of all the emergency buses. For this sensitivity study, a β factor of 0.9 was used, reflecting the very high likelihood of failure (trip) of the motors of the safety loads of both trains.

CCWS Pumps Overloading

The CCWS or RBCCWS provides cooling to the ECCS pumps, and failure of their pumps will cause the failure of ECCS pumps. In both PWRs and BWRs, the cooling water system is a closed, low-pressure system. A typical PWR plant has two identical cooling trains, each having two pumps, one or two heat exchangers, a surge tank, and associated valves. For BWRs, there is a large variation of the number of pumps and heat exchangers from BWR2 to BWR6.

The Westinghouse PWR Information Manual states that "...during normal plant operation, the component cooling is lined up to all essential safety-related heat loads." It appears that the outlet valves of the CCW pumps are likely to be open to the safety injection system, even during normal plant operation. In addition, the CCWS is a low-pressure system (less than 100 psia) and its pumps have a large capacity (about 5000 gpm). Therefore, we consider that overloading of the CCW pumps under the conditions assumed in GSI-171 has a relatively small likelihood.

The BWR4 System Manual shows that valves in the Emergency Equipment Cooling Water System are designed to be hydraulically opened against spring pressure when the emergency equipment's cooling water headers are pressurized as the pumps are started. Then, the scenario of overloading due to re-energization of the pumps with open outlet valves is considered also to have a small likelihood.

$P(VALVOP) = 10^{-3}$ (for both PWRs and BWRs).

Similar to estimates of the probability of the ECCS pumps' overloading, an error factor of 10 is assumed.

Common-Cause Failure (CCF) of Redundant Pump

Both the ECCS pumps follow the same sequence of events in a LOCA/LOOP accident scenario and experience the same conditions during re-energization. Both have the same design and capacity. Accordingly, if the conditions and design characteristics are such that overloading occurs in one of the pumps, then it will certainly occur for the redundant pump. The probability of CCF of the redundant pump, given failure of the first, is expressed as:

$P_{2/1}$ (VALVOP) = 1.0 (ECCS pumps; BWRs)

The sequence of events for redundant pumps in the CCWS for PWRs and RBCCWS for BWRs are different since, typically, emergency operation of one of the pumps is initiated in each train and the second pump in the train remains in standby.

The Westinghouse PWR Information Manual states that "...upon receipt of a safety injection signal during abnormal conditions, automatic emergency operation of the CCWS is initiated. One CCW pump in each train is automatically started by the LOCA sequencer. The second pump in each train remains in standby to start automatically if the operating pump discharge pressure falls below 65 psig." The low discharge pressure described refers to the loss of the function of the operating pump, not the scenario described in GSI-171. The statement indicates that the standby pump will start to provide heat-removal for the ECCS pumps on the loss of the operating CCW pump.

The FSAR of the ANO unit 2 (a Combustion Engineering plant) also states that the CCWS provides an alarm when the pumps' discharge is at low pressure. "Pressure switches on the discharge of each pump are provided to automatically start the standby pump and operate the necessary valves in the event of low pressure in the discharge of the operating pump."

Under these scenarios, the redundant pump is started if the first pump fails. The redundant pump does not experience the starting and tripping due to the sequence of events in a LOCA/LOOP accident. The CCF failure probability for the second pump will be expected to be the same as that modeled in a PRA, and is not considered any different because of the special conditions relating to a LOCA/LOOP accident.

A summary of the estimated probabilities for different conditions discussed in Sections 7.2 to 7.7 is provided in Table 7.3.

7.8 Human Error Probabilities for Recovery Actions

Human error probabilities (HEPs) were evaluated for the recovery actions of the following GSI-171 issues:

1) Overloading of EDGs

2) Lockup of Sequencers

3) Lockout of Circuit Breakers (Anti-pump circuits)

4) Overloading of ECCS pumps.

We used the methodology in Swain (1987) to evaluate HEPs; Table 7.4 shows the results. We summarize the main steps, considerations, and assumptions used to arrive at the estimates in this table.

Human reliability analysis (HRA) uses a screening analysis with conservative estimates of human behavior, i.e., higher human error probabilities than expected.

Next, the main steps are described for evaluating the HEPs for the recovery actions for each of these four issues, and for the three LOCA sizes we considered, i.e., small, medium, and large.

Table 7.3 Summary of estimated probabilities for different conditions in the event tree

Event Tree Headings	Applicable Conditions	Estimated Probabilities PWR	BWR
Conditional LOOP	LOCA loads sequenced to off-site power	0.014	0.061
	LOCA loads block-loaded to off-site power	0.06	0.25
Occurrence of LOOP	During LOCA sequencing	0.73	0.73
	After LOCA sequencing is complete	0.27	0.27
Non-recoverable damage to ECCS pumps	Failure to load shed, with no time delay	0.27	0.27
EDG overloading	- LOOP occurs following LOCA sequencing - Load-shedding occurs - Inadequate EDG sequencing	0.5	0.5
	- LOOP occurs following LOCA sequencing - No load-shedding - Unintentional block loading	1.0	1.0
	- LOOP occurs during LOCA sequencing - Load-shedding occurs - Inadequate EDG sequencing	0.5	0.5
	- LOOP occurs during LOCA sequencing - No load-shedding - Unintentional block loading	0.6	0.6
	- Block-loading to off-site power - Load-shedding occurs - Inadequate EDG sequencing	0.5	0.5

Table 7.3 Summary of estimated probabilities for different conditions in the event tree (cont'd.)

Event Tree Headings	Applicable Conditions	Estimated Probabilities	
		PWR	BWR
EDG overloading (cont'd.)	- Block-loading to off-site power - No load-shedding - Block-loading to EDG	1.0	1.0
Sequencer lockup	LOOP occurs during LOCA sequencing	0.1	0.1
Anti-pump circuit lockout			
EDG	LOCA with consequential LOOP	0.0	0.0
ECCS pumps	LOOP occurs following LOCA sequencing	0.1	0.1
	LOOP occurs during LOCA sequencing	0.05	0.05
	LOCA followed by delayed LOOP in block-loading	0.1	0.1
Pump overloading	No load-shedding following LOOP		
ECCS		0.0	0.001
CCW		0.001	0.001

Table 7.4 Screening evaluation of HEPs for recovery actions

Issue	Large LOCA						Medium LOCA					Small LOCA				
	T_a (min)	T_m (min)	T_d (min)	HEP_d	HEP_a	HEP_t	T_m (min)	T_d (min)	HEP_d	HEP_a	HEP_t	T_m (min)	T_d (min)	HEP_d	HEP_a	HEP_t
Overloading of EDGs	25	2	0	1.0	1.0	1.0	16	0	1.0	1.0	1.0	180	155	$5x10^{-5}$	0.05	$5x10^{-2}$
Lockup of Sequencers	25	2	0	1.0	1.0	1.0	16	0	1.0	1.0	1.0	180	155	$5x10^{-5}$	0.05	$5x10^{-2}$
Lockout of Circuit Breakers (Anti-pump circuits)	40	2	0	1.0	1.0	1.0	16	0	1.0	1.0	1.0	180	140	$7x10^{-5}$	1.0	1.0
Overloading of ECCS pumps	25	2	0	1.0	1.0	1.0	16	0	1.0	1.0	1.0	180	155	$5x10^{-5}$	0.05	$5x10^{-2}$

T_a = Time required to carry out recovery actions, in minutes
T_m = Time to core uncovery, in minutes
T_d = Time available for diagnosis, in minutes = T_m T_a

HEP_a = HEP of correctly carrying out recovery actions
HEP_d = HEP of correctly carrying out a diagnosis
HEP_t = Total HEP from contributions of diagnosis (HEP_d) and actions (HEP_a)

1) The first task in evaluating HEPs is to define the recovery actions that have to be carried out. For each of the four issues, the recovery actions were delineated and are summarized in the table below.

These major actions are assumed to be representative of the set of minor actions carried out to complete the former. Before these recovery actions are carried out, a correct diagnosis must be made. An evaluation is made later of the HEPs in diagnoses.

2) The time to carry out recovery actions, T_a, is estimated next. This time is believed to be plant-specific as the actions required to recover may vary from equipment to equipment and from plant to plant. In addition, the contents and quality of the plant's procedures will impact the performance, and hence, the time required to carry out the recovery actions.

Generic estimates representing an "average" plant were assessed, with the following considerations:

a) With regard to the location of the recovery actions, we note that recovery for the four issues, i.e., overloading of EDGs, lockup of sequencers, lockout of circuit breakers due to anti-pump circuits, and overloading of ECCS pumps, requires the operator to go to the remote location of the equipment, such as the EDGs, loads, and their circuit breakers. We estimate that this will take about 15 minutes.

b) Five minutes is required to manually re-sequence all the safety loads, or those loads that were not energized after a lockup of the sequencers. Automatic sequence of all the safety loads takes less than 5 minutes, but it is believed that the operators will take a little more time.

c) Once an EDG has been overloaded, five minutes is required to re-start the EDG.

d) Once the sequencers have been locked up, and the operator has reached the remote location where the load sequencing is controlled, then about 5 minutes is needed to reset it.

e) Once the circuit breakers are locked out by the anti-pump circuits, and the operator has reached their remote location, the anti-pump circuits have to be de-energized.

Issue	Recovery actions
Overloading of EDGs	Start EDG, re-sequence loads
Lockup of Sequencers	Reset load sequencing, sequence any un-energized loads
Lockout of Circuit Breakers (Anti-pump circuits)	Reach remote location, reset anti-pump circuits, re-sequence loads
Overloading of ECCS pumps	Close outlet valves, re-sequence loads

This action is regarded as an unfamiliar one for the operator, and therefore, it is estimated that about 20 minutes is required.

f) Once the ECCS pumps become overloaded, the outlet valves of the injection systems involved have to be closed, and the loads re-sequenced. The time required to close the outlet valves is estimated as 5 minutes.

The total time required to carry out recovery actions, T_a, is the sum of the individual times required to accomplish each major recovery action. For example, for the lockout of circuitbreakers due to the anti-pump circuits, there are three major recovery actions: reach the remote location, reset the anti-pump circuits, and re-sequence the loads; the time required is 15, 20, and 5 minutes, respectively. Therefore, the total time for the recovery actions, T_a, is 40 minutes. The second column of Table 7.4 shows the total time needed for recovery actions for each of the four issues.

3) The next step is to estimate the total time to both diagnose the failure(s) and to take corrective actions, T_m, before the core is uncovered after a LOCA. Therefore, T_m is the time elapsed from the onset of a LOCA to the time the core is uncovered. The time to core uncovery for each of the three sizes of LOCA are given by Azarm et al. (1996). These estimates are included in Table 7.4.

4) The following step is to estimate the time available for diagnosis, T_d. This time is obtained as the difference between the time to core uncovery, T_m, and the time needed to take recovery actions, T_a. As discussed, T_m is a function of the size of the LOCA, and T_a is a function of the recovery actions required for each of the four issues. If the time needed to take corrective actions is greater than the time to core uncovery, i.e., $T_m < T_a$, then the difference T_m-T_a is assigned a value of 0. This is the case for all four issues in large and medium LOCA scenario.

5) When the time available for diagnosis, T_d, is obtained, the HEP for diagnosis, HEP_d, is obtained from Figure 7-1 of Swain (1987) plotting HEP_d against time available for diagnosis. Table 7.4 gives the median joint HEPs obtained from this figure.

6) The next step consists of estimating the HEP for carrying out the manual corrective actions, HEP_a, once the right diagnosis is made. We considered that a corrective action will consist of performing a critical procedure correctly under moderately high stress. For this type of action, Swain (1987) suggests $HEP_a = 0.05$.

7) Finally, the total HEP, HEP_t, is obtained as the probability the operators will fail to diagnose plus the probability that they will fail to take corrective actions, given that they made a successful diagnosis. This is expressed as:

$$HEP_t = HEP_d + (1 - HEP_d) * HEP_a$$

Table 7.4 shows the values obtained using this expression. For medium and large LOCAs the time needed to take corrective actions, T_a, is longer than the time to core uncovery, and therefore, $HEP_t = 1.0$.

8 QUANTIFICATION OF CDF CONTRIBUTIONS FOR LOCA/LOOP ACCIDENT SEQUENCES

8.1 Quantification Process and Assumptions

This chapter quantifies the CDF contributions form LOCA/LOOP accident sequences. As stated earlier in the report, this contribution is not typically quantified in conventional PRAs. In that regard, this contribution is an additive to the internal event CDF quantified in a conventional PRA, i.e., to that calculated in IPE submittals. We refer to it as the "CDF contribution" which is calculated separately for large, medium, and small LOCAs. Contributions from different sizes of LOCA are added to obtain the (total) CDF contribution.

To evaluate the CDF contribution for a LOCA/LOOP accident, the event trees presented in Chapter 6 were quantified and the following considerations apply.

1) A PWR plant, Sequoyah Unit 1, and a BWR plant, Peach Bottom Unit 2, from the NUREG-1150 study (NRC, 1990) were selected for this analysis.

2) The SAPHIRE computer code, version 5 (Russell et al., 1994), was used. Currently, the modeling of LOCA/LOOP accident sequences is independent of the NUREG-1150 models of Sequoyah Unit 1 and Peach Bottom Unit 2.

3) The detailed event-tree model in Section 6.2.3 models the accident sequences in a LOCA/LOOP scenario. This tree defines the sequence of events leading to GSI-171 concerns for one of the emergency buses of AC power. To evaluate the event tree for both trains of AC power we transformed it into fault trees (presented in Appendix A). This conversion was used for quantification for the following reasons:

   a) Combinations of GSI-171 concerns of one train with that of the other train, and of GSI-171 concerns of one train with the random failure of an EDG, can be implemented in a logical structure in this process.

   b) The plants are grouped into 8 different groups according to four of their design features discussed in Section 8.2. To quantify them, the event-tree model would have to be specialized for each group, thereby creating 8 different event-trees. Using fault trees allowed us to have a single model that is automatically specialized for the 8 groups when it is executed with SAPHIRE, significantly saving computation time and resources.

   c) The fault trees keep the logical structure and the events of each particular accident sequence.

4) Input data for quantification were obtained from different sources, basically of three types: (a) unique failure mechanisms and conditions for which estimates are developed during this study, (b) data from the representative PRA models, and (c) data from databases. Item (a) was discussed in the previous chapter; items (b) and (c) are briefly discussed below.

5) The following data from the Sequoyah and Peach Bottom NUREG-1150 models are used:

   a) initiating event frequency for large, medium, and small LOCAs,

b) random unavailability of EDGs for the following failure models: failure to start, failure to run, unavailable due to maintenance, and common-cause failure.

These parameters are generally similar across the PWR and BWR plants.

6) Failure of load-shedding for one emergency bus was modeled as the failure of a single relay. The relays of both emergency buses may fail independently or from a common-cause failure. Failure of the "time delay before the EDG's circuit breaker closes" was modeled in the same way. Martinez-Guridi and Azarm (1994) previously developed these data from the following three sources: IEEE Std. 500-1984, NUCLARR (Gertman et al., 1990), and failure data from six plants reported by the Nuclear Power Reliability Data System (NPRDS). Data for protective relays from this reference were obtained as follows:

Failure per demand of a protective relay:	$3.5x10^{-6}$
Beta factor for the common cause failure of two relays:	$6.0x10^{-2}$.

7) For plants which block-load the ECCS loads to offsite power in response to a LOCA, the upper bound of the conditional probability of LOOP given a LOCA is used, as estimated in Chapter 4. This is because these plants are judged to be the more vulnerable ones, based on engineering judgment.

8.2 Grouping of Plants

The CDF contribution due to a LOCA/LOOP accident at a plant depends upon several design characteristics. A plant's vulnerability to this accident is determined by these characteristics, and it is very relevant to group the plants according to these characteristics to understand the risk significance of GSI-171. In this evaluation, neither detailed information nor resources were available to carry out a risk analysis of each of the design characteristics. However, to obtain a range of the CDF impacts across the operating nuclear power plants, we grouped the plants in accordance with four design characteristics, described below. Although these characteristics alone do not address all the GSI-171 relevant design features, they may largely determine a plant's vulnerability to a LOCA/LOOP scenario. The groups used and their evaluation identify plants with particular design characteristics that are more vulnerable compared to others, and vice versa.

The issues and concerns raised as part of GSI-171 apply to a plant depending upon the design characteristics. For example, in a plant where LOCA loads are not shed for a delayed LOOP, circuit breaker lockup due to anti-pump circuits is not applicable, whereas such an issue applies when loads are shed.

The objective in grouping the plants was to obtain the appropriate insights, and at the same time, keep the number of groups to a manageable size for general insights. Considering these and the issues relevant to GSI-171, we considered four design characteristics:

1) Energization scheme to offsite power, sequential vs. block-loading.

2) Load shedding given a LOOP following a LOCA.

3) Time delay to connect the EDG to the bus to preclude out-of-phase connection.

   As mentioned in 8.1, failure of load-shedding for one emergency bus was modeled as the failure of a single relay, and the probability of failure of such relays is very small, about 10^{-6}. Load-shedding protects from EDG overload, and, if properly implemented, from damage to the motors due to an out-of-phase transfer, while the time delay before the circuit breaker of the EDG closes only protects from overloading. Since load-shedding, as modeled by this study, will almost always succeed because it is very reliable, and it accomplishes the same function as the time delay, then if it is implemented it makes the function of this delay virtually irrelevant in a LOCA/LOOP scenario. In fact, the event tree of Figure 6.2 demonstrates this point.

4) Energization scheme to EDG.
A sequential scheme of energization to EDG is usually employed. As discussed in Chapter 6, the sequence may be inadequate, or a non-intentional block-loading may occur.

Considering these four characteristics, Table 8.2.1 shows the eight plant groups obtained. The quantification of CDF contribution for each of the eight groups is described in Sections 8.3 and 8.4 for a PWR and a BWR, respectively. The event tree presented in Section 6.2.3 includes each of these four characteristics in the headings. Depending upon these features, a plant grouping is defined and the corresponding sequences apply in obtaining the core-damage frequency. For example, sequences 5, 6, 7, 8, 13, 15, 16, 18, 19, and 20 contribute to CDF for plant group 1.

Table 8.2.1 Grouping of plants

Plant Group	Energization Scheme to Offsite Power	Load Shed	Time Delay	Energization to EDG
1	Sequential	Implemented	Implemented or not	Inadequate sequence
2	Sequential	Implemented	Implemented or not	Sequential
3	Sequential	Not implemented	Implemented	(Non-intentional) Block-loading*
4	Sequential	Not implemented	Not implemented	(Non-intentional) Block-loading*
5	Block-loading	Implemented	Implemented or not	Inadequate sequence
6	Block-loading	Implemented	Implemented or not	Sequential
7	Block-loading	Not implemented	Implemented	(Non-intentional) Block-loading*
8	Block-loading	Not implemented	Not implemented	(Non-intentional) Block-loading*

* Block-loading because load-shed is not implemented.

8.3 PWR Results

This section discusses the results of the quantification of the model for a Sequoyah-like PWR. The quantification is expressed in terms of the core damage frequency (CDF) contribution due to the GSI-171 concerns. Since previous Individual Plant Examinations (IPEs) and PRAs, including NUREG-1150, did not quantify these concerns, the CDF values obtained by this study have to be added to the value in the IPE (or PRA) of a particular plant to get the total, updated CDF. The results given in this section are point estimates, unless otherwise indicated.

8.3.1 Evaluation of the Base-case

A base-case evaluation was carried out for the 8 groups of plants using the nominal values of each of the components comprising the model. Table 8.3.1. lists the CDFs and the GSI-171 concerns which are the dominant contributors to the CDFs; we point out the following insights from these results:

1) The CDFs for the 8 groups of plants range from 2.8×10^{-6}/yr to 1.2×10^{-4}/yr.

2) The plants that block-load the LOCA loads to offsite power have CDFs in the range 1.4×10^{-5}/yr to 1.2×10^{-4}/yr, while the plants sequencing LOCA loads to offsite power have CDFs from 2.8×10^{-6}/yr to 2.5×10^{-5}/yr. Therefore, in general terms, plants that block-load the LOCA loads to offsite power have a CDF about one order of magnitude larger than those plants sequencing LOCA loads to offsite power.

3) The plants with an inadequate sequence or a non-intentional block-loading of the safety loads to the EDG have a CDF between 3 and 10 times larger than those plants that adequately sequence the safety loads to the EDG.

4) Overloading the EDG is the dominant GSI-171 concern for plants with an inadequate sequence or a non-intentional block-loading of the safety loads to the EDG.

5) For plants that adequately sequence the safety loads to the EDG, the dominant GSI-171 concerns are the lockup of sequencers and lockup of circuit breakers of safety loads due to anti-pump circuits.

8.3.2 Contribution to CDF by LOCA Size

Table 8.3.2 breaks down the total CDF for the 8 plant groups by three LOCA sizes: large, medium, and small. The results show that the dominant contributor for all the 8 plant groups is the medium LOCA, for the following two main reasons:

1) The medium LOCA leads to core damage in a few minutes after its onset; there is insufficient time for recovery actions after a GSI-171 concern has occurred.

2) The initiating event of the medium LOCA is larger than that of the large LOCA.

8.3.3 Uncertainty Evaluation

An uncertainty evaluation, using the Latin Hypercube method with 1,000 samples, was made for the base-case of the 8 plant groups. Table 8.3.3. shows the mean, 5th percentile, 95th percentile, and point estimate.

8.3.4 Risk-reduction Evaluation

The impact that each of the GSI-171 concerns has on the CDF can be measured by evaluating the CDF under the condition that the plant is able to completely eliminate one of them; this is the risk reduction evaluation conducted here. In practice, it may be difficult or impossible to completely

Table 8.3.1 Sequoyah-like PWR: CDF contribution for different plant groups.

Plant Group	Energization Scheme From Offsite Power	Load Shed	Time Delay	Energization From EDG	CDF (/yr)	Dominant Contributor to CDF
1	Sequential	Implemented	Implemented or not	Inadequate sequence	1.1×10^{-5}	EDG overload
2	Sequential	Implemented	Implemented or not	Sequential	2.8×10^{-6}	Lockup of sequencers and/or lockup of circuit breakers of safety loads due to anti-pump circuits
3	Sequential	Not implemented	Implemented	(Non-intentional) Block-loading*	1.7×10^{-5}	EDG overload and/or lockup of sequencers
4	Sequential	Not implemented	Not implemented	(Non-intentional) Block-loading*	2.5×10^{-5}	EDG overload and/or damage of pump motors and/or lockup of sequencers
5	Block-loading	Implemented	Implemented or not	Inadequate sequence	4.3×10^{-5}	EDG overload
6	Block-loading	Implemented	Implemented or not	Sequential	1.4×10^{-5}	Lockup of circuit breakers of safety loads due to anti-pump circuits
7	Block-loading	Not implemented	Implemented	(Non-intentional) Block-loading*	8.6×10^{-5}	EDG overload
8	Block-loading	Not implemented	Not implemented	(Non-intentional) Block-loading*	1.2×10^{-4}	EDG overload and/or damage of pump motors

* Block-loading because load-shed is not implemented

Table 8.3.2 Sequoyah-like PWR: Individual contributions by LOCA size (point estimate)

Plant Group	LOCA						(Total) CDF Contribution (/yr)
	Large		Medium		Small		
	CDF (/yr)	% of Total	CDF (/yr)	% of Total	CDF (/yr)	% of Total	
1	3.5×10^{-6}	32	7.0×10^{-6}	65	3.6×10^{-7}	3	1.1×10^{-5}
2	7.3×10^{-7}	26	1.5×10^{-6}	53	5.8×10^{-7}	21	2.8×10^{-6}
3	5.3×10^{-6}	32	1.1×10^{-5}	65	5.4×10^{-7}	3	1.7×10^{-5}
4	7.2×10^{-6}	29	1.4×10^{-5}	57	3.6×10^{-6}	14	2.5×10^{-5}
5	1.4×10^{-5}	32	2.8×10^{-5}	65	1.4×10^{-6}	3	4.3×10^{-5}
6	2.9×10^{-6}	20	5.7×10^{-6}	41	5.5×10^{-6}	39	1.4×10^{-5}
7	2.8×10^{-5}	32	5.5×10^{-5}	65	2.8×10^{-6}	3	8.6×10^{-5}
8	3.4×10^{-5}	29	6.8×10^{-5}	58	1.5×10^{-5}	13	1.2×10^{-4}

Table 8.3.3 Sequoyah-like PWR: Uncertainty of CDF Contribution

Plant Group	CDF Contribution (/yr)			
	Point Estimate	5th	Mean	95th
1	1.1×10^{-5}	4.3×10^{-7}	1.1×10^{-5}	4.4×10^{-5}
2	2.8×10^{-6}	1.1×10^{-7}	2.7×10^{-6}	9.0×10^{-6}
3	1.7×10^{-5}	5.8×10^{-7}	1.8×10^{-5}	6.0×10^{-5}
4	2.5×10^{-5}	1.0×10^{-6}	2.5×10^{-5}	9.4×10^{-5}
5	4.3×10^{-5}	1.6×10^{-6}	4.3×10^{-5}	1.8×10^{-4}
6	1.4×10^{-5}	4.1×10^{-7}	1.4×10^{-5}	5.6×10^{-5}
7	8.6×10^{-5}	3.4×10^{-6}	9.1×10^{-5}	3.3×10^{-4}
8	1.2×10^{-4}	5.0×10^{-6}	1.1×10^{-4}	3.9×10^{-4}

eliminate such a concern, but this type of evaluation provides an upper bound of the maximum reduction in CDF if the concern is eliminated.

Table 8.3.4 shows the results of the risk-reduction evaluation. Only the dominant contributors to the CDF for each of the 8 groups were evaluated; hence, some cells in the table are empty because the impact of some of the concerns is negligible for some groups. The results show that all the plant groups in which EDG overload is a dominant contributor to CDF can most effectively reduce their CDF by trying to reduce the impact of this contributor. Similarly, for example, group 6 can most effectively reduce its CDF by reducing the impact of the lockup of the circuit breakers of the safety loads due to anti-pump circuits.

8.4 BWR Results

This section discusses the results of the quantification of the model for a Peach Bottom-like BWR. The accident sequence model discussed in Section 6.4 was quantified for the 8 groups defined in Section 8.2. Similar to the PWR results discussed in Section 8.3, the CDF values obtained here have to be added to the IPE (or PRA) of a particular plant to get the total, updated CDF. As discussed in Section 6.4, our results do not cover BWRs which do not have a RCIC or a HPCI.

8.4.1 Evaluation of the Base-case

A base-case evaluation was carried out for the 8 plant groups. Table 8.4.1 lists the CDFs and the GSI-171 concerns which are the dominant contributors to the CDFs; we point out the following insights from these results.

1) The CDFs for the 8 groups of plants range from $6.1x10^{-7}$/yr to $3.1x10^{-5}$/yr; BWRs appear less vulnerable than PWRs to LOCA/LOOP.

2) The plants that block-load the LOCA loads to offsite power have CDFs in the range $2.7x10^{-6}$/yr to $3.1x10^{-5}$/yr, while those sequencing LOCA loads to offsite power have CDFs from $6.1x10^{-7}$/yr to $6.5x10^{-6}$/yr. Similar to PWRs, plants that block-load the LOCA loads have a CDF about one order of magnitude larger than those sequencing LOCA loads.

3) The plants with an inadequate sequence or a non-intentional block-loading of the safety loads to the EDG can have a CDF up to 10 times larger than those that adequately sequence the safety loads to the EDG.

4) Similar to PWRs, overload of the EDG is the dominant GSI-171 concern for plants with an inadequate sequence or non-intentional block-loading of the safety loads to the EDG.

5) Similar to PWRs, lockup of sequencers and lockup of circuit breakers of safety loads due to anti-pump circuits are the main concern for plants that adequately sequence the safety loads to the EDG.

From information in the Peach Bottom FSAR, Peach Bottom's design corresponds to plant group 2; that is, given a LOCA, the LOCA loads are connected sequentially to the buses; with a delayed LOOP, the loads will be shed and EDGs will be connected to the buses only after the voltage on the bus becomes zero. The loads then will be connected to the buses sequentially.

8.4.2 Contribution to CDF by LOCA Size

Table 8.4.2 breaks down the total CDF for the 8 plant groups by three LOCA sizes: large, medium, and small. Contrary to PWRs, the CDF contribution is dominated by large LOCA. Due to the AC independence of RCIC and HPCI, the small LOCA contribution is negligible and it was

Table 8.3.4 Sequoyah-like PWR: Risk-reduction evaluation of dominant contributors to CDF

Plant Group	Base-case		No Damage		No EDG Overload		No Lockup of Circuit Breakers due to Anti-Pump Circuits		No Sequencer Lockup	
	Dominant Contributor to CDF	CDF(x)* (/yr)	CDF(0) (/yr)	RRR	CDF(0) (/yr)	RRR	CDF(0) (/yr)	RRR	CDF(0) (/yr)	RRR
1	EDG overload	$1.1x10^{-5}$			$8.3x10^{-8}$	133				
2	Lockup of sequencers and/or lockup of circuit breakers of safety loads due to anti-pump circuits	$2.8x10^{-6}$					$1.2x10^{-6}$	2	$1.5x10^{-6}$	2
3	EDG overload and/or lockup of sequencers	$1.7x10^{-5}$			$1.2x10^{-6}$	14			$1.5x10^{-5}$	1
4	EDG overload and/or damage of pump motors and/or lockup of sequencers	$2.5x10^{-5}$	$1.7x10^{-5}$	2	$1.0x10^{-5}$	3			$2.3x10^{-5}$	1
5	EDG overload	$4.3x10^{-5}$			$3.3x10^{-7}$	130				
6	Lockup of circuit breakers of safety loads due to anti-pump circuits	$1.4x10^{-5}$					$3.4x10^{-7}$	41		
7	EDG overload	$8.6x10^{-5}$			$3.3x10^{-7}$	261				
8	EDG overload and/or damage of pump motors	$1.2x10^{-4}$	$8.6x10^{-5}$	1	$3.2x10^{-5}$	4				

* CDF(x) = Base-case CDF; CDF(0) = CDF with the corresponding GSI-171 concern eliminated; RRR = Risk-reduction Ratio = CDF(x)/CDF(0).

Table 8.4.1 Peach Bottom-like BWR: CDF contribution for different plant groups.

Plant Group	Energization scheme to Offsite Power	Load Shed	Time Delay	Energization to EDG	CDF (/yr)	Dominant Contributor to CDF
1	Sequential	Implemented	Implemented or not	Inadequate sequence	3.2×10^{-6}	EDG overload
2	Sequential	Implemented	Implemented or not	Sequential	6.1×10^{-7}	Lockup of sequencers and/or lockup of circuit breakers of safety loads due to anti-pump circuits
3	Sequential	Not implemented	Implemented	(Non-intentional) Block-loading*	4.9×10^{-6}	EDG overload and/or lockup of sequencers
4	Sequential	Not implemented	Not implemented	(Non-intentional) Block-loading*	6.5×10^{-6}	EDG overload and/or damage of pump motors and/or lockup of sequencers
5	Block-loading	Implemented	Implemented or not	Inadequate sequence	1.3×10^{-5}	EDG overload
6	Block-loading	Implemented	Implemented or not	Sequential	2.7×10^{-6}	Lockup of circuit breakers of safety loads due to anti-pump circuits
7	Block-loading	Not implemented	Implemented	(Non-intentional) Block-loading*	2.6×10^{-5}	EDG overload
8	Block-loading	Not implemented	Not implemented	(Non-intentional) Block-loading*	3.1×10^{-5}	EDG overload and/or damage of pump motors

* Block-loading because load-shed is not implemented

Table 8.4.2 Peach Bottom-like BWR: Individual contributions by LOCA size (point estimates)

Plant Group	LOCA						(Total) CDF Contribution (/yr)
	Large		Medium		Small		
	CDF (/yr)	% of Total	CDF (/yr)	% of Total	CDF (/yr)	% of Total	
1	$3.0x10^{-6}$	95	$1.7x10^{-7}$	5	0	0	$3.2x10^{-6}$
2	$5.9x10^{-7}$	96	$2.3x10^{-8}$	4	0	0	$6.1x10^{-7}$
3	$4.6x10^{-6}$	93	$3.2x10^{-7}$	7	0	0	$4.9x10^{-6}$
4	$6.1x10^{-6}$	94	$4.0x10^{-7}$	6	0	0	$6.5x10^{-6}$
5	$1.3x10^{-5}$	95	$6.8x10^{-7}$	5	0	0	$1.3x10^{-5}$
6	$2.5x10^{-6}$	95	$1.4x10^{-7}$	5	0	0	$2.7x10^{-6}$
7	$2.5x10^{-5}$	95	$1.4x10^{-6}$	5	0	0	$2.6x10^{-5}$
8	$2.9x10^{-5}$	95	$1.7x10^{-6}$	5	0	0	$3.1x10^{-5}$

screened out in our modeling. The medium LOCAs have a lower contribution compared to PWRs mainly because a random failure of the HPCI is required for core damage.

8.4.3 Uncertainty Evaluation

An uncertainty evaluation was conducted in a manner similar to that for the PWR evaluation. Table 8.4.3 shows the mean, 5th percentile, 95th percentile, and the point estimate.

8.4.4 Risk-reduction Evaluation

Risk-reduction evaluations were made for BWRs, similar to those conducted for PWRs. Table 8.4.4 shows the results. The insights obtained are similar to those for PWRs, i.e., EDG overloading is the dominant contributor to CDF.

8.5 Sensitivity Analysis for Plant-specific Vulnerabilities

The probability of occurrence of each of the elements of the risk model, such as the delayed LOOP or EDG overload, was developed to obtain an average value which may be representative of the entire population of operating plants. Because engineering judgment was used in many cases to obtain an estimate of the parameters, sensitivity analyses are presented in the next section that address the impact of changes in these parameters. In addition, individual plants may have specific vulnerabilities that may affect the CDF impact of a LOCA/LOOP accident. In this section, we present the sensitivity of the CDF for selected, specific plant vulnerabilities to show how they influence the CDF impact of a LOCA/LOOP accident. The intent is not to address all possible plant vulnerabilities, but rather to provide the perspective that depending upon the design and operational characteristics of an individual plant, the CDF impact can be different, and plant-specific evaluations can be conducted to address them.

Plant-specific vulnerabilities may relate to each of the issues considered in modeling the LOCA/LOOP accident. For example, if a plant is operating with an undervoltage in the switchyard, similar to that experienced at the Palo Verde Nuclear Power Station before administrative controls were put in

Table 8.4.3 Peach Bottom-like BWR: Uncertainty of CDF contribution

Plant Group	CDF Contribution (/yr)			
	Point Estimate	5th	Mean	95th
1	3.2×10^{-6}	3.8×10^{-8}	2.8×10^{-6}	1.3×10^{-5}
2	6.1×10^{-7}	4.5×10^{-9}	4.5×10^{-7}	1.8×10^{-6}
3	4.9×10^{-6}	5.8×10^{-8}	3.7×10^{-6}	1.6×10^{-5}
4	6.5×10^{-6}	7.5×10^{-8}	6.2×10^{-6}	2.4×10^{-5}
5	1.3×10^{-5}	1.2×10^{-7}	9.9×10^{-6}	4.0×10^{-5}
6	2.7×10^{-6}	2.0×10^{-8}	2.0×10^{-6}	7.9×10^{-6}
7	2.6×10^{-5}	3.4×10^{-7}	2.0×10^{-5}	7.8×10^{-5}
8	3.1×10^{-5}	3.4×10^{-7}	2.1×10^{-5}	7.7×10^{-5}

place (Palo Verde, 1994), then the likelihood of a consequential LOOP can be higher than the values discussed earlier in Chapter 4. Under such conditions, the motors of the safety loads may be overloaded and trip. Other examples of specific vulnerabilities are the specific design characteristics of the load sequencers that will definitely cause the lockup of the sequencers, or settings in anti-pump circuits that may increase the likelihood of a lockup of the circuit breakers involved.

8.5.1 Increased Probability of a Delayed LOOP Due to Switchyard Undervoltage

This plant-specific vulnerability was exemplified by the analysis of Palo Verde Nuclear Power Station (1994) which showed that the switchyard was experiencing undervoltage for a significant fraction of time during power operation. Administrative controls now have been implemented to take care of such occurrences. If a LOCA had occurred before the administrative controls were in place, an electric transient due to the events triggered by the LOCA, such as a reactor trip, could have exacerbated the undervoltage, leading to a consequential LOOP. Therefore, a plant experiencing a similar switchyard undervoltage is expected to have a higher likelihood of a consequential LOOP than the average used in quantifying the CDF contribution of a LOCA/LOOP accident.

At the same time, the design and operation of other plants may be such that the likelihood of a consequential LOOP is smaller than the average used for the quantifications (sections 8.3 and 8.4). Six sensitivity cases were evaluated; Tables 8.5.1 and 8.5.2 show the results for a Sequoyah-like PWR and for a Peach Bottom-like BWR, respectively.

The base case uses a conditional probability of LOOP after LOCA as a function of the energization

Table 8.4.4 Peach Bottom-like BWR: Risk-reduction evaluation of dominant contributors to CDF

Plant Group	Base-case		No Damage		No EDG Overload		No Lockup of Circuit Breakers due to Anti-Pump Circuits		No Sequencer Lockup	
	Dominant Contributor to CDF	CDF(x)* (/yr)	CDF(0) (/yr)	RRR	CDF(0) (/yr)	RRR	CDF(0) (/yr)	RRR	CDF(0) (/yr)	RRR
1	EDG overload	$3.2x10^{-6}$			$1.1x10^{-8}$	291				
2	Lockup of sequencers and/or lockup of circuit breakers of safety loads due to anti-pump circuits	$6.1x10^{-7}$					$3.0x10^{-7}$	2	$2.7x10^{-7}$	2
3	EDG overload and/or lockup of sequencers	$4.9x10^{-6}$			$3.0x10^{-7}$	16			$4.6x10^{-6}$	1
4	EDG overload and/or damage of pump motors and/or lockup of sequencers	$6.5x10^{-6}$	$4.9x10^{-6}$	1	$2.0x10^{-6}$	3			$6.0x10^{-6}$	1
5	EDG overload	$1.3x10^{-5}$			$4.7x10^{-8}$	277				
6	Lockup of circuit breakers of safety loads due to anti-pump circuits	$2.7x10^{-6}$					$4.8x10^{-8}$	56		
7	EDG overload	$2.6x10^{-5}$			$4.7x10^{-8}$	553				
8	EDG overload and/or damage of pump motors	$3.1x10^{-5}$	$2.6x10^{-5}$	1	$5.9x10^{-6}$	5				

* CDF(x) = Base-case CDF; CDF(0) = CDF with the corresponding GSI-171 concern eliminated; RRR = Risk-reduction Ratio = CDF(x)/CDF(0).

Table 8.5.1 Sequoyah-like PWR: CDF sensitivity to the conditional probability of LOCA/LOOP

Plant Group	Energization from Offsite Power	Conditional Probability of LOCA/LOOP						
		$1.0x10^{-3}$	$3.0x10^{-3}$	$1.0x10^{-2}$	Base-case	$3.0x10^{-2}$	$1.0x10^{-1}$	$3.0x10^{-1}$
		CDF (/yr)						
1	Sequential	$7.8x10^{-7}$	$2.3x10^{-6}$	$7.8x10^{-6}$	$1.1x10^{-5}$	$2.3x10^{-5}$	$7.8x10^{-5}$	$2.3x10^{-4}$
2	Sequential	$2.0x10^{-7}$	$5.9x10^{-7}$	$2.0x10^{-6}$	$2.8x10^{-6}$	$5.9x10^{-6}$	$2.0x10^{-5}$	$5.9x10^{-5}$
3	Sequential	$1.2x10^{-6}$	$3.5x10^{-6}$	$1.2x10^{-5}$	$1.7x10^{-5}$	$3.5x10^{-5}$	$1.2x10^{-4}$	$3.5x10^{-4}$
4	Sequential	$1.8x10^{-6}$	$5.4x10^{-6}$	$1.8x10^{-5}$	$2.5x10^{-5}$	$5.4x10^{-5}$	$1.8x10^{-4}$	$5.4x10^{-4}$
5	Block-loading	$7.8x10^{-7}$	$2.3x10^{-6}$	$7.8x10^{-6}$	$4.3x10^{-5}$	$2.3x10^{-5}$	$7.8x10^{-5}$	$2.3x10^{-4}$
6	Block-loading	$2.6x10^{-7}$	$7.7x10^{-7}$	$2.6x10^{-6}$	$1.4x10^{-5}$	$7.7x10^{-6}$	$2.6x10^{-5}$	$7.7x10^{-5}$
7	Block-loading	$1.6x10^{-6}$	$4.7x10^{-6}$	$1.6x10^{-5}$	$8.6x10^{-5}$	$4.7x10^{-5}$	$1.6x10^{-4}$	$4.7x10^{-4}$
8	Block-loading	$2.1x10^{-6}$	$6.3x10^{-6}$	$2.1x10^{-5}$	$1.2x10^{-4}$	$6.3x10^{-5}$	$2.1x10^{-4}$	$6.3x10^{-4}$

scheme of safety loads from offsite power as follows:

1) plants that sequence the safety loads: $1.4x10^{-2}$ for a PWR, and $6.0x10^{-2}$ for a BWR

2) plants that block load them: $5.5x10^{-2}$ for a PWR, and $2.5x10^{-1}$ for a BWR.

The results shown for each of the columns for the sensitivity cases use the constant value given in the header of the column, which is independent of the energization scheme of safety loads. On the other hand, plants that block-load the safety loads to offsite power are expected to have a higher likelihood of a consequential LOOP than plants employing a sequential scheme of energization.

In addition, plants that experience switchyard undervoltage are expected to have a higher likelihood of a consequential LOOP than those without this vulnerability. Consequently, vulnerable plants will have a higher CDF, shown in the columns to the right of the column headed "Base-case" in Tables 8.5.1 and 8.5.2, than the base-case.

8.5.2 Pump Overload Due to Start-up Under Undervoltage Conditions

When a LOCA occurs, several events may lead to undervoltage on the safety buses:

1) The plant trip associated with the LOCA may degrade the voltage on the safety buses due to the loss of generation to the grid (switchyard),

2) Large safety motors will be started on the safety buses. If the energization scheme from offsite power is a block-load, then the voltage of the switchyard may be further degraded,

Table 8.5.2 Peach Bottom-like BWR: CDF sensitivity to the conditional probability of LOCA/LOOP

Plant Group	Energization from Offsite Power	Conditional Probability of LOCA/LOOP						
		1.0×10^{-3}	3.0×10^{-3}	1.0×10^{-2}	Base-case	3.0×10^{-2}	1.0×10^{-1}	3.0×10^{-1}
		CDF (/yr)						
1	Sequential	5.3×10^{-8}	1.6×10^{-7}	5.3×10^{-7}	3.2×10^{-6}	1.6×10^{-6}	5.3×10^{-6}	1.6×10^{-5}
2		1.0×10^{-8}	3.0×10^{-8}	1.0×10^{-7}	6.1×10^{-7}	3.0×10^{-7}	1.0×10^{-6}	3.0×10^{-6}
3		8.1×10^{-8}	2.4×10^{-7}	8.1×10^{-7}	4.9×10^{-6}	2.4×10^{-6}	8.1×10^{-6}	2.4×10^{-5}
4		1.1×10^{-7}	3.2×10^{-7}	1.1×10^{-6}	6.5×10^{-6}	3.2×10^{-6}	1.1×10^{-5}	3.2×10^{-5}
5	Block-loading	5.3×10^{-8}	1.6×10^{-7}	5.3×10^{-7}	1.3×10^{-5}	1.6×10^{-6}	5.3×10^{-6}	1.6×10^{-5}
6		1.1×10^{-8}	3.2×10^{-8}	1.1×10^{-7}	2.7×10^{-6}	3.2×10^{-7}	1.1×10^{-6}	3.2×10^{-6}
7		1.1×10^{-7}	3.2×10^{-7}	1.1×10^{-6}	2.6×10^{-5}	3.2×10^{-6}	1.1×10^{-5}	3.2×10^{-5}
8		1.2×10^{-7}	3.7×10^{-7}	1.2×10^{-6}	3.1×10^{-5}	3.7×10^{-6}	1.2×10^{-5}	3.7×10^{-5}

3) In some cases, non-safety loads are transferred to a transformer fed from the switchyard.

In addition, for plants that experience switchyard undervoltage during non-negligible periods, as did the Palo Verde plant earlier, the three conditions mentioned above may exacerbate the undervoltage at the safety buses.

If the voltages are low enough, they cause the undervoltage relays of the emergency bus to trip and begin timing out until they finally trip the bus from offsite power and transfer the loads to the EDGs. While the relays are timing out (delays are about 10 - 35 seconds), the motors of the safety loads attempt to start on very low voltages; some may even stall for some time, especially motor-operated valves (MOVs). This could cause excessively long acceleration times with substantial heating of the motors. Overload relays could trip as a result. If the relays do not trip, the pre-heated motors must then undergo another start on the EDGs, which further increases the heat.

Continuous-duty motors are not usually designed for quick successive starts, and MOVs typically require a higher starting-voltage, so both types of motors are at risk (thermal damage or overload trip) during this scenario.

When the switchyard is experiencing undervoltage due to such factors, the chance that the motors of the safety loads will be overloaded and trip increases. Following this reasoning and for this sensitivity study, we assigned a probability of 0.1 for pump overload given undervoltage.

Since the emergency buses are initially connected to offsite power (switchyard), then the undervoltage conditions will affect all the emergency buses of the plant. Therefore, there is a high potential for a common-cause failure of the motors of the safety loads of all the emergency buses. For this sensitivity study, a β factor of 0.9 was used, reflecting the very high likelihood of failure (trip) of the motors of the safety loads of both trains.

Since overloading the pumps is more likely for plants that experience switchyard undervoltage, the sensitivity study of pump overload was combined with a sensitivity study of the conditional probability of LOOP after LOCA with two high values: 0.1 and 0.3. The results are shown in Tables 8.5.3 and 8.5.4 for a Sequoyah-like PWR and for a Peach Bottom-like BWR, respectively.As before, the base-case uses a conditional probability of LOOP after LOCA as a function of the energization scheme of safety loads from offsite power as follows:

1) plants that sequence the safety loads: 1.4×10^{-2} for a PWR, and 6.0×10^{-2} for a BWR

2) plants that block load them: 5.5×10^{-2} for a PWR, and 2.5×10^{-1} for a BWR.

The results shown for each of the columns for the sensitivity cases use the constant value given in the header of the column, which is independent of the energization scheme of safety loads.

The results in Tables 8.5.3 and 8.5.4 show that for those plant that experience switchyard undervoltage, like the Palo Verde station before it had administrative controls, the combination of a high likelihood of a LOOP after LOCA with the potential for pump overload increases CDF very significantly. On the other hand, even if a plant does not experience switchyard undervoltage, there is a potential for undervoltage at the emergency buses due to the events triggered by the LOCA, in which case pump overload will contribute to the CDF.

8.5.3 Lockup of Sequencers (With Probability 1 or 0)

If the design and operation of a particular plant is such that when a LOOP occurs after a LOCA the load sequencers are reset so that the LOCA and the LOOP sequencing do not interfere with each other, then the probability of a lockup of sequencers will be small. On the other hand, if a particular plant's configuration does not incorporate the possibility of a LOCA with a delayed LOOP scenario, and does not have mechanisms, such as resetting the sequencers, to protect them from lockup, then that probability will be large.

Consequently, the lockup of sequencers is a plant-specific vulnerability whose probability can be 1 for plants without protective mechanisms, and 0 for those with protective measures.

Lockup of sequencers only occurs for plants that sequence the loads to offsite power after a LOCA. By definition, those plants that block-load the loads to offsite power after a LOCA do not experience it because there is no LOCA sequencing. Accordingly, the sensitivity evaluations were only carried out for plant groups 1 to 4.

The CDF for the base-case for the plant groups includes the contribution of the lockup of sequencers which was obtained by using a value for its probability based on engineering judgment. Tables 8.5.5 and 8.5.6 show the results for a Sequoyah-like PWR and for a Peach Bottom-like BWR, respectively, of the two sensitivity studies, of the base-case, and two ratios providing a measure of the impact of the two boundary values, 0 and 1. Since the lockup of sequencers is a dominant contributor to CDF for groups 2 to 4, then the Risk Increase Ratio reflects a significant increase in CDF for those plants lacking preventative mechanisms.

8.6 Sensitivity Analyses Addressing Assumptions

Additional sensitivity analyses were made to address some of the assumptions in this study. Because of the lack of plant-specific information on the design characteristics that influence the

Table 8.5.3 Sequoyah-like PWR: CDF sensitivity to pump overload

Plant Group	Conditional Probability of LOOP after LOCA		
	Base-case	$1.0x10^{-1}$	$3.0x10^{-1}$
	CDF (/yr)		
1	$1.1x10^{-5}$	$9.3x10^{-5}$	$2.8x10^{-4}$
2	$2.8x10^{-6}$	$3.5x10^{-5}$	$1.1x10^{-4}$
3	$1.7x10^{-5}$	$1.3x10^{-4}$	$4.0x10^{-4}$
4	$2.5x10^{-5}$	$2.0x10^{-4}$	$5.9x10^{-4}$
5	$4.3x10^{-5}$	$9.4x10^{-5}$	$2.8x10^{-4}$
6	$1.4x10^{-5}$	$4.1x10^{-5}$	$1.2x10^{-4}$
7	$8.6x10^{-5}$	$1.7x10^{-4}$	$5.1x10^{-4}$
8	$1.2x10^{-4}$	$2.3x10^{-4}$	$6.8x10^{-4}$

Table 8.5.4 Peach Bottom-like BWR: CDF sensitivity to pump overload

Plant Group	Conditional Probability of LOOP After LOCA		
	Base-case	$1.0x10^{-1}$	$3.0x10^{-1}$
	CDF (/yr)		
1	$3.2x10^{-6}$	$9.3x10^{-6}$	$2.8x10^{-5}$
2	$6.1x10^{-7}$	$5.0x10^{-6}$	$1.5x10^{-5}$
3	$4.9x10^{-6}$	$1.2x10^{-5}$	$3.6x10^{-5}$
4	$6.5x10^{-6}$	$1.5x10^{-5}$	$4.4x10^{-5}$
5	$1.3x10^{-5}$	$9.3x10^{-6}$	$2.8x10^{-5}$
6	$2.7x10^{-6}$	$5.1x10^{-6}$	$1.5x10^{-5}$
7	$2.6x10^{-5}$	$1.5x10^{-5}$	$4.4x10^{-5}$
8	$3.1x10^{-5}$	$1.6x10^{-5}$	$4.9x10^{-5}$

Table 8 5.5 Sequoyah-like PWR: Probability of sequencer lockup equal to 1 and 0

Plant Group	Base-case		Probability of Sequencer Lockup = 1		Probability of Sequencer Lockup = 0	
	Dominant Contributor to CDF	CDF(B)* (/yr)	CDF(1)	RIR	CDF(0) (/yr)	RRR
1	EDG overload	$1.1x10^{-5}$	$1.1x10^{-5}$	1	$1.1x10^{-5}$	1
2	Lockup of sequencers and/or lockup of circuit breakers of safety loads due to anti-pump circuits	$2.8x10^{-6}$	$3.6x10^{-5}$	13	$1.5x10^{-6}$	2
3	EDG overload and/or lockup of sequencers	$1.7x10^{-5}$	$4.8x10^{-5}$	3	$1.5x10^{-5}$	1
4	EDG overload and/or damage of pump motors and/or lockup of sequencers	$2.5x10^{-5}$	$6.4x10^{-5}$	3	$2.3x10^{-5}$	1

*CDF(B) = Base-case CDF;
CDF(1) = CDF conditional to sequencer lockup always happening (probability = 1);
RIR = Risk Increase Ratio = CDF(1)/CDF(B); rounded to the nearest integer;
CDF(0) = CDF conditional to sequencer lockup never happening (probability = 0);
RRR = Risk-reduction Ratio = CDF(B)/CDF(0); rounded to the nearest integer.

parameters estimated for quantifying the CDF contributions, judgments were based on engineering analyses. The sensitivity analyses discussed in the previous section address plant-specific vulnerabilities. Here, some additional sensitivity analyses relating to other assumptions during the quantification are presented:

(a) probability of lockup of circuit breakers due to anti-pump circuits,

(b) time to complete LOCA sequencing, and

(c) time to initiate EDG load sequencing.

These evaluations were selected because they are specific to LOCA/LOOP sequence modeling.

Probability of Lockup of Circuit Breakers due to Anti-Pump Circuits

Similar to the lockup of sequencers, the probability of lockup of anti-pump circuits can be very plant-specific. Depending on the settings in the equipment and the timing of the sequencing, this probability can be close to 1 or 0. Sensitivity analyses are conducted with these two values. Table 8.6.1 and 8.6.2 show the results for a PWR and a BWR, respectively. For a plant where the settings are such that lockup of circuit breakers due to anti-pump circuits will take place, the CDF is substantially larger than that of the base-case. When this failure mechanism is eliminated, the CDF substantially decreases. These evaluations are consistent with the risk-reduction evaluations discussed in subsections 8.3.4 and 8.4.4.

Table 8.5.6 Peach Bottom-like BWR: Probability of sequencer lockup equal to 1 and 0

Plant Group	Base-case		Probability of Sequencer Lockup = 1		Probability of Sequencer Lockup = 0	
	Dominant Contributor to CDF	CDF(B)* (/yr)	CDF(1) (/yr)	RIR	CDF(0) (/yr)	RRR
1	EDG overload	3.2×10^{-6}	3.2×10^{-6}	1	3.2×10^{-6}	1
2	Lockup of sequencers and/or lockup of circuit breakers of safety loads due to anti-pump circuits	6.1×10^{-7}	9.6×10^{-6}	16	2.7×10^{-7}	2
3	EDG overload and/or lockup of sequencers	4.9×10^{-6}	1.3×10^{-5}	3	4.6×10^{-6}	1
4	EDG overload and/or damage of pump motors and/or lockup of sequencers	6.5×10^{-6}	1.7×10^{-5}	3	6.0×10^{-6}	1

*CDF(B) = Base-case CDF;
CDF(1) = CDF conditional to sequencer lockup always happening (probability = 1);
RIR = Risk Increase Ratio = CDF(1)/CDF(B); rounded to the nearest integer;
CDF(0) = CDF conditional to sequencer lockup never happening (probability = 0);
RRR = Risk-reduction Ratio = CDF(B)/CDF(0); rounded to the nearest integer.

Time to Complete LOCA Sequencing

For plants where LOCA loads are sequenced to offsite power, the time to complete the load sequencing can affect the CDF contribution; this time varies from plant to plant. A sensitivity analysis was carried out where this time is changed. Tables 8.6.3 and 8.6.4 show the results for a PWR and BWR, respectively. The results include only groups 1 to 4, since this situation does not apply to plants that block-load. The CDF contribution slightly increases when non-intentional block-loading takes place.

Time to Initiate EDG Load Sequencing

The time to initiate EDG load sequencing also can vary from plant to plant and can influence some of the failure mechanisms addressed in modeling the LOCA/LOOP sequences. Sensitivity analyses for this time were made; the time in the base-case of 3 sec. is varied to 5 and 10 sec.

Time to Initiate EDG Load Sequencing

Table 8.6.5 and 8.6.6 give the results for a PWR and a BWR, respectively; the CDF decreases with the increase in time. This is because the likelihood of lockup of circuit breakers due to anti-pump circuits decreases, but a large increase in time may have opposite effects.

8.7 Comparison with Previous Evaluations

Table 8.7.1 compares the results of this study with the previous evaluations made in prioritizing the GSI-171. The CDF contributions for PWR and BWR plants reveal the following points:

Table 8.6.1 Sequoyah-like PWR: Probability of lockup of circuit breakers of safety loads due to anti-pump circuits equal to 0 and 1

Plant Group	Energization Scheme to Offsite Power	Load Shed	Time Delay	Energization Scheme to EDG	Base-Case	Probability of Anti-pump Circuits-induced Lockup=1		Probability of Anti-pump Circuits-induced Lockup=0	
					CDF(B)* (/yr)	CDF(1) (/yr)	RIR	CDF(0) (/yr)	RRR
2	Sequential	Implemented	Implemented or not	Sequential	2.8×10^{-6}	3.6×10^{-5}	13	1.2×10^{-6}	2
6	Block-loading	Implemented	Implemented or not	Sequential	1.4×10^{-5}	1.4×10^{-4}	10	3.4×10^{-7}	41

*CDF(B) = Base-case CDF;
CDF(1) = CDF conditional to sequencer lockup always happening (probability = 1);
RIR = Risk Increase Ratio = CDF(1)/CDF(B); rounded to the nearest integer;
CDF(0) = CDF conditional to sequencer lockup never happening (probability = 0);
RRR = Risk-reduction Ratio = CDF(B)/CDF(0); rounded to the nearest integer.

Table 8.6.2 Peach Bottom-like BWR: Probability of lockup of circuit breakers of safety loads due to anti-pump circuits equal to 0 and 1

Plant Group	Energization Scheme to Offsite Power	Load Shed	Time Delay	Energization Scheme to EDG	Base-case	Probability of Anti-pump Circuits-induced Lockup = 1		Probability of Anti-pump Circuits-induced Lockup = 0	
					CDF (/yr)	CDF(1) (/yr)	RIR	CDF(0) (/yr)	RRR
2	Sequential	Implemented	Implemented or not	Sequential	6.1×10^{-7}	6.6×10^{-6}	11	6.1×10^{-7}	2
6	Block-loading	Implemented	Implemented or not	Sequential	2.7×10^{-6}	2.6×10^{-5}	10	4.8×10^{-8}	56

*CDF(B) = Base-case CDF;
CDF(1) = CDF conditional to sequencer lockup always happening (probability = 1);
RIR = Risk Increase Ratio = CDF(1)/CDF(B); rounded to the nearest integer;
CDF(0) = CDF conditional to sequencer lockup never happening (probability = 0);
RRR = Risk-reduction Ratio = CDF(B)/CDF(0); rounded to the nearest integer.

Table 8.6.3 Sequoyah-like PWR: CDF sensitivity to the time to complete LOCA sequencing

Case	Energization Scheme to Offsite Power	Load Shed	Time Delay	Energization Scheme to EDG	Time to Complete LOCA Sequencing: Base-case = 60 sec. CDF (/yr)	Time to Complete LOCA Sequencing: Sensitivity Case = 45 sec. CDF (/yr)
1	Sequential	Implemented	Implemented or not	Inadequate sequence	1.1×10^{-5}	1.1×10^{-5}
2	Sequential	Implemented	Implemented or not	Sequential	2.8×10^{-6}	2.7×10^{-6}
3	Sequential	Not implemented	Implemented	(Non-intentional) Block-loading*	1.7×10^{-5}	1.9×10^{-5}
4	Sequential	Not implemented	Not implemented	(Non-intentional) Block-loading*	2.5×10^{-5}	2.7×10^{-5}

*Block-loading because load shed is not implemented.

Table 8.6.4 Peach Bottom-like BWR: CDF sensitivity to the time to complete LOCA sequencing

Case	Energization Scheme to Offsite Power	Load Shed	Time Delay	Energization Scheme to EDG	Time to Complete LOCA Sequencing: Base-case = 60 sec. CDF (/yr)	Time to Complete LOCA Sequencing: Sensitivity Case = 45 sec. CDF (/yr)
1	Sequential	Implemented	Implemented or not	Inadequate sequence	$3.2x10^{-6}$	$3.2x10^{-6}$
2	Sequential	Implemented	Implemented or not	Sequential	$6.1x10^{-7}$	$5.9x10^{-7}$
3	Sequential	Not implemented	Implemented	(Non-intentional) Block-loading*	$4.9x10^{-6}$	$5.4x10^{-6}$
4	Sequential	Not implemented	Not implemented	(Non-intentional) Block-loading*	$6.5x10^{-6}$	$7.0x10^{-6}$

*Block-loading because load shed is not implemented.

Table 8.6.5 Sequoyah-like PWR: CDF sensitivity to the time to initiate EDG load sequencing

Case	Energization Scheme to Offsite Power	Load Shed	Time Delay	Energization Scheme to EDG	Time to Initiate EDG Load Sequencing: Base-case = 3 sec. CDF (/yr)	Time to Initiate EDG Load Sequencing: Sensitivity Case = 5 sec. CDF (/yr)	Time to Initiate EDG Load Sequencing: Sensitivity Case = 10 sec. CDF (/yr)
1	Sequential	Implemented	Implemented or not	Inadequate sequence	$1.1x10^{-5}$	$9.3x10^{-6}$	$9.3x10^{-6}$
2	Sequential	Implemented	Implemented or not	Sequential	$2.8x10^{-6}$	$2.0x10^{-6}$	$1.5x10^{-6}$
3	Sequential	Not implemented	Implemented	(Non-intentional) Block-loading*	$1.7x10^{-5}$	$1.5x10^{-5}$	$1.3x10^{-5}$
4	Sequential	Not implemented	Not implemented	(Non-intentional) Block-loading*	$2.5x10^{-5}$	$2.4x10^{-5}$	$2.2x10^{-5}$
6	Block-loading	Implemented	Implemented or not	Sequential	$1.4x10^{-5}$	$7.2x10^{-6}$	$4.5x10^{-6}$

* Block-loading because load-shed is not implemented.

Table 8.6.6 Peach Bottom-like BWR: CDF sensitivity to the time to initiate EDG load sequencing

Case	Energization Scheme to Offsite Power	Load Shed	Time Delay	Energization Scheme to EDG	Time to Initiate EDG Load Sequencing		
					Base-case = 3 sec.	Sensitivity Case = 5 sec.	Sensitivity Case = 10 sec.
					CDF (/yr)	CDF (/yr)	CDF (/yr)
1	Sequential	Implemented	Implemented or not	Inadequate sequence	3.2×10^{-6}	2.8×10^{-6}	2.8×10^{-6}
2	Sequential	Implemented	Implemented or not	Sequential	6.1×10^{-7}	4.7×10^{-7}	3.6×10^{-7}
3	Sequential	Not implemented	Implemented	(Non-intentional) Block-loading*	4.9×10^{-6}	4.4×10^{-6}	4.0×10^{-6}
4	Sequential	Not implemented	Not implemented	(Non-intentional) Block-loading*	6.5×10^{-6}	6.1×10^{-6}	5.6×10^{-6}
6	Block-loading	Implemented	Implemented or not	Sequential	2.7×10^{-6}	1.4×10^{-6}	8.6×10^{-7}

* Block-loading because load shed is not implemented.

Table 8.7.1 Comparison of LOCA/LOOP CDF contribution

Reference Study	CDF Contribution (/yr)	
	PWR	BWR
1. GSI-171 Prioritization Evaluation (NRC Memorandum, DL Morrison to L.C. Shao, Attachment 1, June 1995)	8×10^{-6} to 5.5×10^{-3}	1.7×10^{-5} to 5×10^{-3}
2. Re-Evaluation of GSI-171 (NRC Memorandum, M.C. Cunningham to C.Z. Serpan, Oct. 1995)	5×10^{-7} to 1.5×10^{-4}	3×10^{-7} to 8×10^{-5}
3. This Study	2.8×10^{-6} to 1.2×10^{-4}	6.1×10^{-7} to 3.1×10^{-5}

1) The results for PWR plants are slightly lower than, or comparable to, those obtained in some previous analyses. As observed previously, for some groups of plants the CDF remains high (in the order of 10^{-4}/yr, or greater).

2) The results for BWR plants are lower than those obtained previously and their risk impact lies in the intermediate range of about 10^{-5}/yr.

3) The technical issues to be addressed in resolving GSI-171 are different based on present evaluations; EDG overloading and lockup of ECCS pumps are of primary concern as opposed to damage to the EDG and to the ECCS pumps which was the earlier focus.

Table 8.7.2 compares CDF contribution of LOCA/LOOP accident sequences in this study with the CDF from internal events calculated in the NUREG-1150 study. The CDF values from internal events in NUREG-1150 are comparable to those calculated in the IPE submittals. The CDF from internal events of Sequoyah and Peach Bottom plants are used as examples since some data from these two plants was used during our quantification of LOCA/LOOP accident sequences. The intent here is to obtain a perspective on the relative significance of LOCA/LOOP accident sequences compared to the internal-event CDF of the operating plants; the latter does not include a contribution from the GSI-171 concerns. This comparison can be interpreted as stating that for some plant designs the LOCA/LOOP can be a dominant contributor to CDF, whereas in others it is a small contributor.

Table 8.7.2 Comparison of LOCA/LOOP CDF contribution with internal event CDF

Contribution	CDF Contribution (/yr)	
	PWR	BWR
LOCA/LOOP accident sequence (This study)	2.8×10^{-6} to 1.2×10^{-4} +	6.1×10^{-7} to 3.1×10^{-5} +
Internal event CDF (Sequoyah)	5.7×10^{-5} *	—
Internal event CDF (Peach Bottom)	—	4.5×10^{-6} *

+ point estimates representing different plant groups
* mean values

9 SUMMARY AND CONCLUSIONS

This report presents an evaluation of LOCA with delayed LOOP (LOCA/LOOP) and LOOP with delayed LOCA (LOOP/LOCA) accidents in nuclear power plants, as postulated within the Generic Safety Issue 171 (GSI-171), and discusses the technical findings related to them. To arrive at the technical findings, the following studies were undertaken:

(a) Selected IPE submittals were reviewed to determine whether the accident sequences (LOCA/LOOP and LOOP/LOCA) postulated in GSI-171 were modeled or addressed in them.

(b) Operating experience data were evaluated to estimate the probability of LOOP given a LOCA, and of LOCA given a LOOP, using surrogate events and data.

(c) Event tree models were developed defining the progression of events leading to core damage for LOCA/LOOP accidents.

(d) Core-damage frequency (CDF) contributions were quantified for LOCA/LOOP accidents at a PWR and a BWR plant using engineering analyses and judgment to estimate the required parameters for quantification.

(e) Sensitivity and uncertainty analyses were conducted to address plant-specific vulnerabilities, data variabilities, and assumptions in modeling, and to obtain insights on dominant contributors to CDF for a LOCA/LOOP accident.

Treatment of LOCA/LOOP and LOOP/LOCA Accidents in IPE Submittals

Individual Plant Examination (IPE) submittals for 20 plants were reviewed to understand the extent to which GSI-171 accident scenarios and the associated issues were addressed as part of these examinations. The technical findings from these reviews can be summarized as follows:

1) The IPEs do not model, nor do they discuss LOCA/LOOP, i.e., LOCA with consequential or delayed LOOP, along with the GSI-171 concerns relating to damage to EDGs and ECCS pumps, the loss of this equipment due to overloading, lockup of the load sequencer, and lockout energization of circuit breakers due to their anti-pump circuits. Some IPEs model random occurrence of LOOP following LOCA in the LOCA analysis, but these analyses do not address nor provide any insights into the plant's response in the GSI-171 postulated scenario.

2) The IPEs model LOOP/LOCA sequences and the associated core-damage frequency (CDF) contribution can be greater than $1.0x10^{-5}$/yr. Fifteen PWRs have sequences with a CDF contribution greater than $1.0x10^{-6}$/yr, with the highest being $4.7x10^{-5}$/yr. However, these models do not address GSI-171 concerns.

3) The IPEs provide limited information about the protective devices that may be present in a plant to adequately respond to LOCA/LOOP and LOOP/LOCA sequences. Such information shows that some plants may have protection against damage to the EDGs and ECCS pumps. Plant-specific information is needed to develop a complete understanding about whether plants have or lack such protective features.

Frequency of LOCA/LOOP and LOOP/LOCA Accidents

Operating experience data were used to estimate the initiating-event frequencies associated with GSI-171 accident scenarios: LOCA/LOOP and LOOP/LOCA. Since the initiating-event frequencies associated with LOCA and LOOP have been studied separately as part of PRAs, this work focussed on estimating the probability of LOOP given a LOCA, and the probability of LOCA given a LOOP.

The probability of LOOP given a LOCA, as postulated in GSI-171, was estimated using automatic reactor scram and ECCS actuations as surrogate events for a LOCA. Operating experience data relating to reactor trips, ECCS actuations, and LOOP events over a ten-year period (1984 to 1993) were reviewed to obtain the estimates for PWRs and BWRs; they are averages over the population of each type of reactor. The average estimates can be significantly different for a specific plant where a specific vulnerability to such an event exists. An example was found at the Palo Verde plant (Palo Verde Nuclear Power Plant, Dec. 1994) before an administrative control was implemented at the site. Also, although ten years of data were evaluated, a relatively small number of conditional LOOP events were observed which were used to obtain the estimates. The conclusions from this assessment can be summarized as follows:

1) The point estimates for the probability of LOOP given LOCA for BWRs and PWRs are, respectively, 6.0×10^{-2} and 1.4×10^{-2}, while the comparable probability of random occurrence of a LOOP given a LOCA is of the order of 10^{-4} or smaller.

2) There is an increased likelihood of LOOP given a LOCA compared to a random occurrence of LOOP; the estimates obtained for PWRs and BWRs are higher than a random occurrence probability by factors of approximately 70 and 300, respectively, but the range is comparable to, or less than, some previous estimates used for prioritization in GSI-171.

LOOP/LOCA scenarios are modeled in almost all IPEs. Some IPEs, and some PRAs completed as part of the NUREG-1150 study were reviewed to obtain their frequency estimates. LERs were examined to obtain estimates for the probability of PORVs or SRVs to open subsequent to a LOOP. These estimates then were multiplied by the probability that the valve will be stuck or fail to close, to obtain an assessment for the stuck-open PORV or SRV, i.e., a small LOCA. The findings can be summarized as follows:

1) The estimates for stuck-open PORV or SRV subsequent to a LOOP, based on operating experience, are lower than those used in IPEs or other PRAs reviewed for this study.

2) The LOOP/LOCA frequency used in the IPEs or PRAs reviewed appear to be conservative.

Modeling and Quantification of LOCA/LOOP Accident Sequences

In this report, a LOCA/LOOP accident, i.e., LOCA with delayed LOOP, in a nuclear power plant was analyzed and its risk impact estimated in terms of its contribution to core-damage frequency (CDF). Because a LOCA/LOOP accident, as postulated in GSI-171, involves several issues and unique combinations of failure mechanisms not routinely analyzed in a probabilistic risk assessment (PRA), new event-tree models were developed to analyze the progression of events leading to core damage. Quantification of the event tree to obtain CDF contributions involved assessing the probability of some parameters that are not quantified in PRAs, nor available elsewhere. As practical, in some cases (e.g., conditional probability of LOOP given LOCA, timing of LOOP given LOCA), available data were evaluated to obtain the probability estimates, whereas in other cases, (e.g., EDG overloading, lockout energization of circuit breakers due to their anti-pump circuits, pump overloading) the estimates were based on engineering judgments. These judgments were made from information given in NRC Info Notices, FSARs, and insights from reviewing LERs relating to selected, relevant incidents that have occurred. A more detailed model was established of the electrical characteristics of EDGs and ECCS pumps to estimate their probability of damage due to an out-of-phase bus transfer. In general, because of the unique situation and conditions that were modeled for which operating experience data are not available or expected, the evaluation involved engineering analyses, judgments, and several assumptions; these are discussed in the report.

The evaluation was carried out for a PWR and a BWR plant based on their general characteristics, but using information from reference plants (Sequoyah, a PWR, and Peach Bottom, a BWR). For both types, various design characteristics were considered relating to loading the ECCS loads to offsite power, load-shedding, and reloading to EDGs; this allowed us to develop different plant groups since such characteristics significantly influence the CDF contribution in such an accident. In addition, we conducted sensitivity analyses to elucidate the dominating influence(s) to the CDF contribution in a particular plant group, and to observe the influence of the assumptions in estimating the parameters used in the quantification.

LOCA/LOOP Accident at a PWR Plant

The evaluation of PWR plants showed that the CDF contribution of a LOCA/LOOP accident can vary by two orders of magnitude ($2.8x10^{-6}$/yr to $1.2x10^{-4}$/yr), depending on the design characteristics relating to the load-shedding/load-energization features in such an accident scenario. The major conclusions relating to the PWR plants are summarized as follows:

1) For some combination of design characteristics, the CDF contribution can be of the order $1.0x10^{-4}$/yr. Plants using block-loading to the offsite power and block-loading to the EDG following a LOOP without a load shed are associated with these high contributions. The identification of specific plants with these features was not within the scope of this project.

2) Plants where sequential loading to offsite power and the EDG is used along with load-shedding appear better equipped to handle this accident, and their CDF contribution is about $3x10^{-6}$/yr.

3) Plants which use a combination of block- and sequential-loading schemes have CDF contributions about $2x10^{-5}$/yr.

4) Sensitivity analyses show that the dominant contributors to risk from a LOCA/LOOP accident are EDG overloading and lockout of circuit breakers due to their anti-pump circuits, i.e., plant design features which avoid failures from those concerns will significantly reduce the CDF contribution. These aspects may be further explored to identify and eliminate conservatism associated with their evaluation, as discussed in this study.

5) Some plants may have specific vulnerabilities. Examples relate to the operation with switchyard undervoltage that may increase the probability of a delayed LOOP and overloading of pumps, the specific design of load sequencers making lockup in such a scenario highly likely, and the setting in anti-pump circuits causing increased likelihood of lockout of circuit breakers of safety loads. Such vulnerabilities further increase the CDF contributions of LOCA/LOOP accidents, as the results in Chapter 8 show.

6) A comparison of our results with those obtained in earlier studies shows that, similar to previous evaluations, for some plants the risk contribution for such an accident remains high, but our calculated contributions are generally lower than, or comparable to, previous ones. Earlier studies only considered the damage to EDG and ECCS pumps. Present modeling and analyses evaluated the relative impacts of different issues identified as part of GSI-171 which showed that EDG overloading and lockout of circuit breakers due to their anti-pump circuits dominate the risk contribution, and focussing on them can reduce the impact of such an accident.

LOCA/LOOP Accident at a BWR Plant

The evaluation of a BWR plant showed that, similar to the PWR plants, the CDF contribution of a LOCA/LOOP accident can vary by orders of magnitude and depends on similar design characteristics, i.e., load shedding, and load energization features. Our insights on differences and similarities can be summarized as follows:

1) The CDF impact of a LOCA/LOOP accident for most BWR plants (6.1×10^{-7}/yr to 3.1×10^{-5}/yr) is about an order of magnitude lower than PWR plants, and thus, most BWRs are less vulnerable to a LOCA/LOOP accident.

2) Similar to PWR plants, BWRs that block-load to offsite power in response to a LOCA, and block-load to the EDG without load-shed in response to a LOOP are the most vulnerable; the relative impact of other design features is similar to that observed for PWRs.

3) Similar to PWR plants, EDG overloading and lockout of circuit breakers due to their anti-pump circuits dominate the risk contributions and these concerns can be addressed to further reduce risk.

4) Similar plant-specific vulnerabilities may exist for BWR plants, and if present, CDF contributions will be higher.

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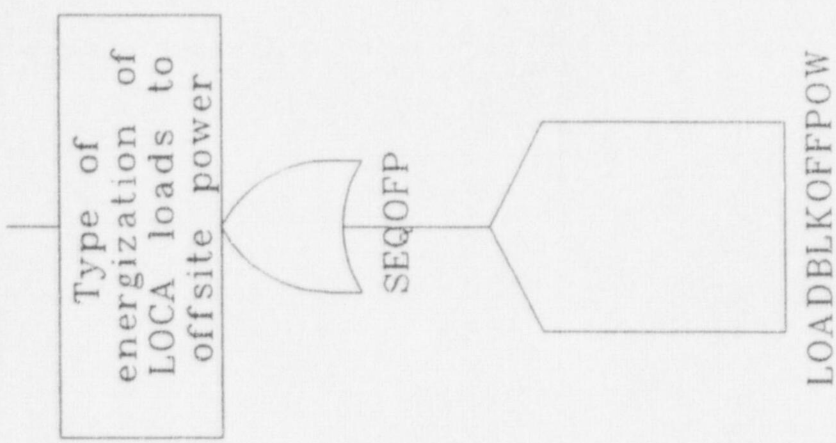
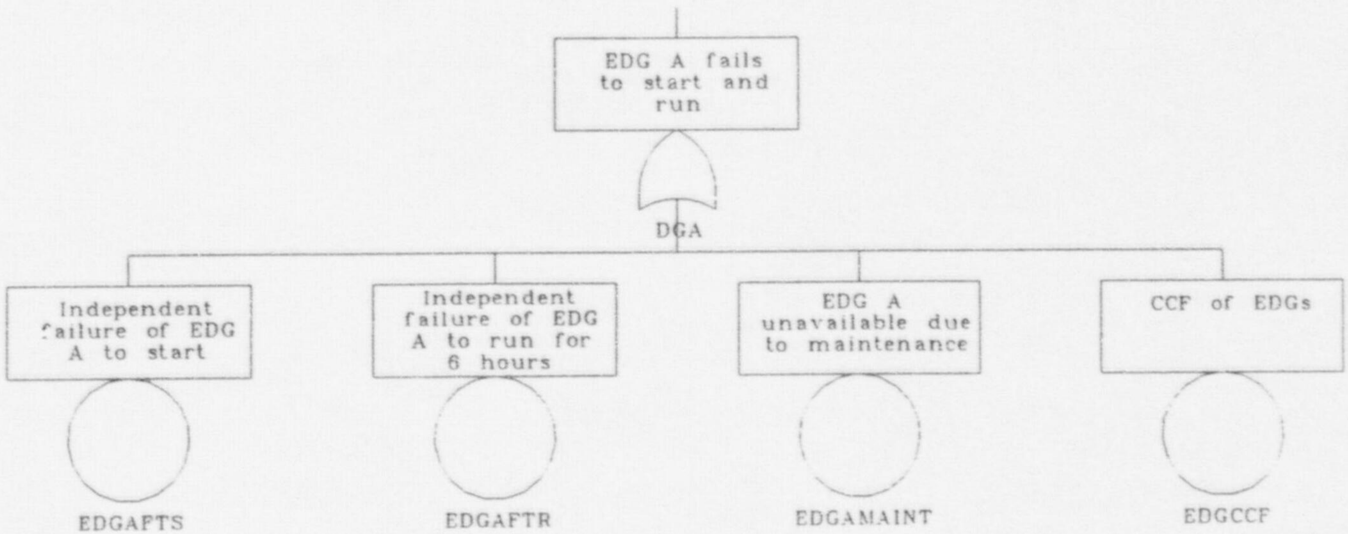
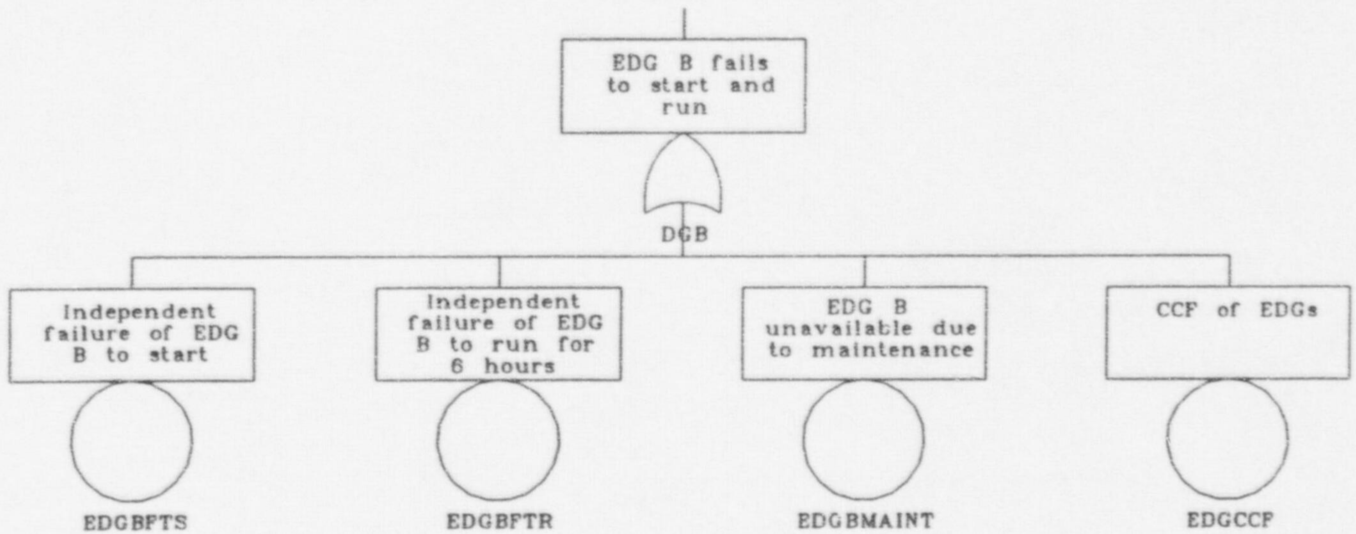
APPENDIX A

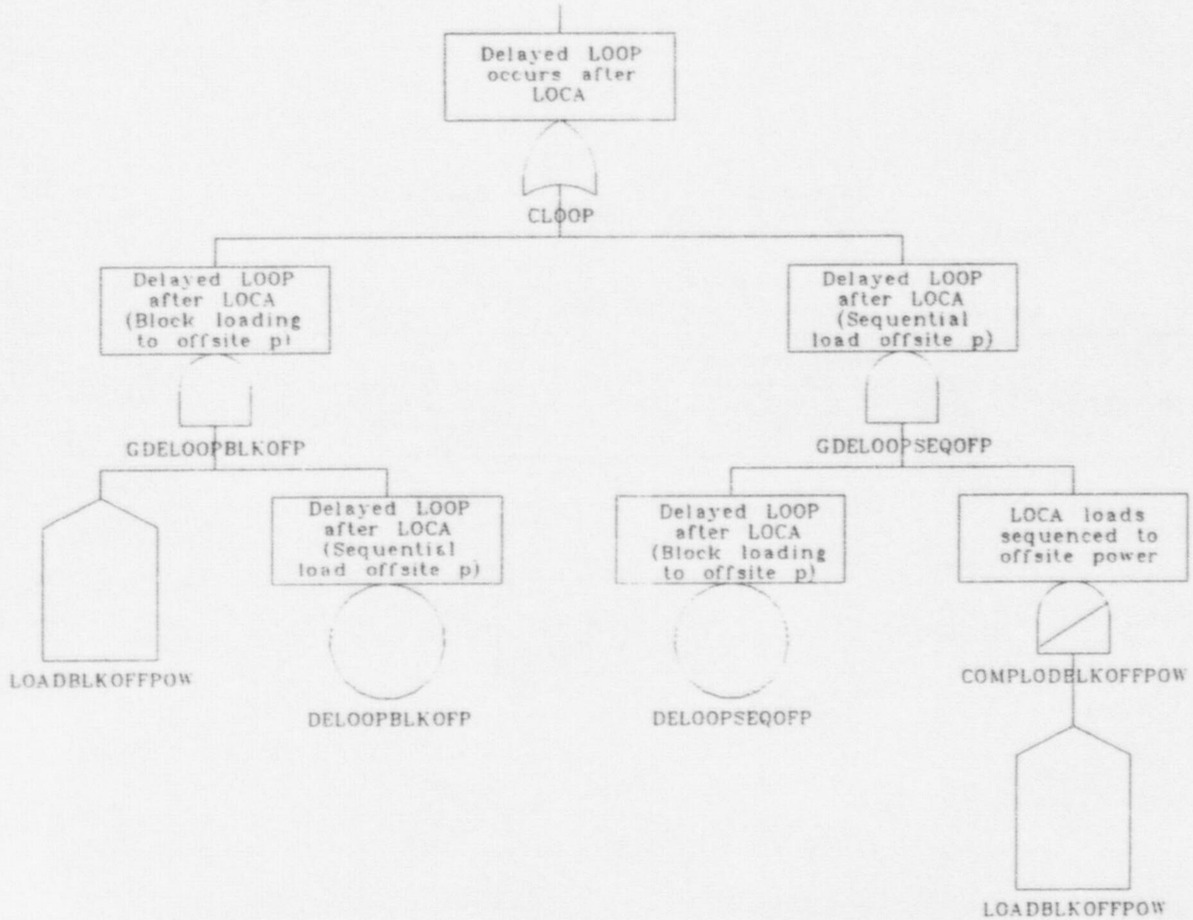
FAULT TREES USED TO QUANTIFY LOCA/LOOP SEQUENCES

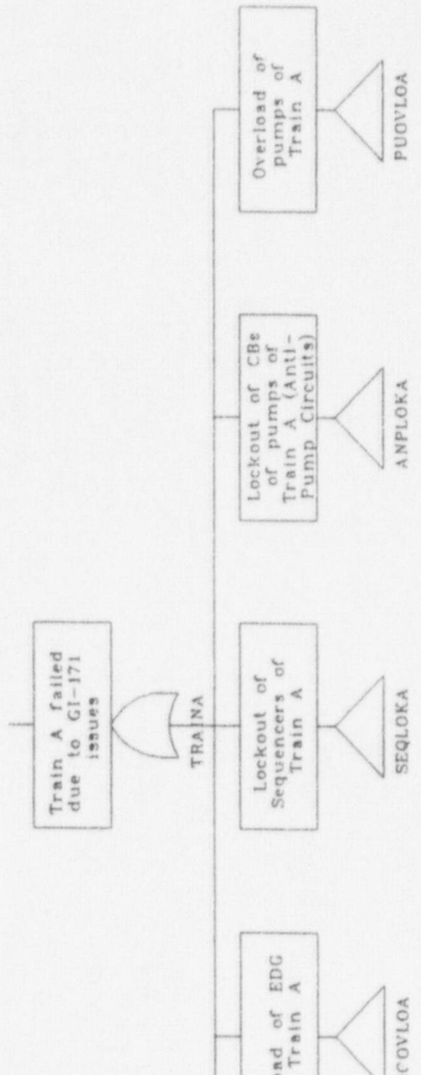
This appendix presents the fault trees developed to quantify the LOCA/LOOP accident sequences using the event trees discussed in Chapter 6 of the main text.

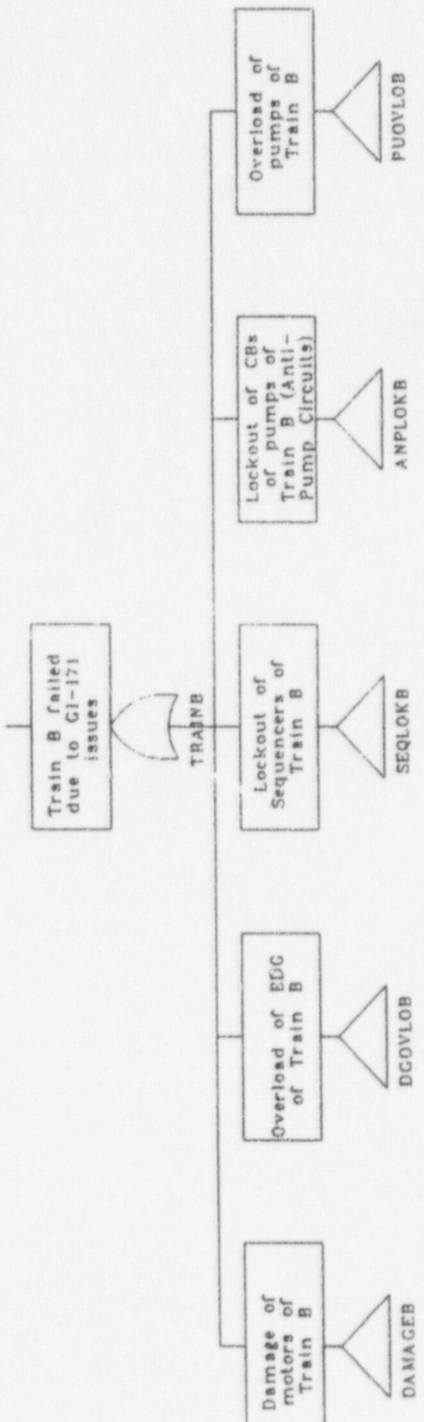

Type of energization of LOCA loads to offsite power
SEQOFP
LOADBLKOFFPOW

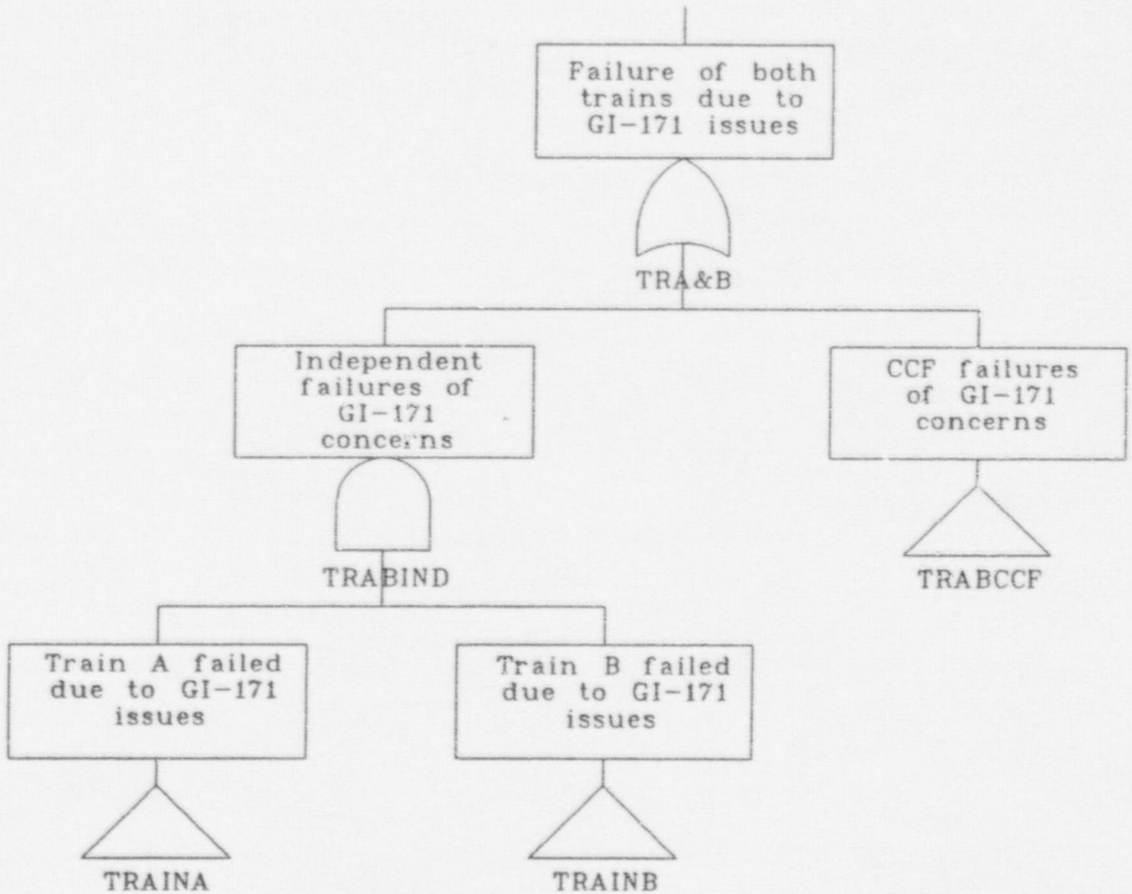

EDG A fails to start and run
DGA
Independent failure of EDG A to start
Independent failure of EDG A to run for 6 hours
EDG A unavailable due to maintenance
CCF of EDGs
EDGAFTS
EDGAFTR
EDGAMAINT
EDGCCF

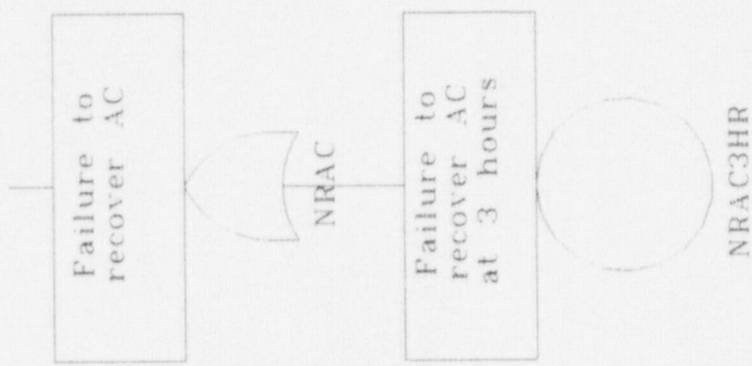

EDG B fails to start and run
DGB
Independent failure of EDG B to start
Independent failure of EDG B to run for 6 hours
EDG B unavailable due to maintenance
CCF of EDGs
EDGBFTS
EDGBFTR
EDGBMAINT
EDGCCF

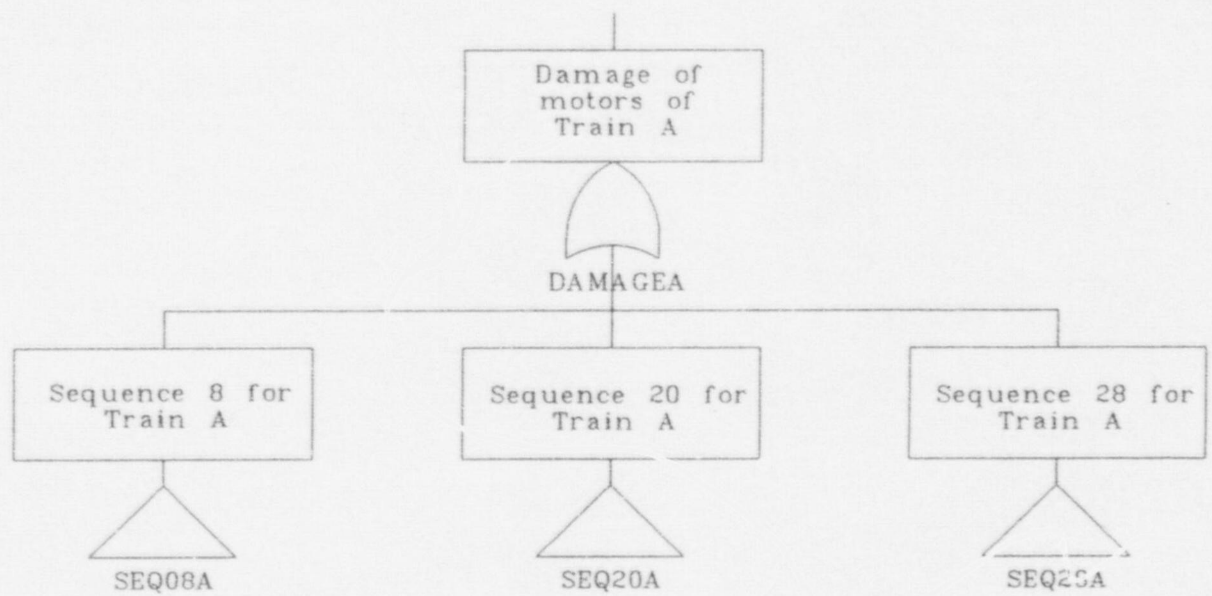

Delayed LOOP occurs after LOCA
CLOOP
Delayed LOOP after LOCA (Block loading to offsite p)
GDELOOPBLKOFP
Delayed LOOP after LOCA (Sequential load offsite p)
GDELOOPSEQOFP
LOADBLKOFFPOW
Delayed LOOP after LOCA (Sequential load offsite p)
DELOOPBLKOFP
Delayed LOOP after LOCA (Block loading to offsite p)
DELOOPSEQOFP
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW

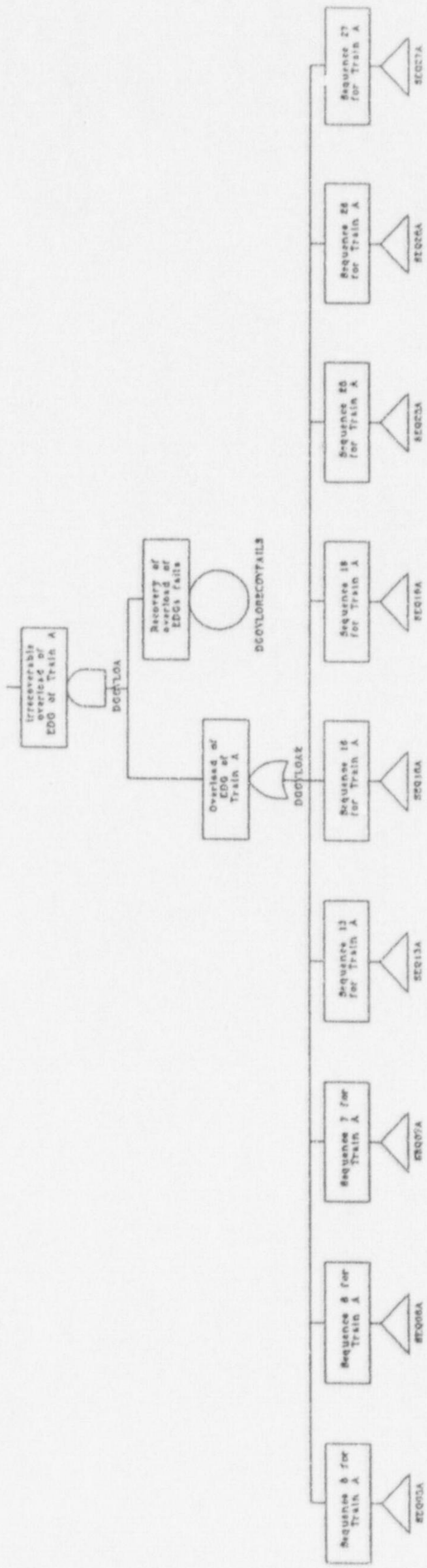

Train A failed due to GI-171 issues
TRAINA
Damage of motors of Train A
DAMAGEA
Overload of EDG of Train A
DGOVLOA
Lockout of Sequencers of Train A
SEQLOKA
Lockout of CBs of pumps of Train A (Anti-Pump Circuits)
ANPLOKA
Overload of pumps of Train A
PUOVLOA

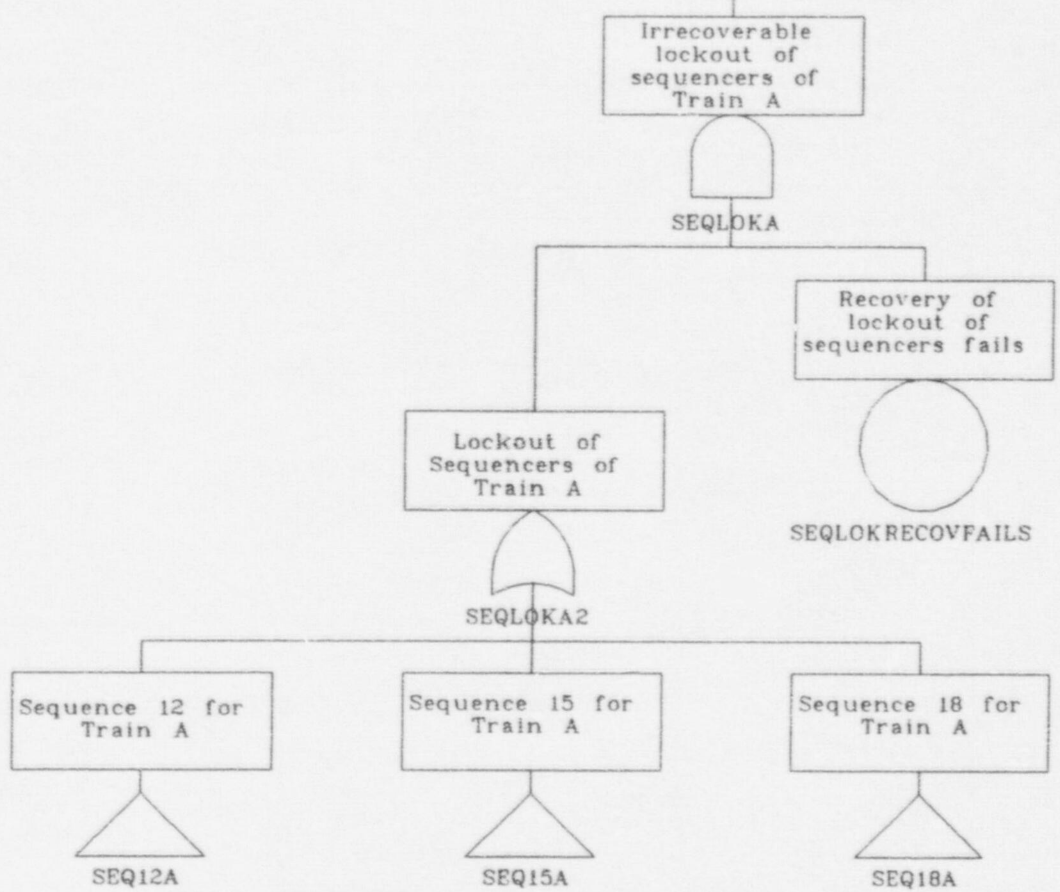

Train B failed due to GI-171 issues
TRAINB
Damage of motors of Train B
DAMAGEB
Overload of EDG of Train B
DGOVLOB
Lockout of Sequencers of Train B
SEQLOKB
Lockout of CBs of pumps of Train B (Anti-Pump Circuits)
ANPLOKB
Overload of pumps of Train B
PUOVLOB

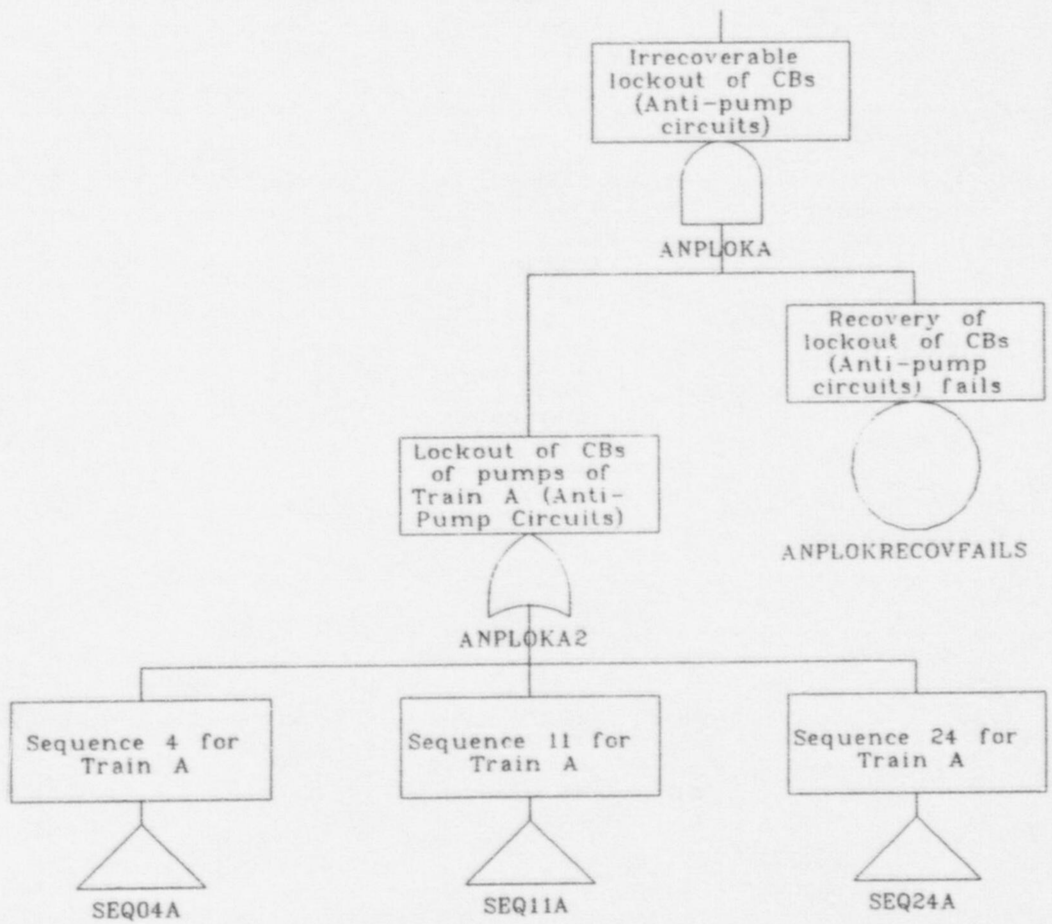

Failure of both trains due to GI-171 issues
TRA&B
Independent failures of GI-171 concerns
CCF failures of GI-171 concerns
TRABIND
TRABCCF
Train A failed due to GI-171 issues
Train B failed due to GI-171 issues
TRAINA
TRAINB

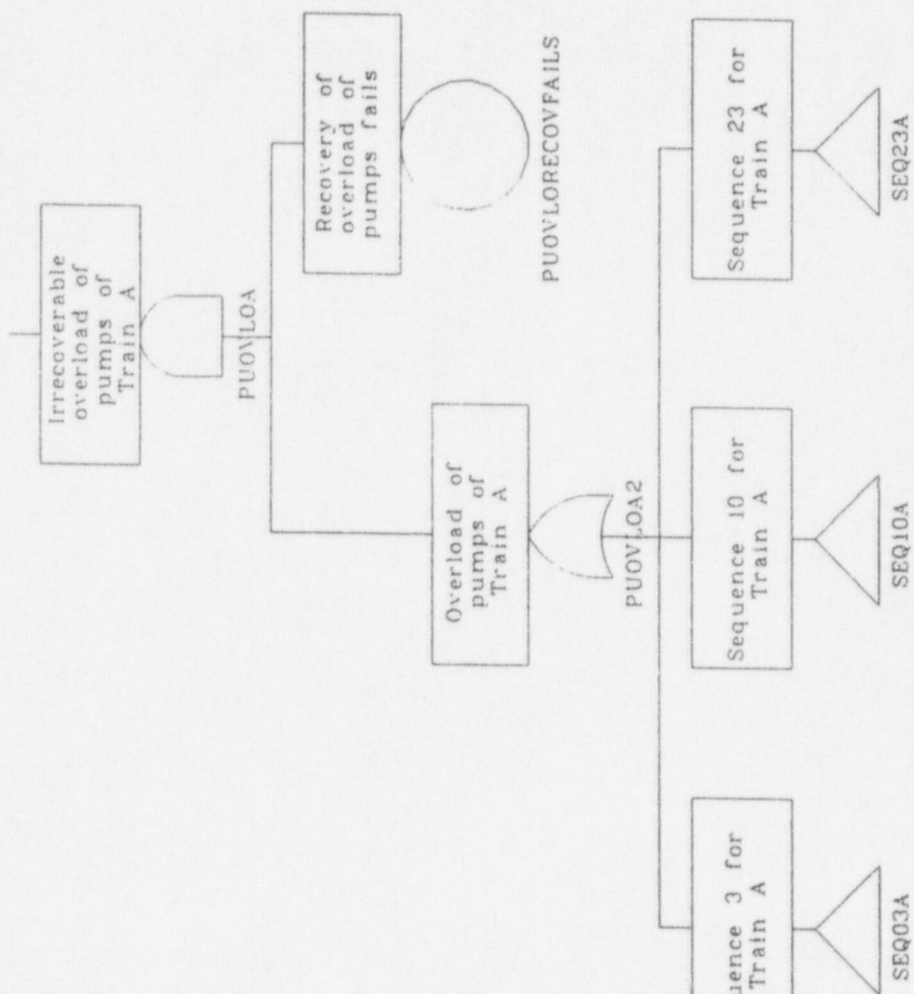

Failure to recover AC
NRAC
Failure to recover AC at 3 hours
NRAC3HR


Damage of motors of Train A
DAMAGEA
Sequence 8 for Train A
Sequence 20 for Train A
Sequence 28 for Train A
SEQ08A
SEQ20A
SEQ28A

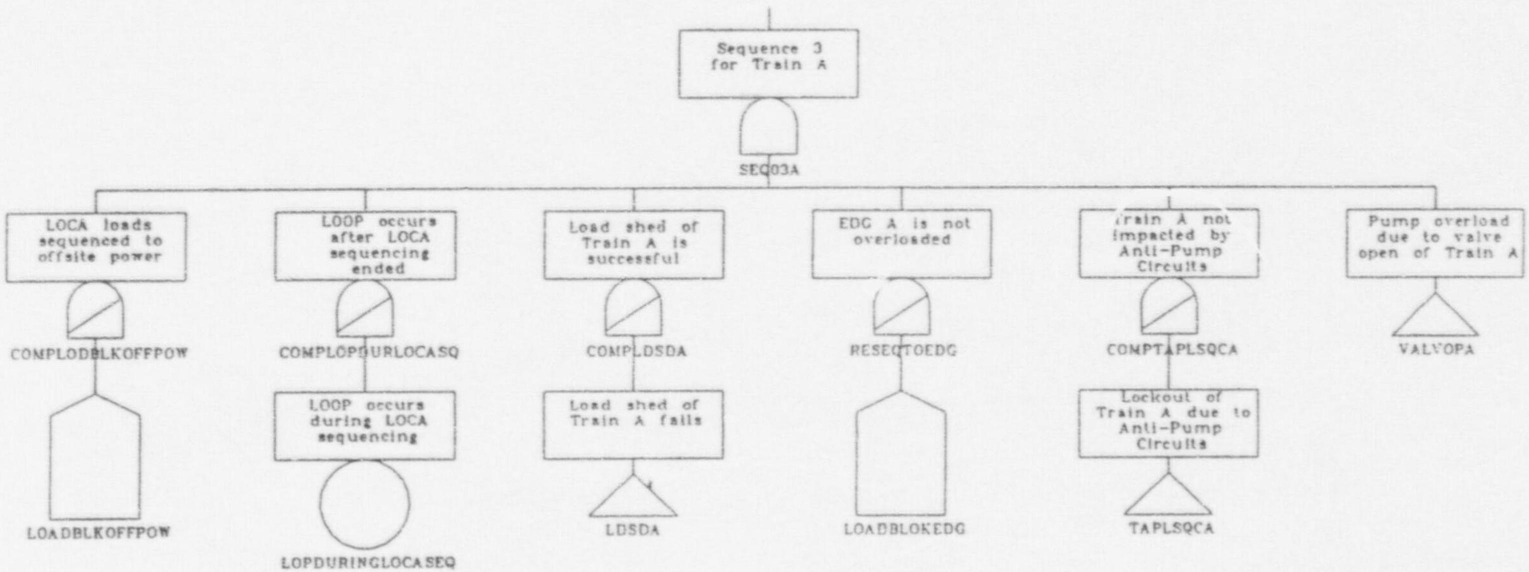

Irrecoverable overload of EDG of Train A
DGOVLOA
Recovery of overload of EDGs fails
DGOVLORECOVFAILS
Overload of EDG of Train A
DGOVLOAR
Sequence 7 for Train A

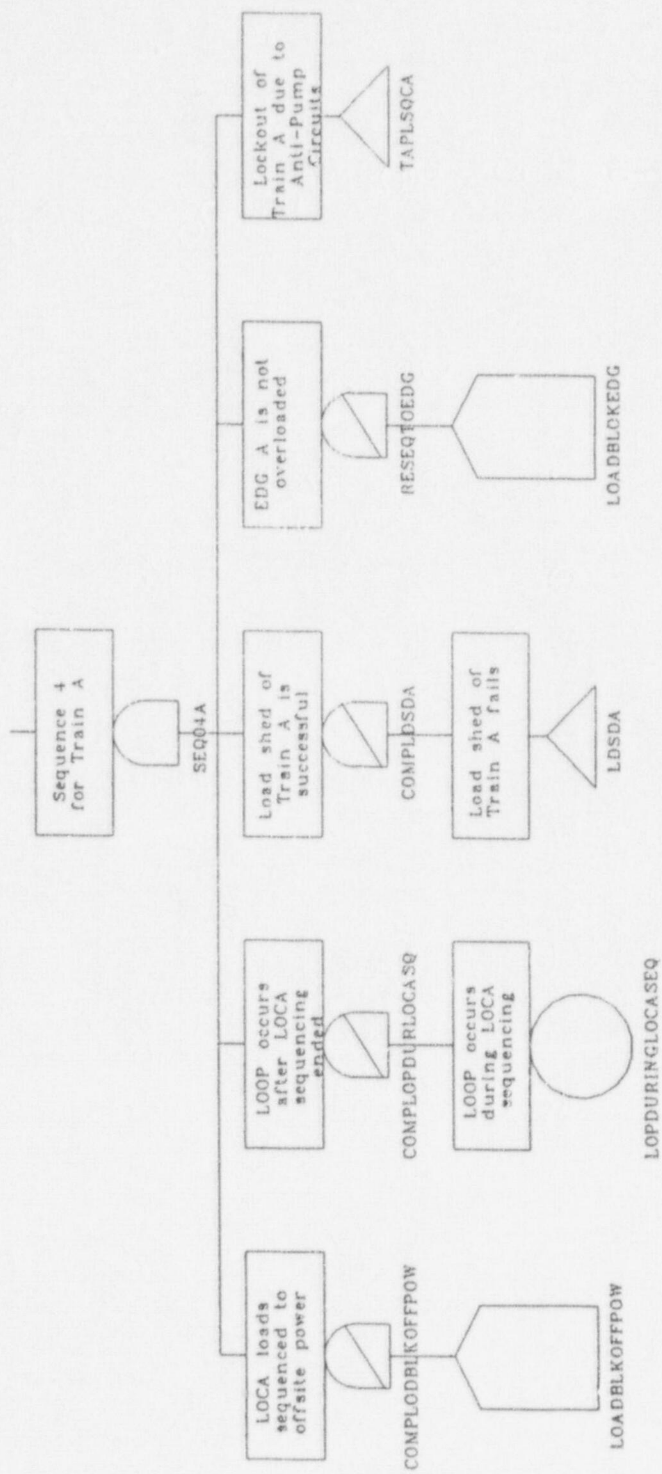

Irrecoverable lockout of sequencers of Train A
SEQLOKA
Recovery of lockout of sequencers fails
SEQLOKRECOVFAILS
Lockout of Sequencers of Train A
SEQLOKA2
Sequence 12 for Train A
SEQ12A
Sequence 15 for Train A
SEQ15A
Sequence 18 for Train A
SEQ18A

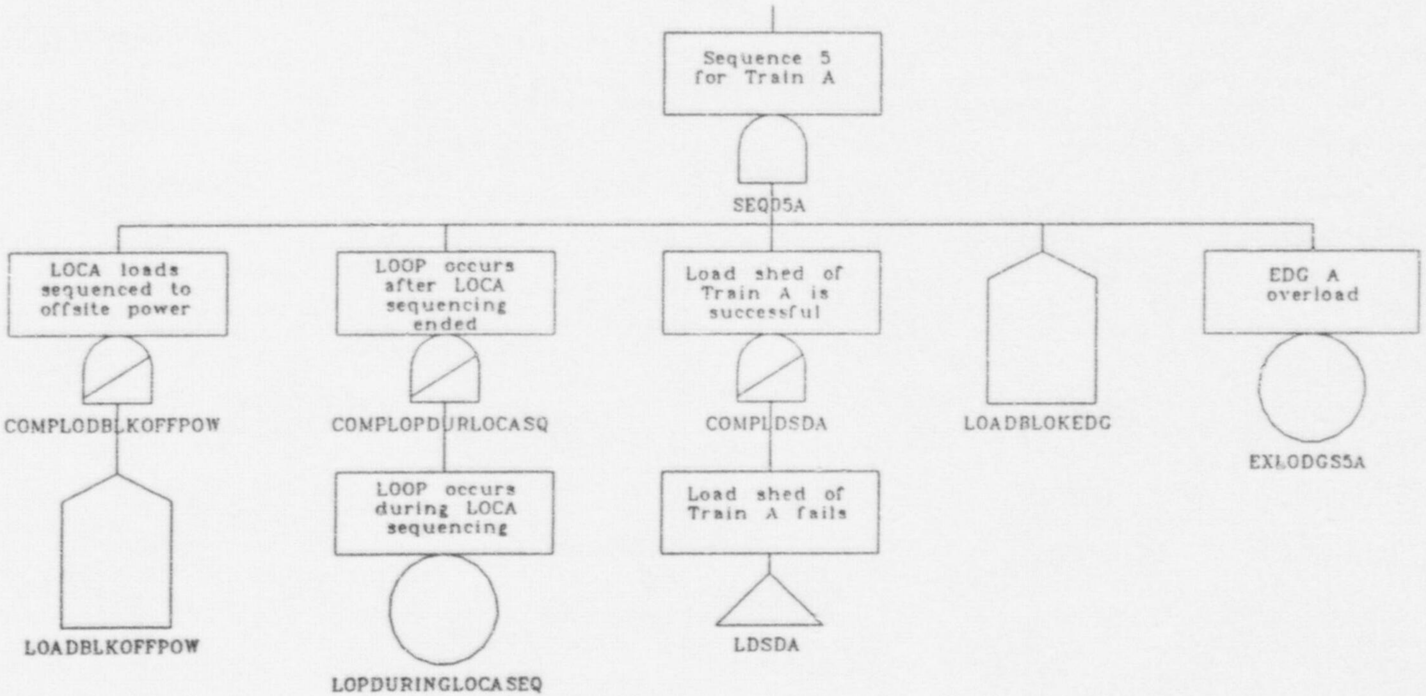

Irrecoverable lockout of CBs (Anti-pump circuits)
ANPLOKA
Lockout of CBs of pumps of Train A (Anti-Pump Circuits)
Recovery of lockout of CBs (Anti-pump circuits) fails
ANPLOKRECOVFAILS
ANPLOKA2
Sequence 4 for Train A
Sequence 11 for Train A
Sequence 24 for Train A
SEQ04A
SEQ11A
SEQ24A

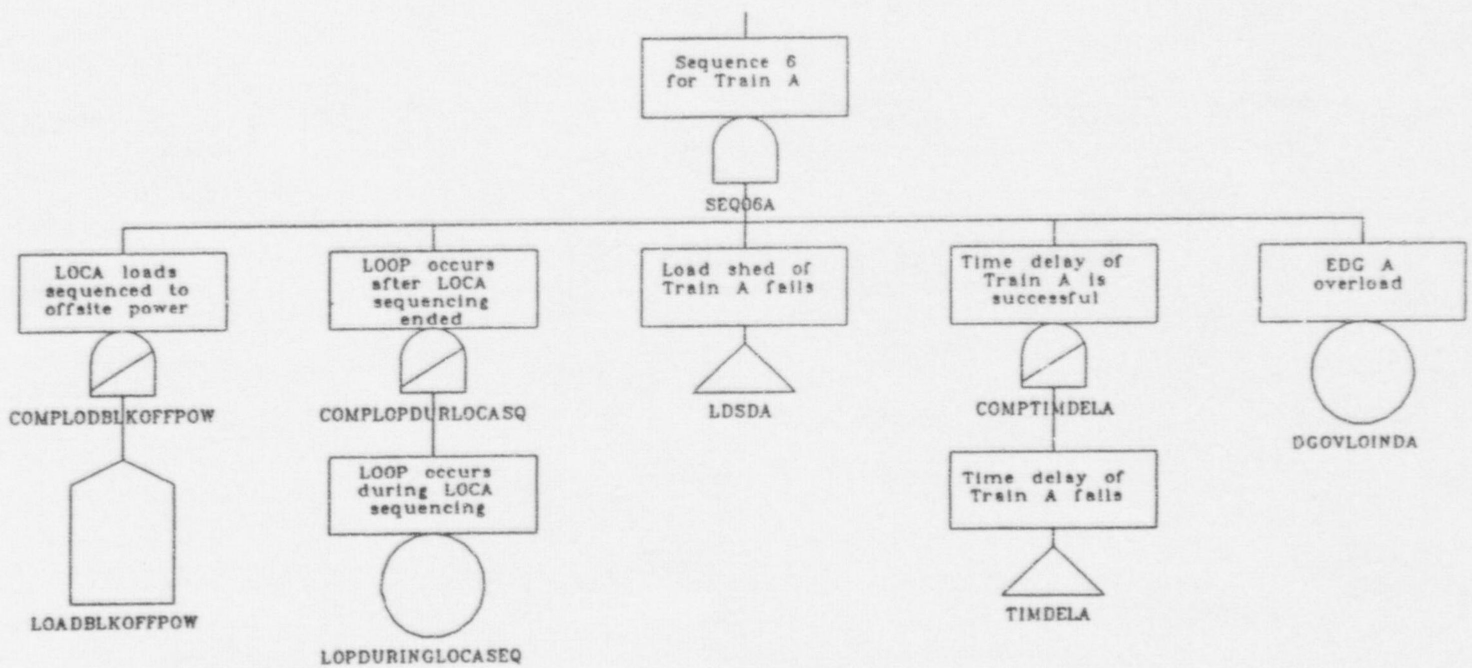


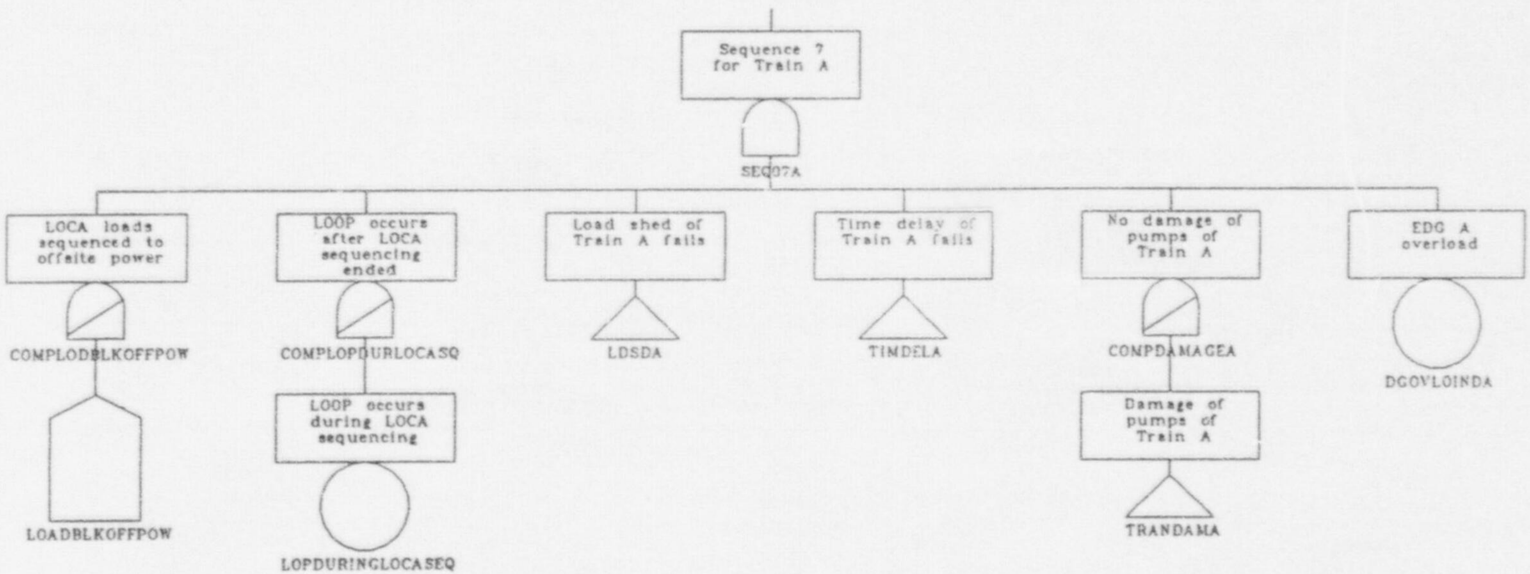
Irrecoverable overload of pumps of Train A
PUOVLOA
Recovery of overload of pumps fails
PUOVLORECOVFAILS
Overload of pumps of Train A
PUOVLOA2
Sequence 3 for Train A
SEQ03A
Sequence 10 for Train A
SEQ10A
Sequence 23 for Train A
SEQ23A

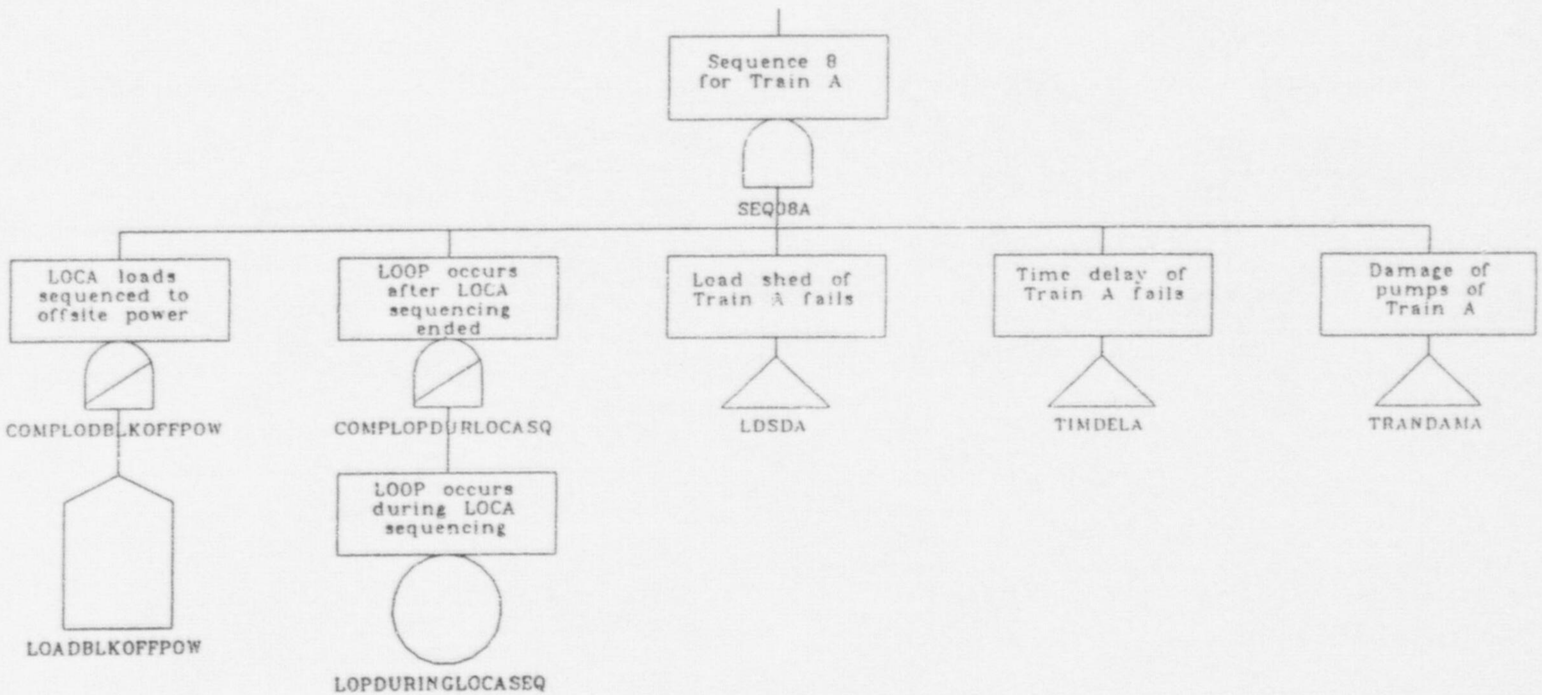

Sequence 3 for Train A
SEQ03A
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASQ
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train A is successful
COMPLDSDA
Load shed of Train A fails
LDSDA
EDG A is not overloaded
RESEQTOEDG
LOADBLOKEDG
Train A not impacted by Anti-Pump Circuits
COMPTAPLSQCA
Lockout of Train A due to Anti-Pump Circuits
TAPLSQCA
Pump overload due to valve open of Train A
VALVOPA

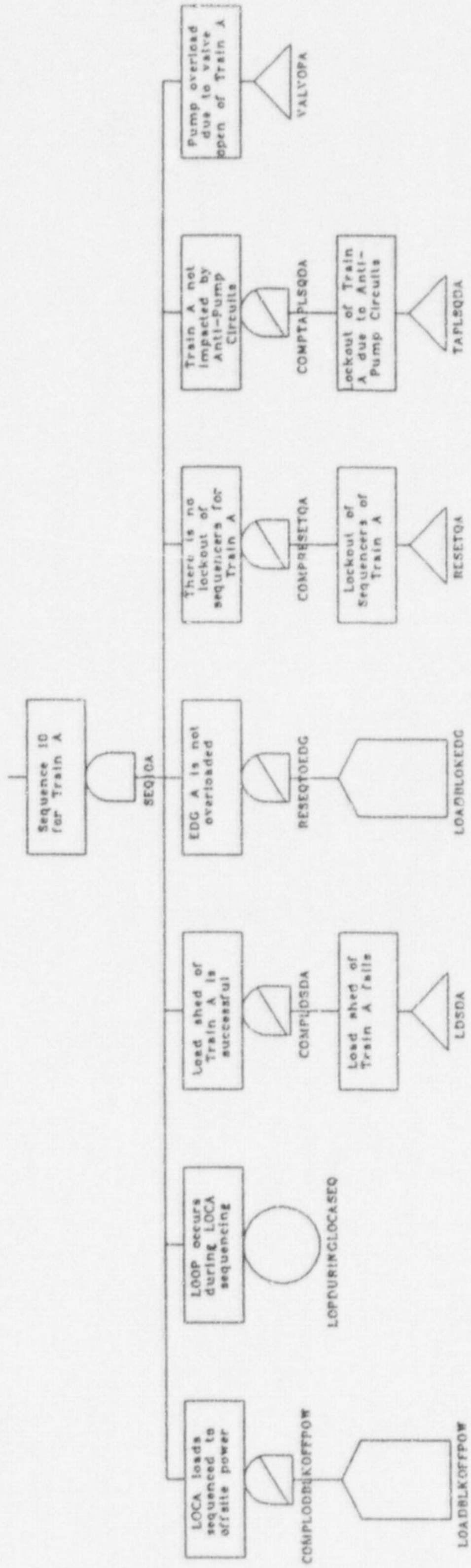

Sequence 4 for Train A
SEQ04A
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASEQ
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train A is successful
COMPLDSDA
Load shed of Train A fails
LDSDA
EDG A is not overloaded
RESEQTOEDG
LOADBLOKEDG
Lockout of Train A due to Anti-Pump Circuits
TAPLSQCA


Sequence 5 for Train A
SEQ05A
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASQ
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train A is successful
COMPLDSDA
Load shed of Train A fails
LDSDA
LOADBLOKEDG
EDG A overload
EXLODGS5A

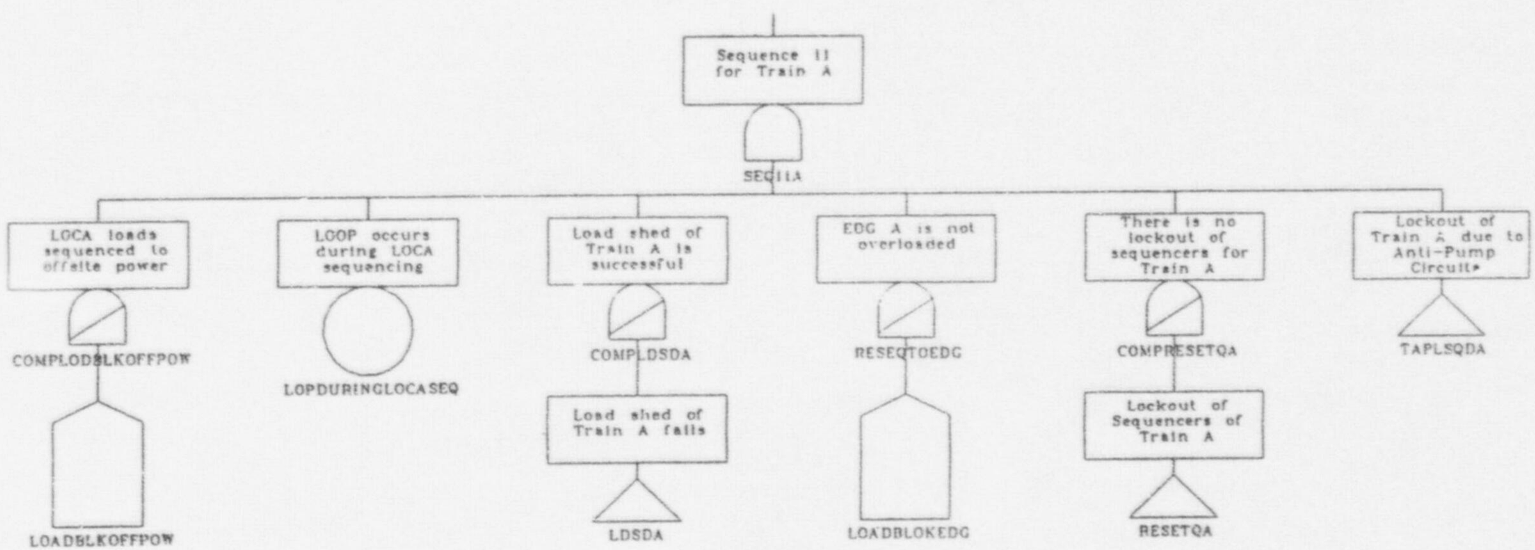

Sequence 6 for Train A
SEQ06A
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASQ
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train A fails
LDSDA
Time delay of Train A is successful
COMPTIMDELA
Time delay of Train A fails
TIMDELA
EDG A overload
DGOVLOINDA

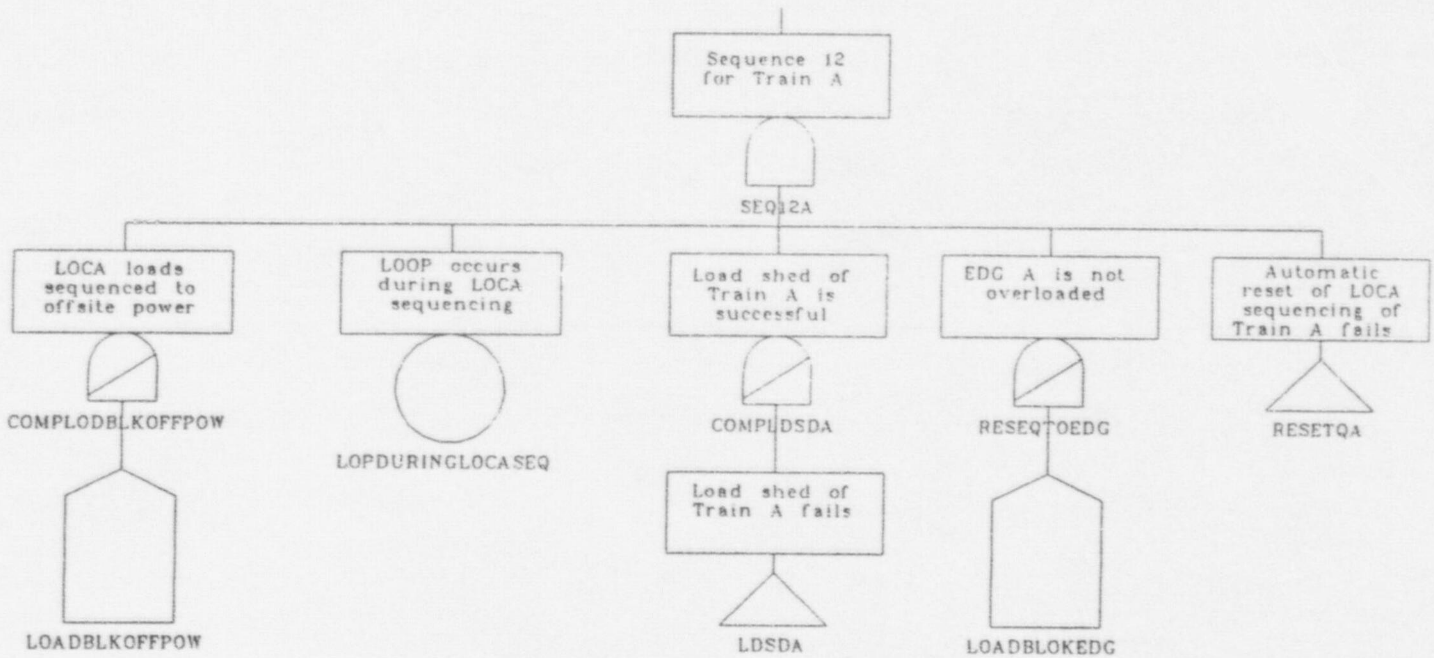

Sequence 7
for Train A
SEQ07A
LOCA loads
sequenced to
offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs
after LOCA
sequencing
ended
COMPLOPDURLOCASQ
LOOP occurs
during LOCA
sequencing
LOPDURINGLOCASEQ
Load shed of
Train A fails
LDSDA
Time delay of
Train A fails
TIMDELA
No damage of
pumps of
Train A
COMPDAMAGEA
Damage of
pumps of
Train A
TRANDAMA
EDG A
overload
DGOVLOINDA

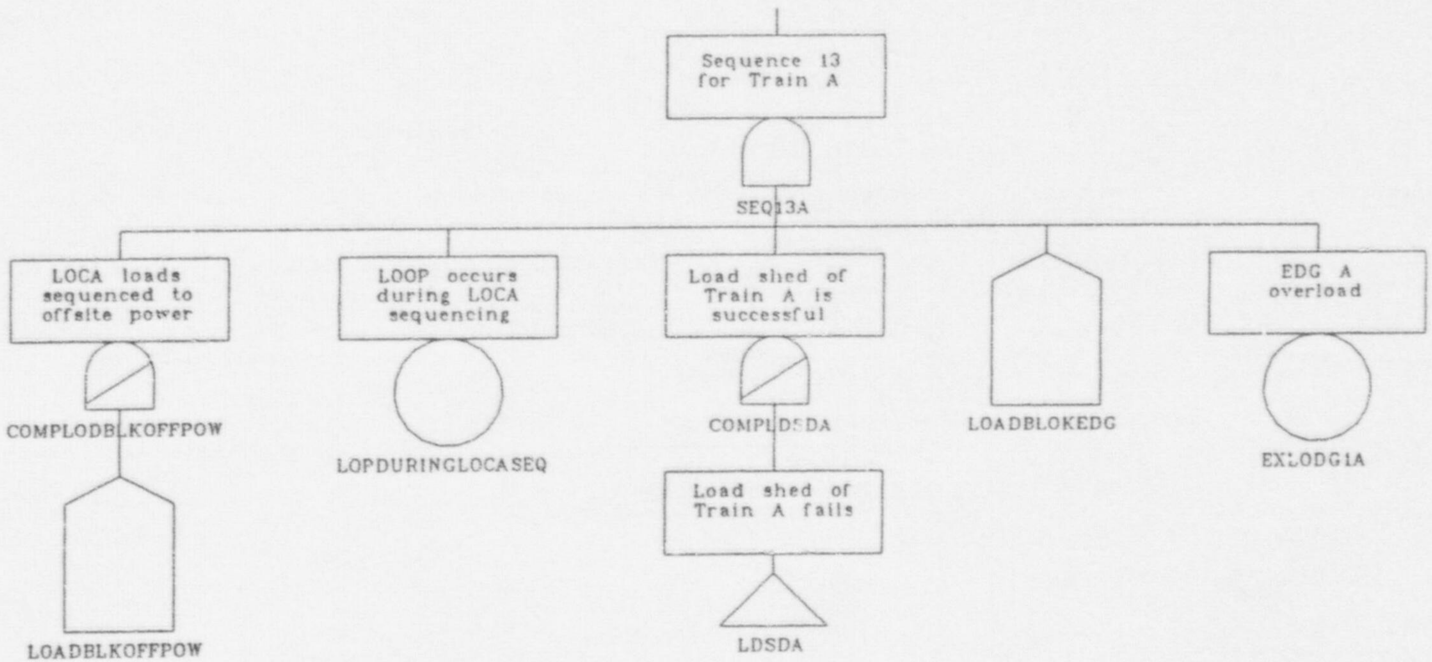

Sequence 8 for Train A
SEQ08A
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASQ
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train A fails
LDSDA
Time delay of Train A fails
TIMDELA
Damage of pumps of Train A
TRANDAMA

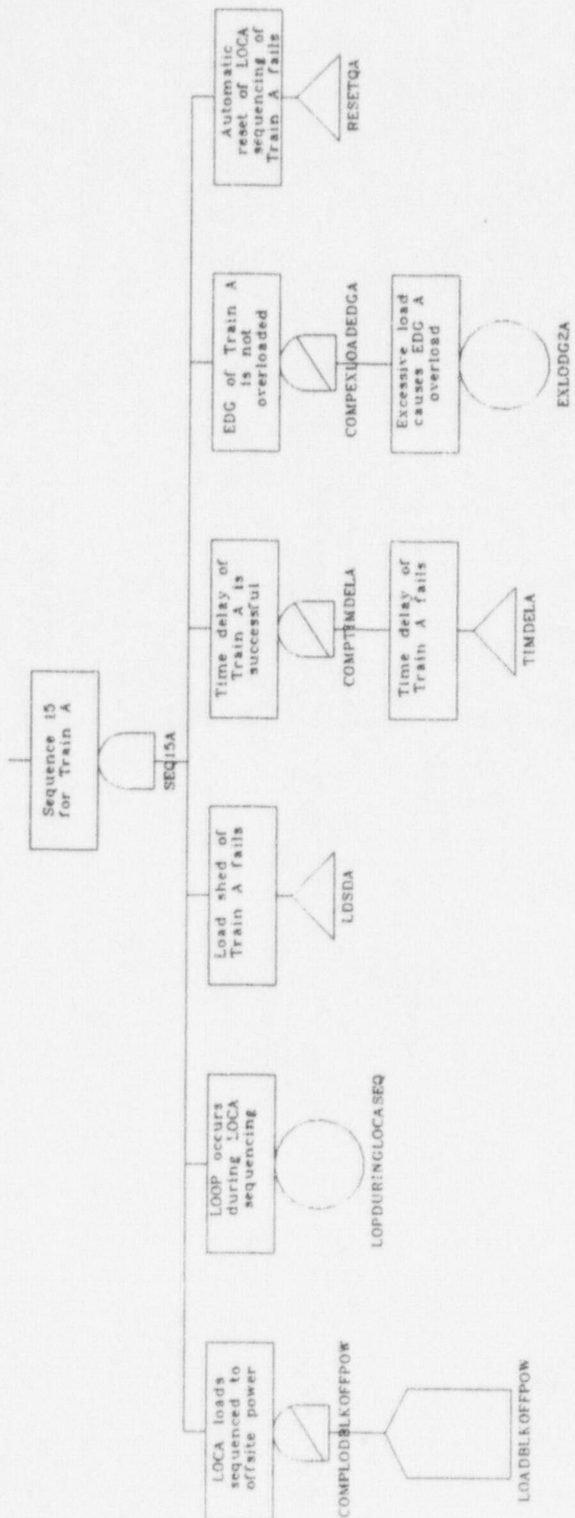


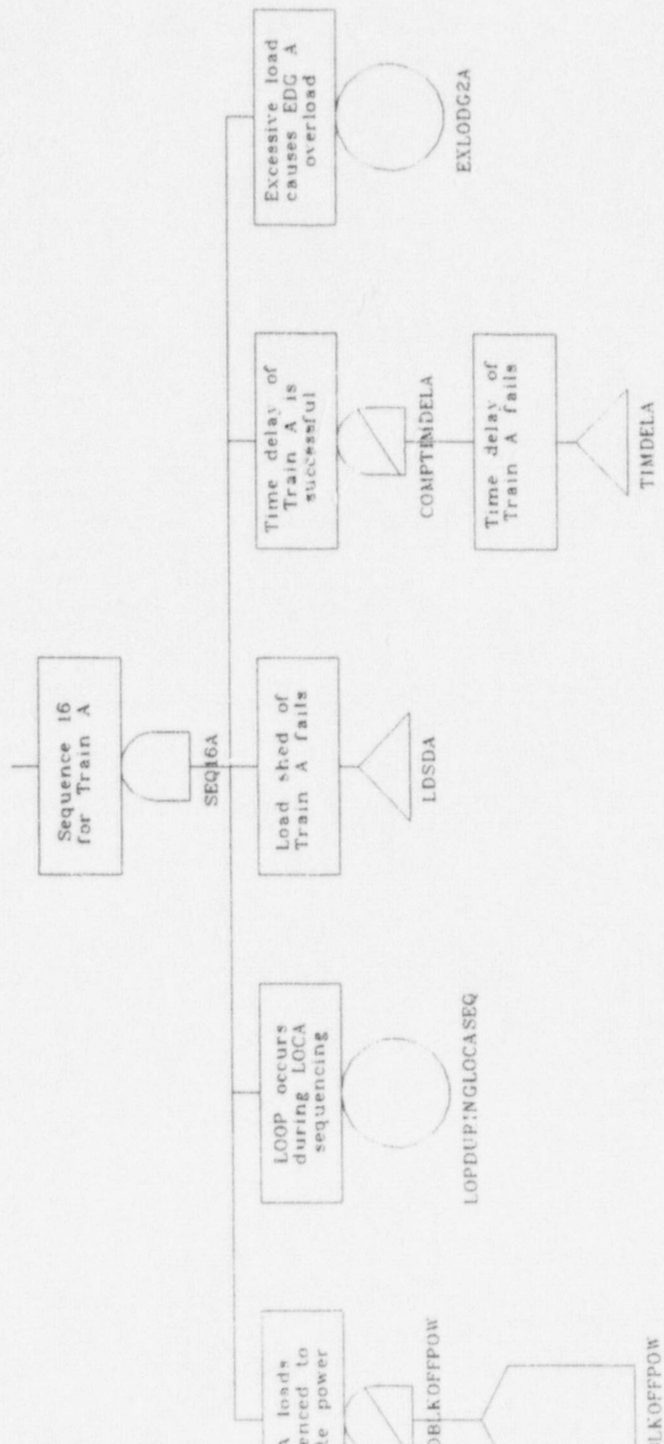
Sequence 10 for Train A
SEQ10A
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train A is successful
COMPLDSDA
Load shed of Train A fails
LDSDA
EDG A is not overloaded
RESEQ10EDG
LOADBLOKEDG
There is no lockout of sequencers for Train A
COMPRESETQA
Lockout of Sequencers of Train A
RESETQA
Train A not impacted by Anti-Pump Circuits
COMPTAPLSQQA
Lockout of Train A due to Anti-Pump Circuits
TAPLSQQA
Pump overload due to valve open of Train A
VALVOPA


Sequence II for Train A
SEQIIA
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train A is successful
COMPLDSDA
Load shed of Train A fails
LDSDA
EDG A is not overloaded
RESEQTOEDG
LOADBLOKEDG
There is no lockout of sequencers for Train A
COMPRESETQA
Lockout of Sequencers of Train A
RESETQA
Lockout of Train A due to Anti-Pump Circuits
TAPLSQDA

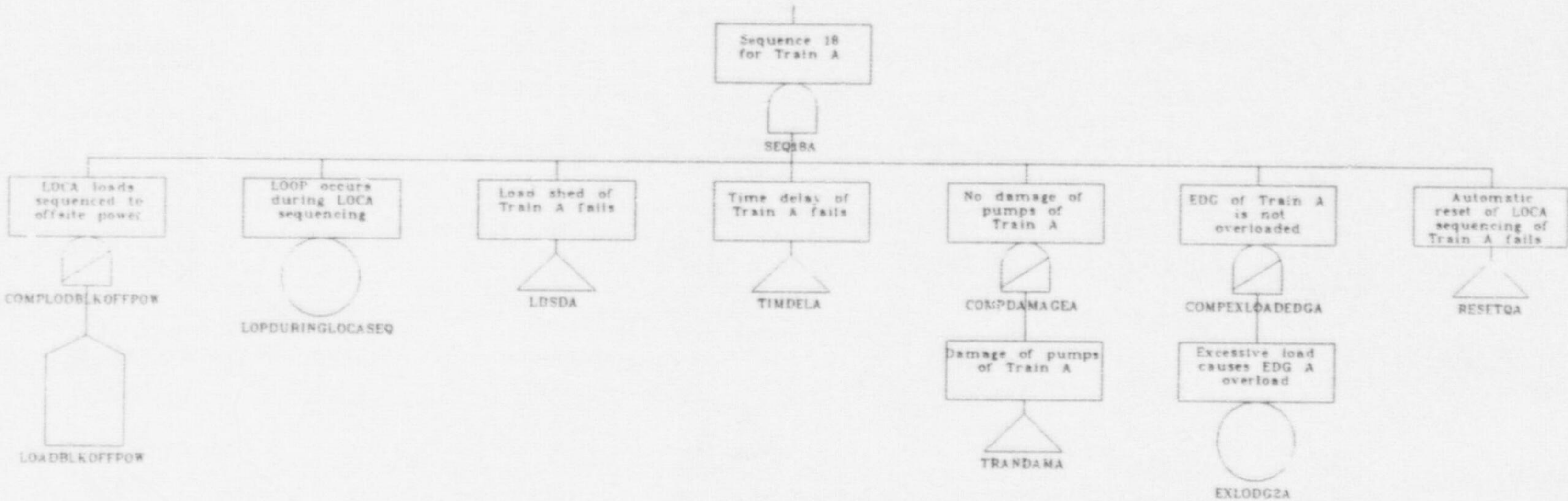

Sequence 12 for Train A
SEQ12A
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train A is successful
COMPLDSDA
Load shed of Train A fails
LDSDA
EDG A is not overloaded
RESEQTOEDG
LOADBLOKEDG
Automatic reset of LOCA sequencing of Train A fails
RESETQA

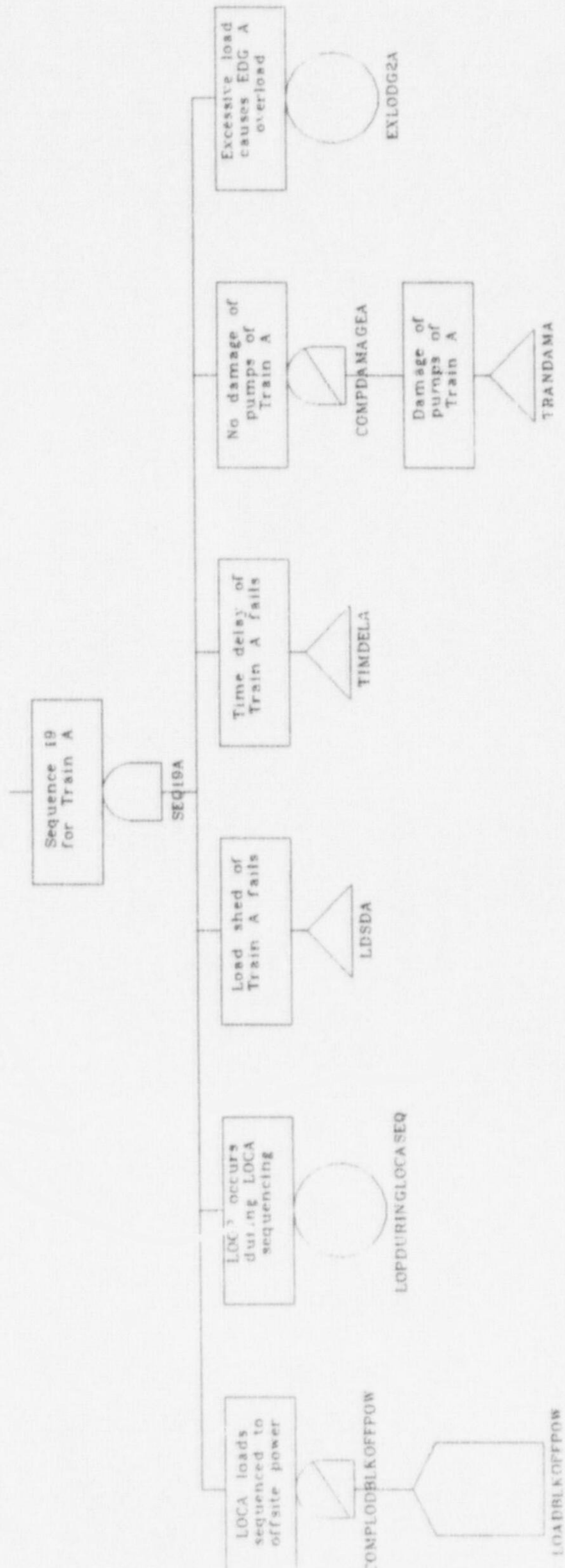

Sequence 13 for Train A
SEQ13A
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train A is successful
COMPLDSDA
Load shed of Train A fails
LDSDA
LOADBLOKEDG
EDG A overload
EXLODG1A


Sequence 15 for Train A
SEQ15A
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train A fails
LDSDA
Time delay of Train A is successful
COMPTIMDELA
Time delay of Train A fails
TIMDELA
EDG of Train A is not overloaded
COMPEXLOADEDGA
Excessive load causes EDG A overload
EXLODG2A
Automatic reset of LOCA sequencing of Train A fails
RESETQA

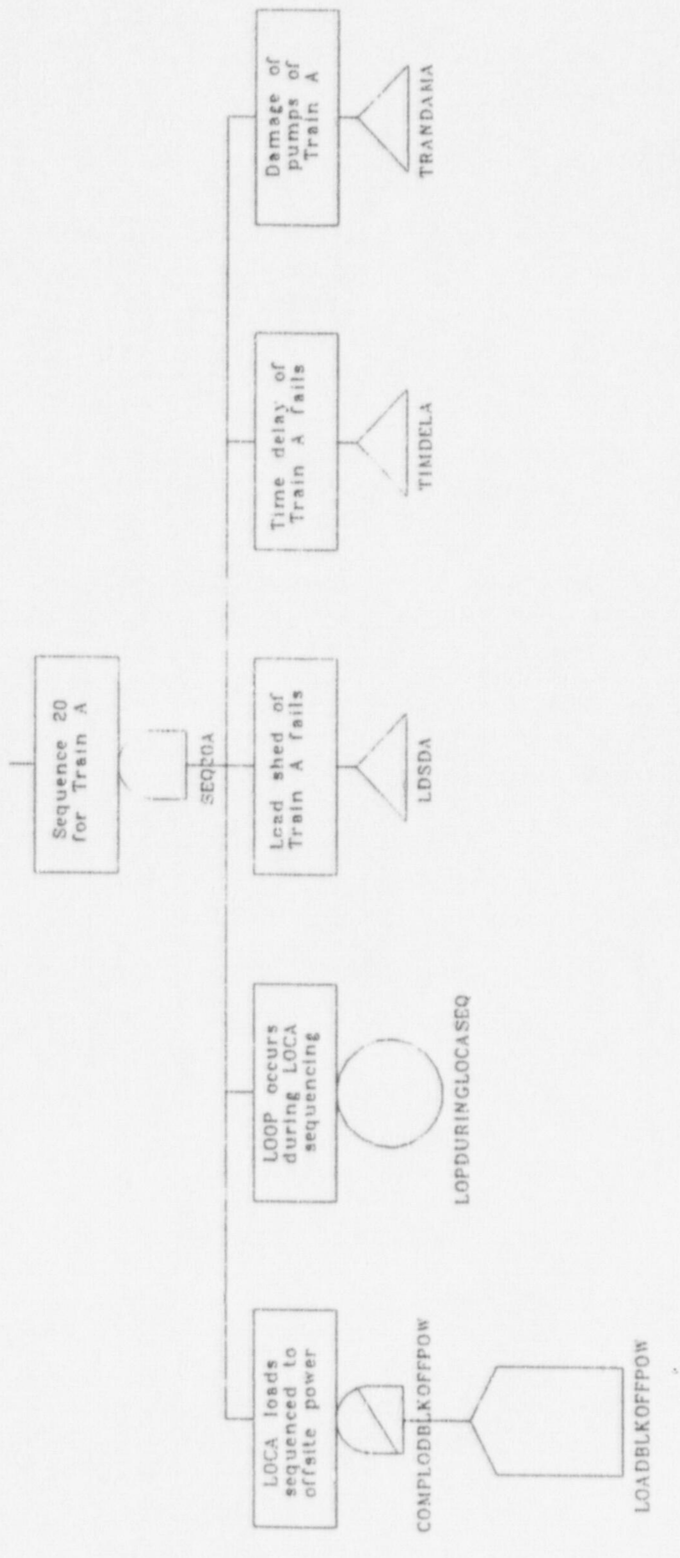


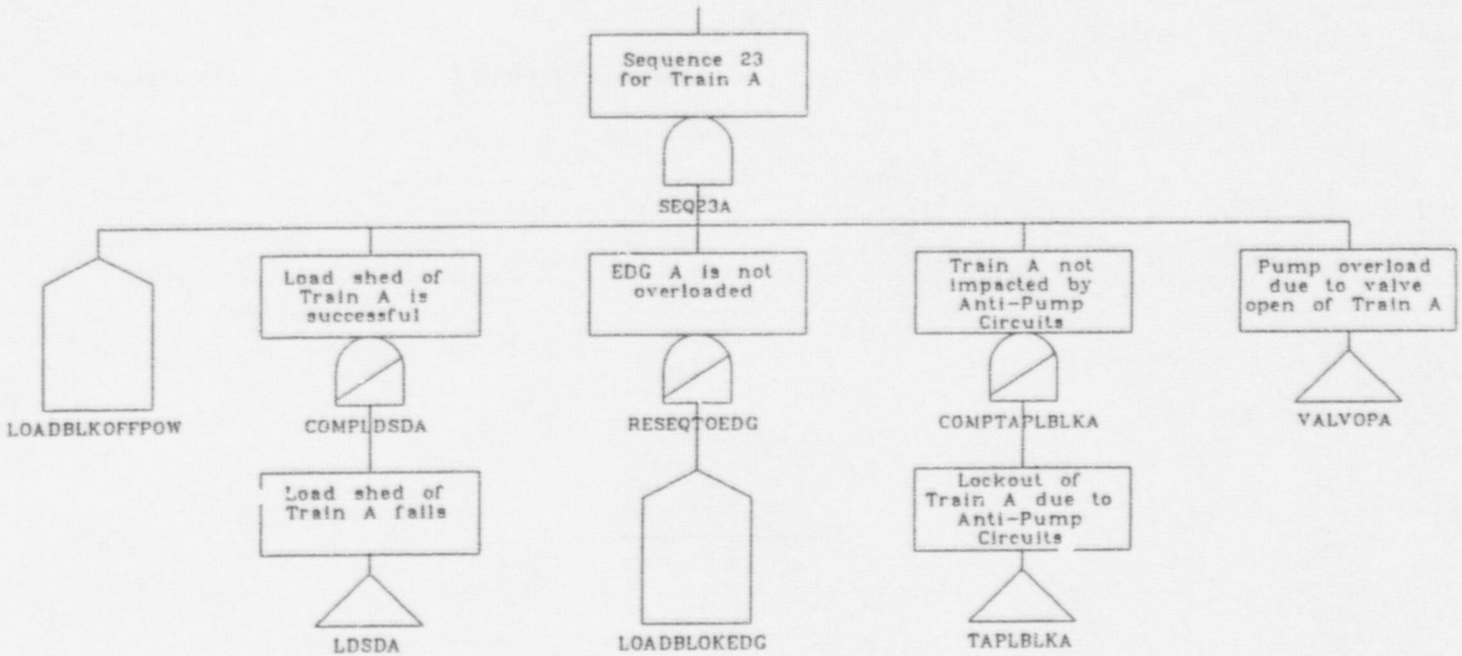
Sequence 16 for Train A
SEQ16A
LOCA loads sequenced to offsite power
CONPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDUPINGLOCASEQ
Load shed of Train A fails
LDSDA
Time delay of Train A is successful
COMPTIMDELA
Time delay of Train A fails
TIMDELA
Excessive load causes EDG A overload
EXLODG2A

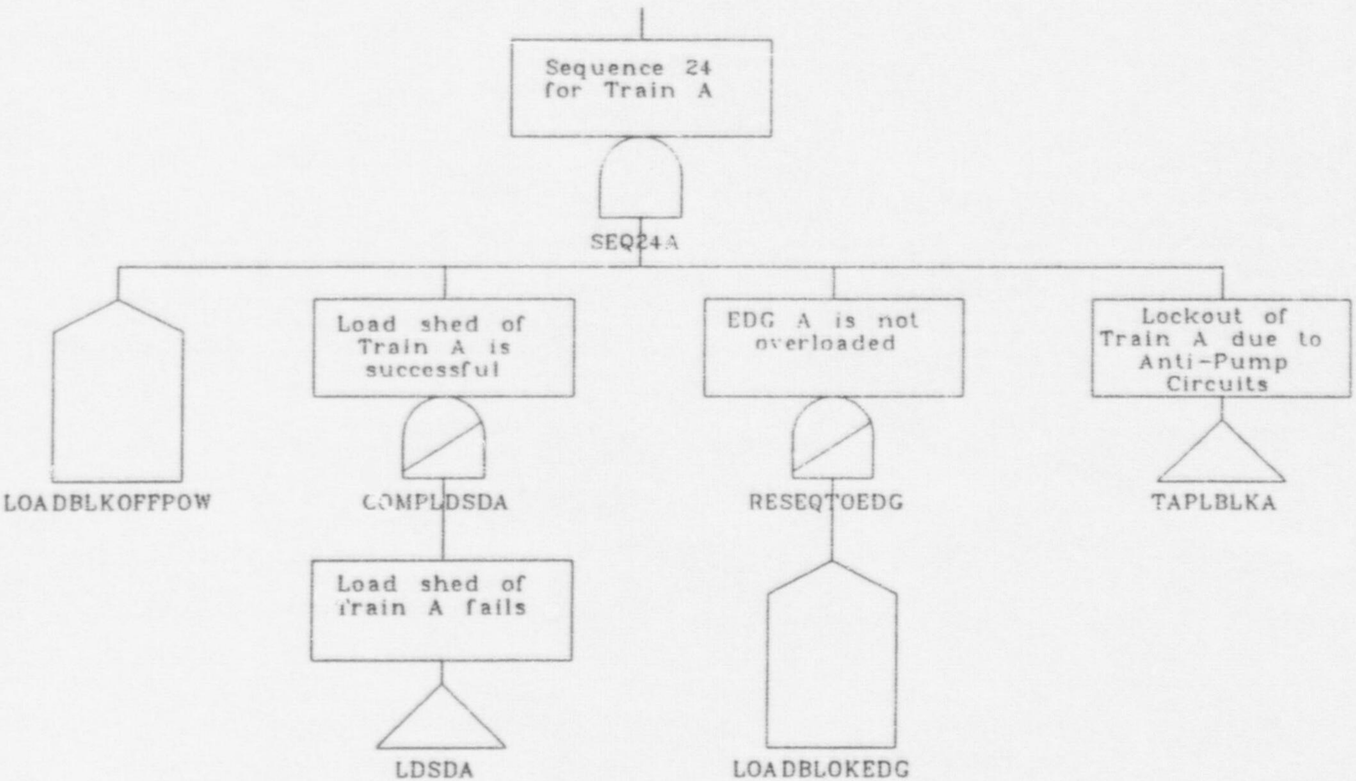

Sequence 18
for Train A
SEQ18A
LOCA loads
sequenced to
offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs
during LOCA
sequencing
LOPDURINGLOCASEQ
Load shed of
Train A fails
LDSDA
Time delay of
Train A fails
TIMDELA
No damage of
pumps of
Train A
COMPDAMAGEA
Damage of pumps
of Train A
TRANDAMA
EDG of Train A
is not
overloaded
COMPEXLOADEDGA
Excessive load
causes EDG A
overload
EXLODG2A
Automatic
reset of LOCA
sequencing of
Train A fails
RESETQA

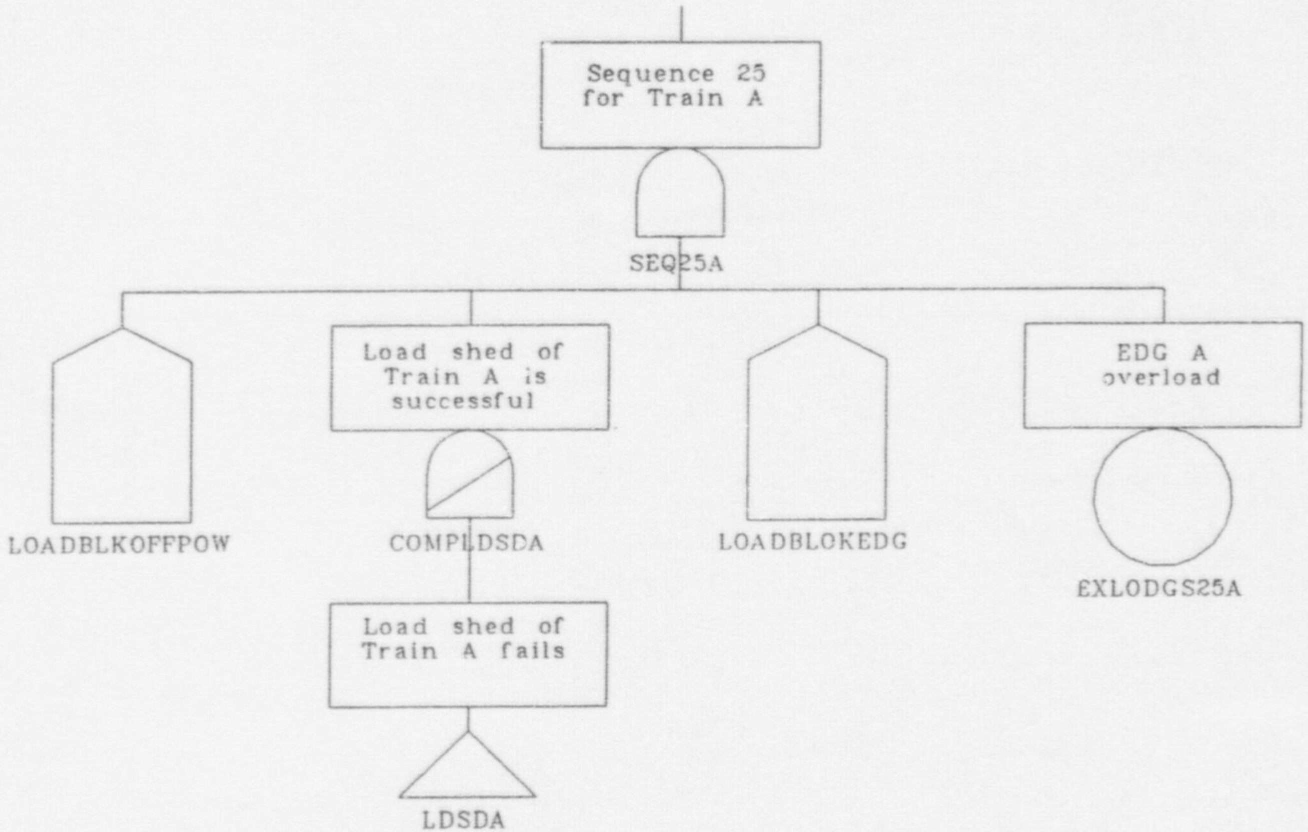


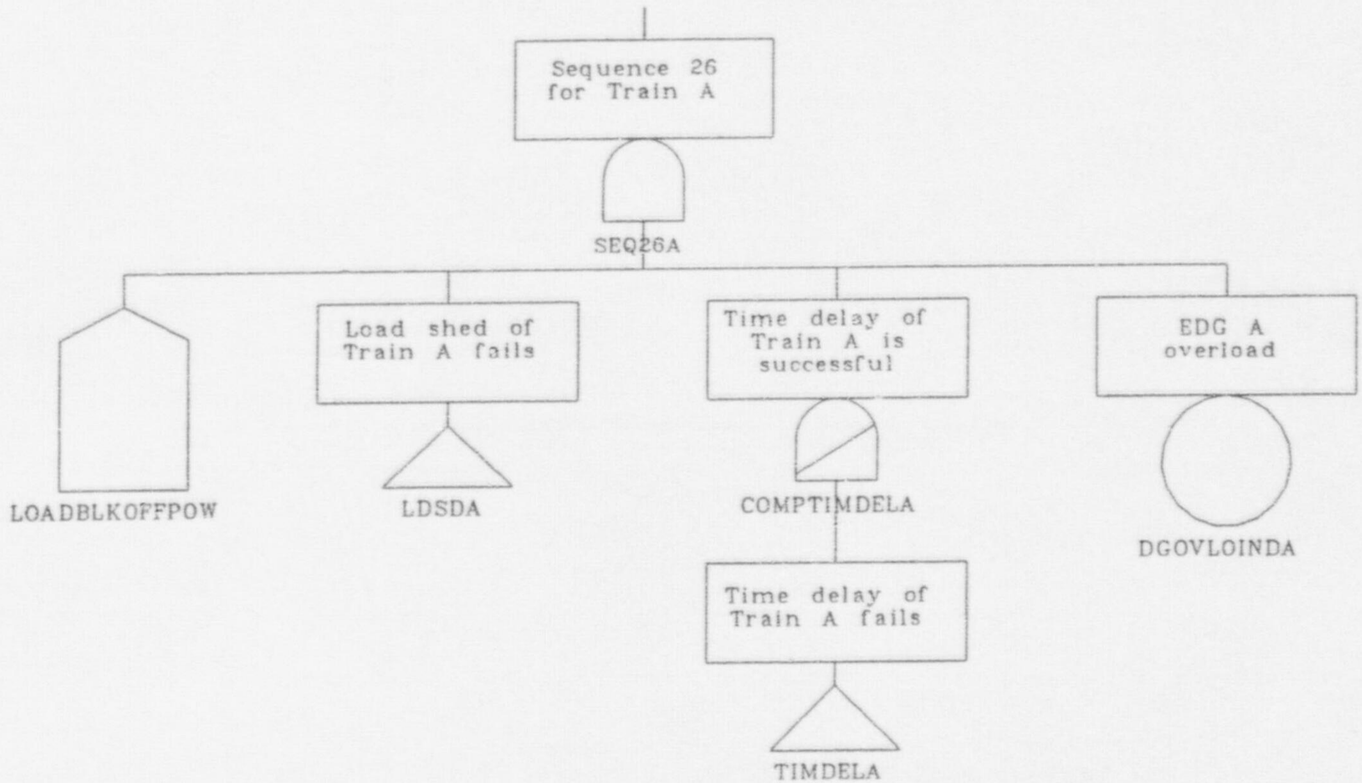
Sequence 19 for Train A
SEQ19A
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOCA occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train A fails
LDSDA
Time delay of Train A fails
TIMDELA
No damage of pumps of Train A
COMPDAMAGEA
Damage of pumps of Train A
TRANDAMA
Excessive load causes EDG A overload
EXLODG2A

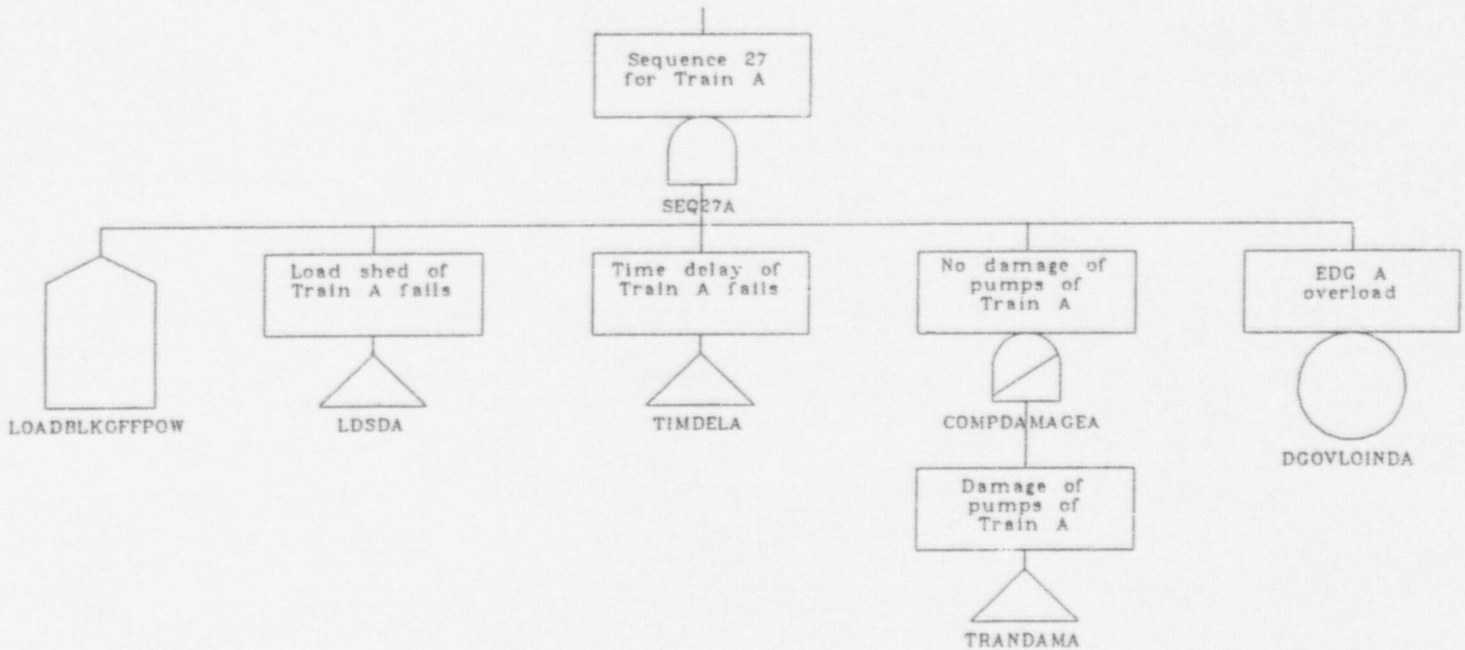

Sequence 20 for Train A
SEQ20A
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train A fails
LDSDA
Time delay of Train A fails
TIMDELA
Damage of pumps of Train A
TRANDAMA

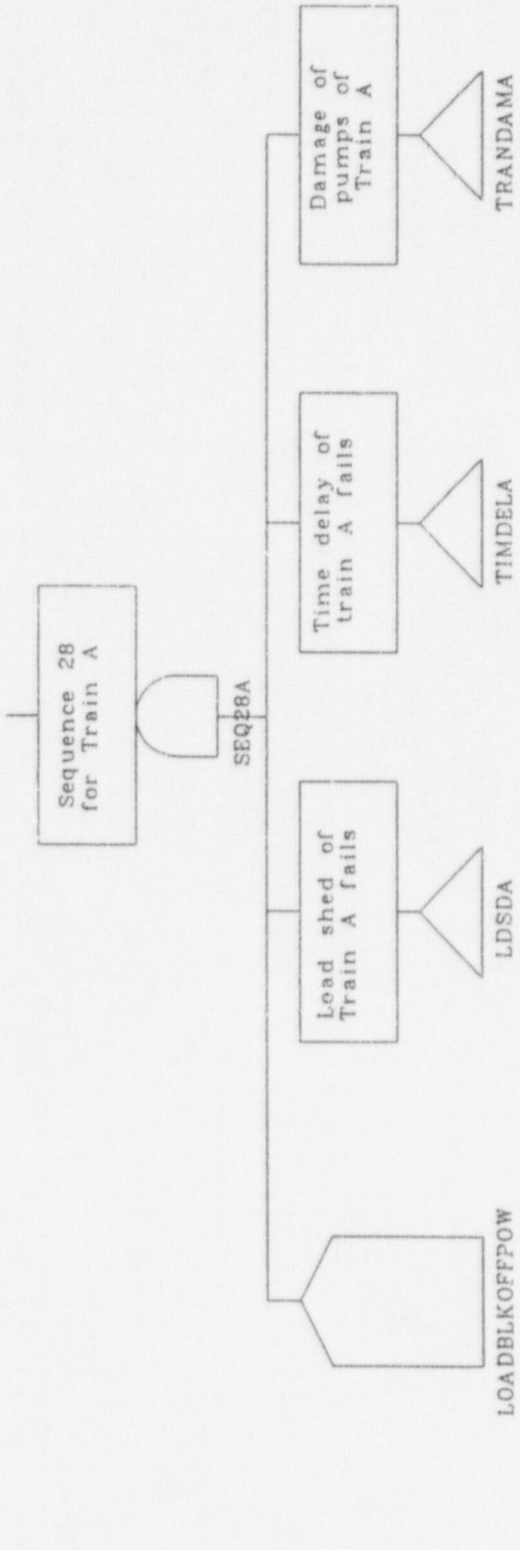

Sequence 23 for Train A
SEQ23A
LOADBLKOFFPOW
Load shed of Train A is successful
COMPLDSDA
Load shed of Train A fails
LDSDA
EDG A is not overloaded
RESEQTOEDG
LOADBLOKEDG
Train A not impacted by Anti-Pump Circuits
COMPTAPLBLKA
Lockout of Train A due to Anti-Pump Circuits
TAPLBLKA
Pump overload due to valve open of Train A
VALVOPA


Sequence 24
for Train A
SEQ24A
Load shed of
Train A is
successful
EDG A is not
overloaded
Lockout of
Train A due to
Anti-Pump
Circuits
LOADBLKOFFPOW
COMPLDSDA
RESEQTOEDG
TAPLBLKA
Load shed of
Train A fails
LDSDA
LOADBLOKEDG

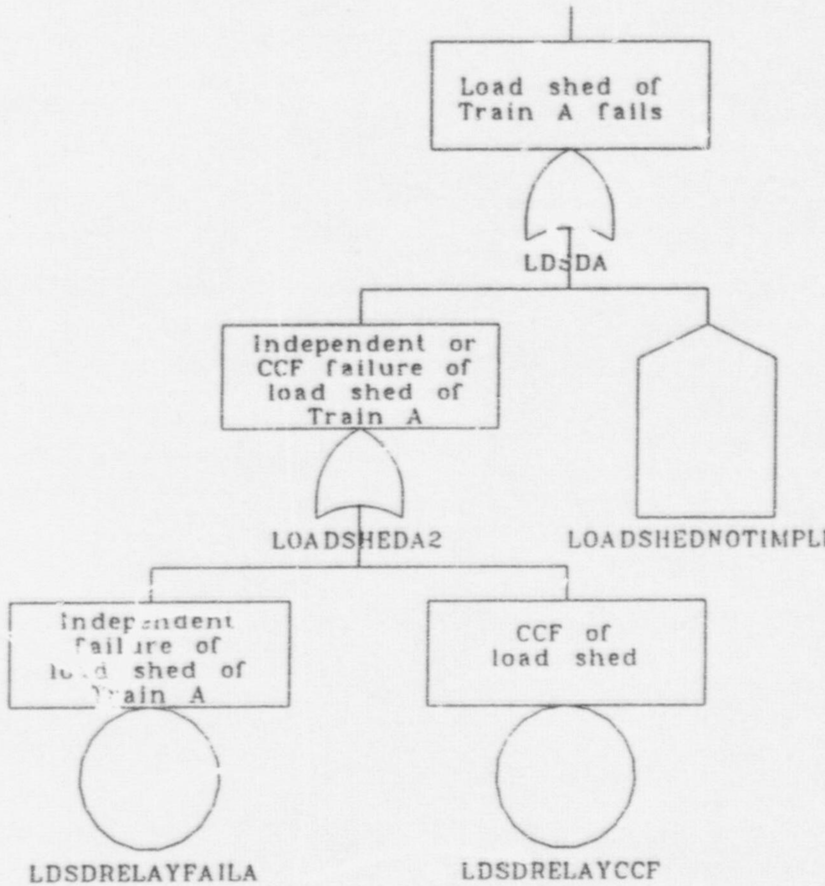

Sequence 25
for Train A
SEQ25A
Load shed of
Train A is
successful
EDG A
overload
LOADBLKOFFPOW
COMPLDSDA
LOADBLOKEDG
EXLODGS25A
Load shed of
Train A fails
LDSDA

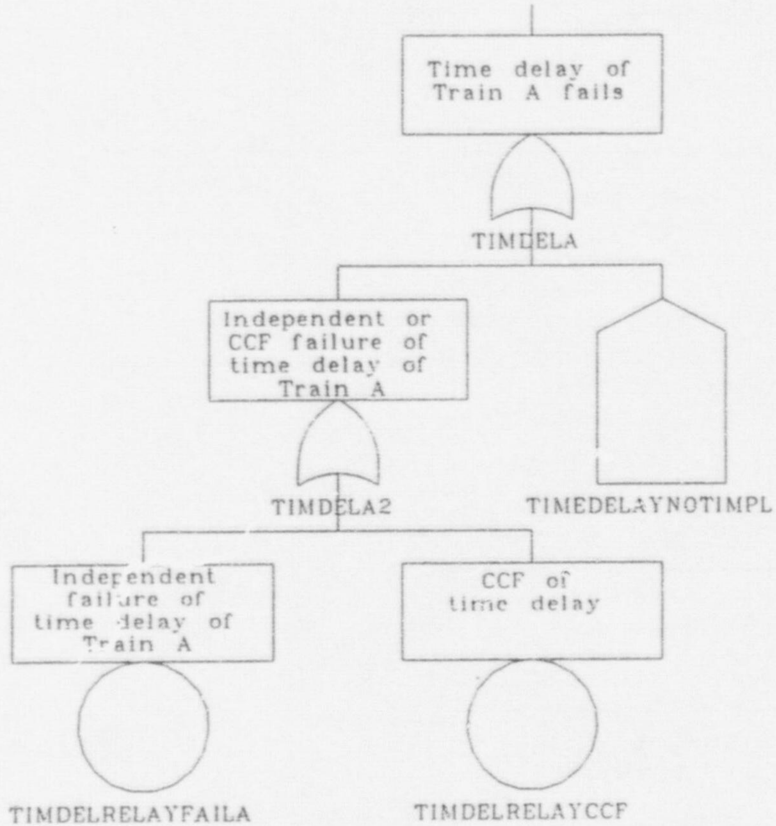

Sequence 26 for Train A
SEQ26A
LOADBLKOFFPOW
Load shed of Train A fails
LDSDA
Time delay of Train A is successful
COMPTIMDELA
Time delay of Train A fails
TIMDELA
EDG A overload
DGOVLOINDA

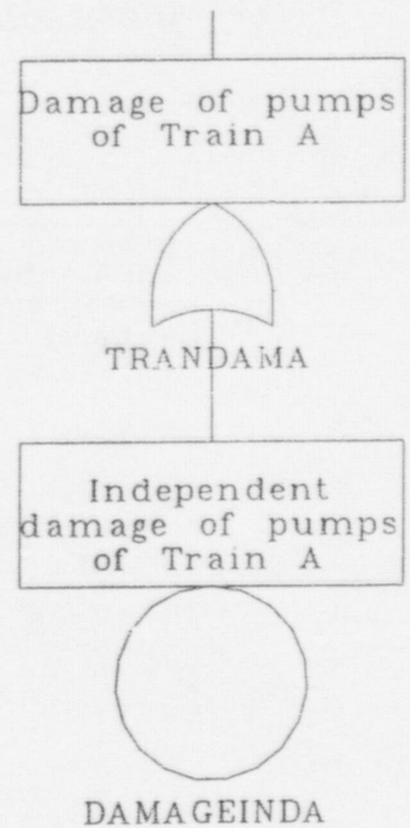

Sequence 27 for Train A
SEQ27A
LOADBLKOFFPOW
Load shed of Train A fails
LDSDA
Time delay of Train A fails
TIMDELA
No damage of pumps of Train A
COMPDAMAGEA
Damage of pumps of Train A
TRANDAMA
EDG A overload
DGOVLOINDA

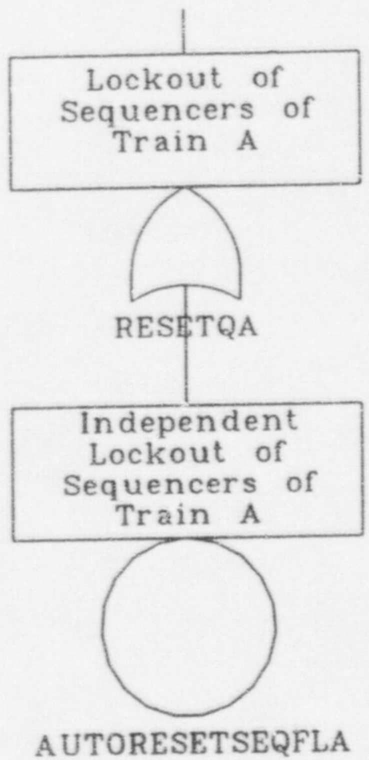


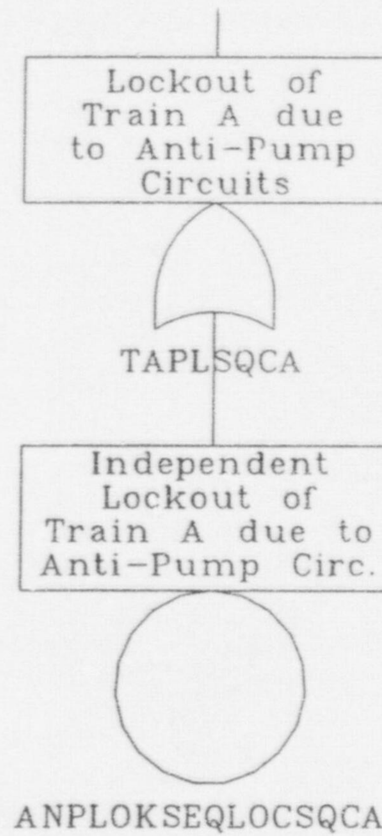
Sequence 28
for Train A
SEQ28A
Lead shed of
Train A fails
LDSDA
Time delay of
train A fails
TIMDELA
Damage of
pumps of
Train A
TRANDAMA
LOADBLKOFFPOW


Load shed of Train A fails
LDSDA
Independent or CCF failure of load shed of Train A
LOADSHEDA2
LOADSHEDNOTIMPLE
Independent failure of load shed of Train A
CCF of load shed
LDSDRELAYFAILA
LDSDRELAYCCF

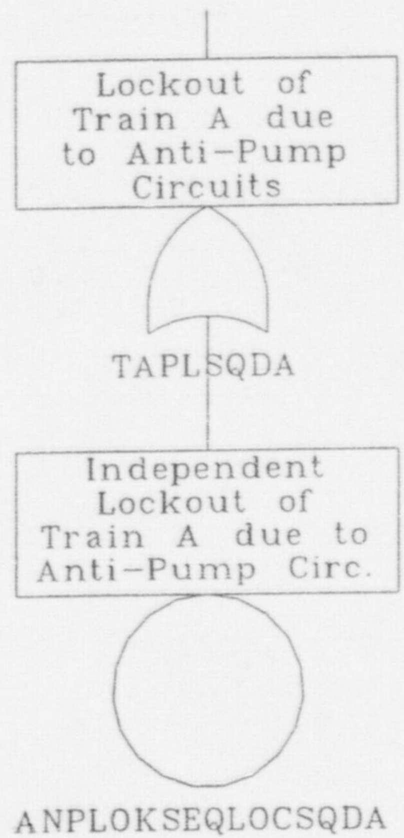

Time delay of Train A fails
TIMDELA
Independent or CCF failure of time delay of Train A
TIMDELA2
TIMEDELAYNOTIMPL
Independent failure of time delay of Train A
CCF of time delay
TIMDELRELAYFAILA
TIMDELRELAYCCF

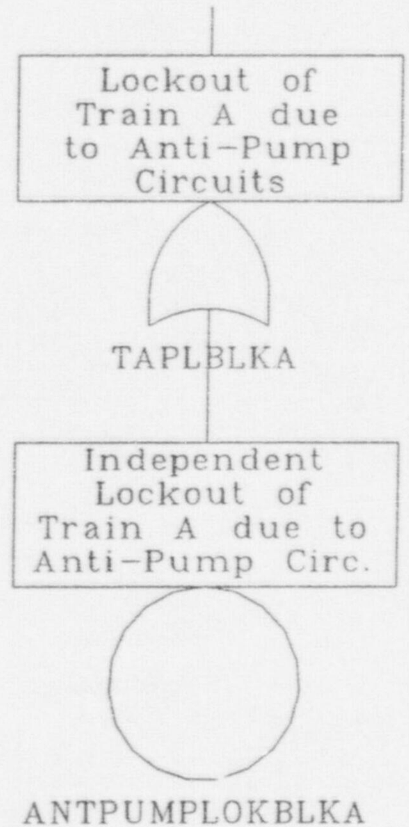

Damage of pumps of Train A
TRANDAMA
Independent damage of pumps of Train A
DAMAGEINDA

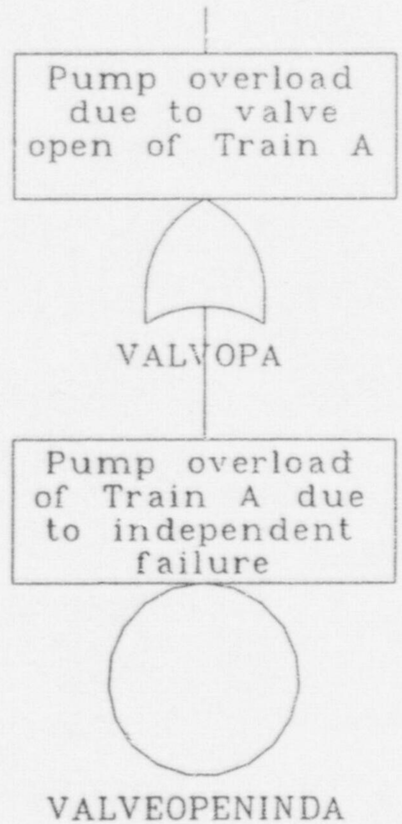

Lockout of Sequencers of Train A
RESETQA
Independent Lockout of Sequencers of Train A
AUTORESETSEQFLA

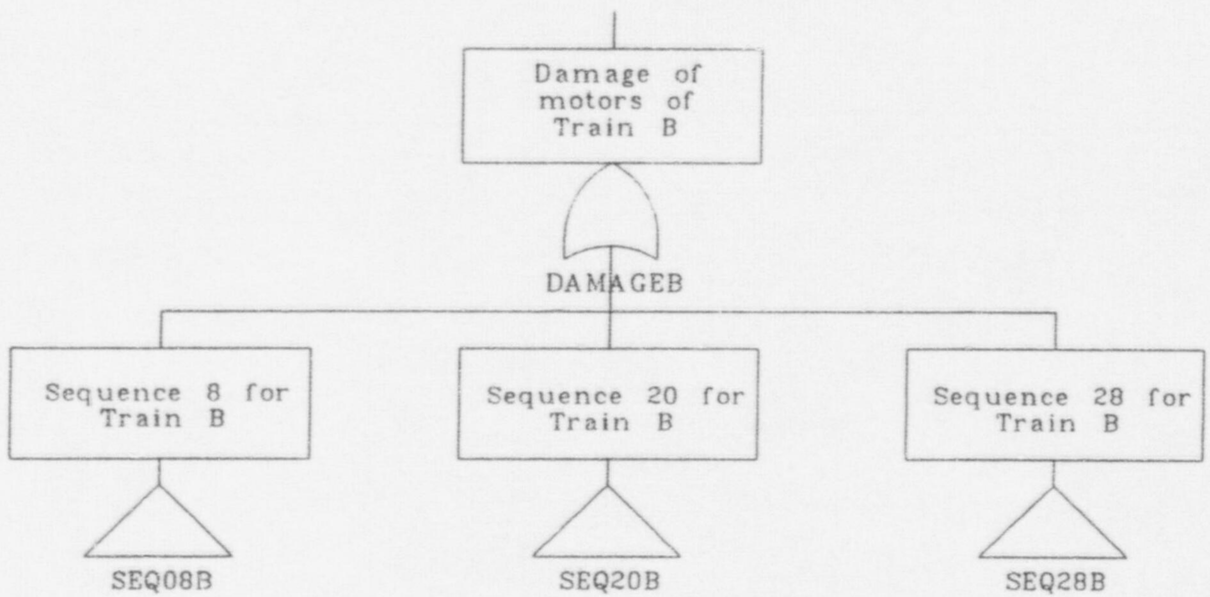


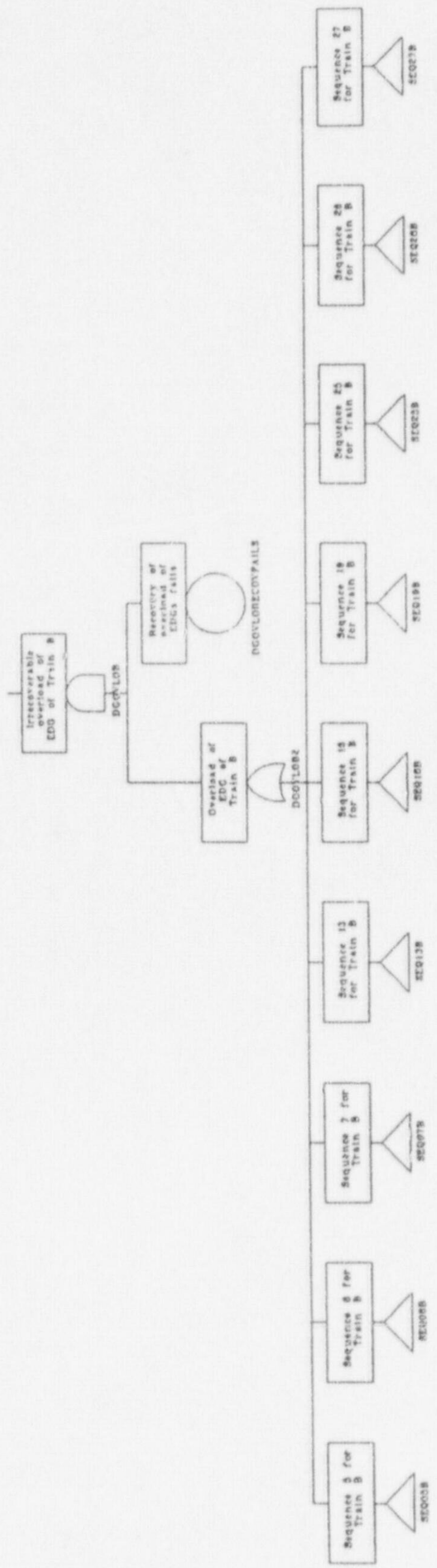
Lockout of Train A due to Anti-Pump Circuits
TAPLSQCA
Independent Lockout of Train A due to Anti-Pump Circ.
ANPLOKSEQLOCSQCA


Lockout of Train A due to Anti-Pump Circuits
TAPLSQDA
Independent Lockout of Train A due to Anti-Pump Circ.
ANPLOKSEQLOCSQDA

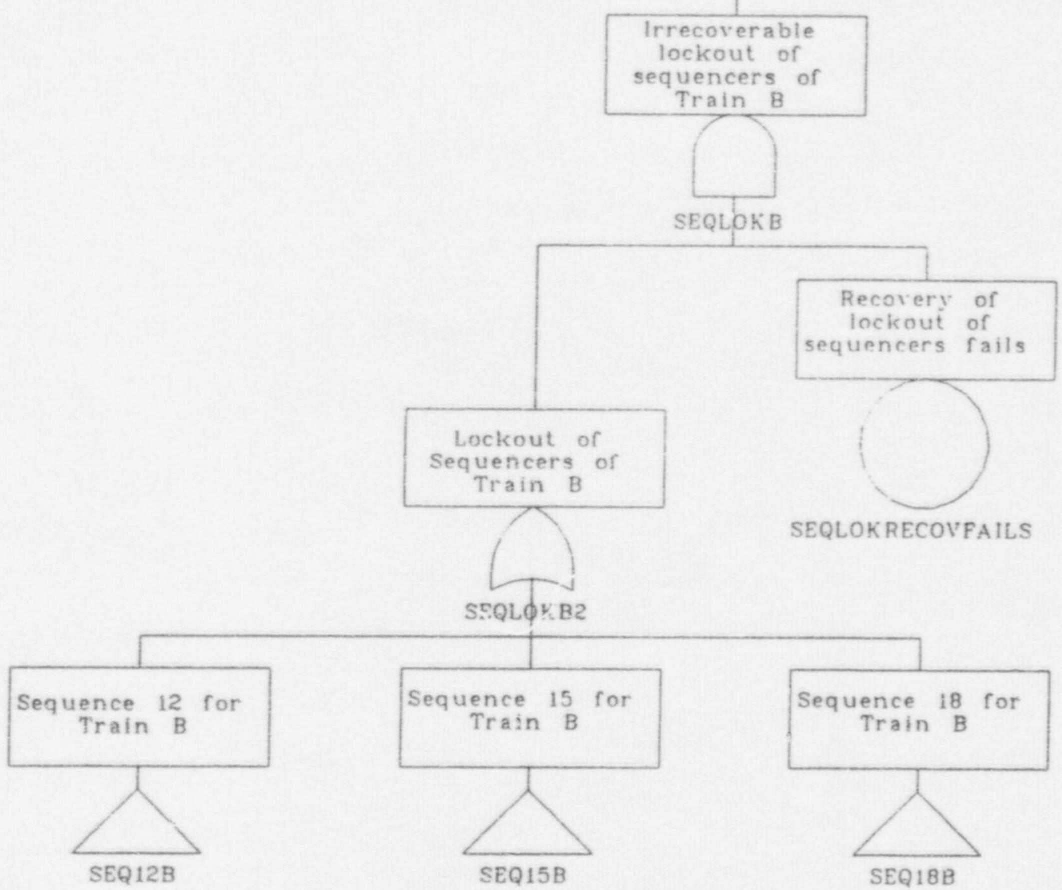

Lockout of Train A due to Anti-Pump Circuits
TAPLBLKA
Independent Lockout of Train A due to Anti-Pump Circ.
ANTPUMPLOKBLKA

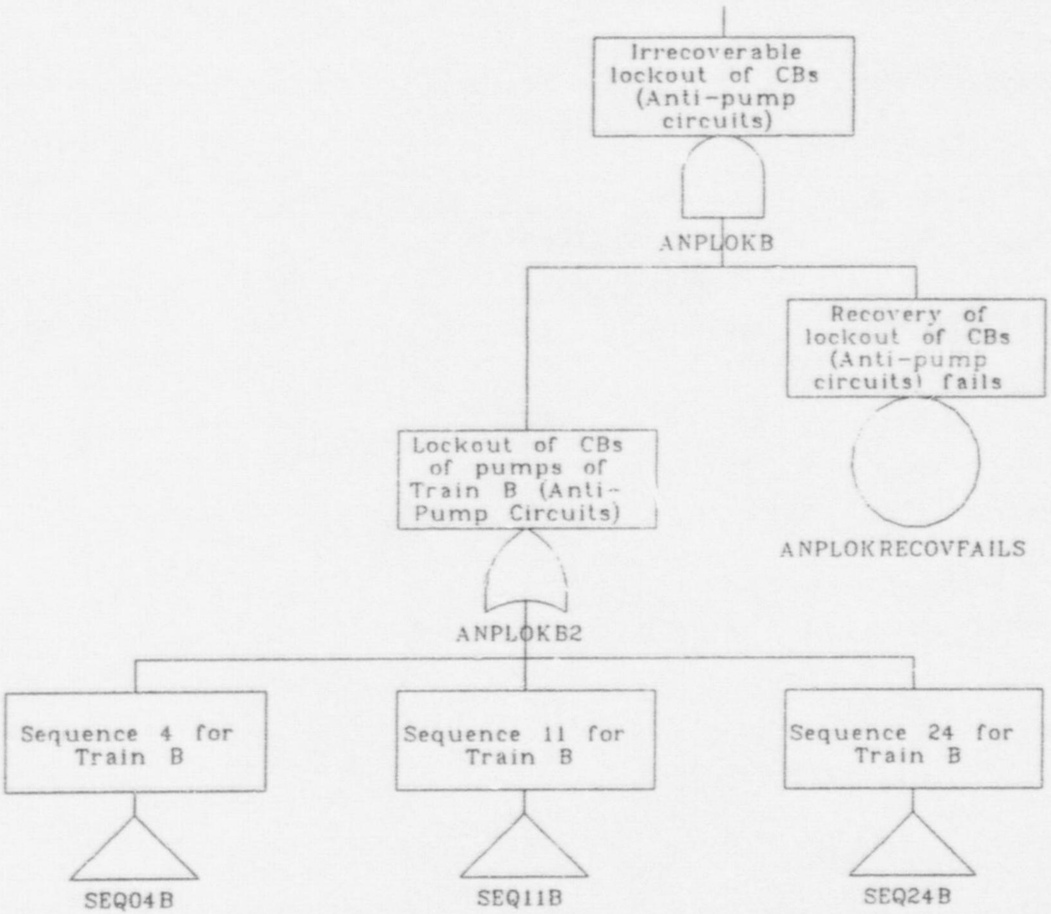

Pump overload due to valve open of Train A
VALVOPA
Pump overload of Train A due to independent failure
VALVEOPENINDA

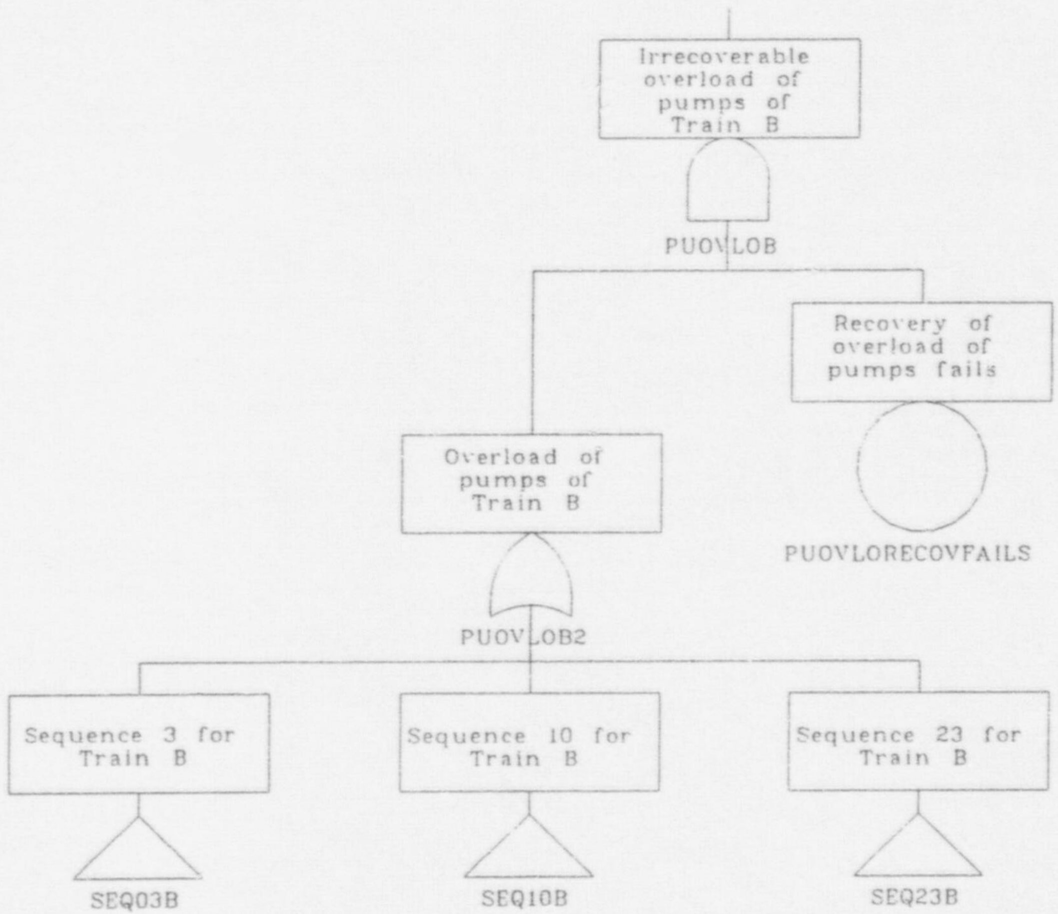

Damage of motors of Train B
DAMAGEB
Sequence 8 for Train B
Sequence 20 for Train B
Sequence 28 for Train B
SEQ08B
SEQ20B
SEQ28B

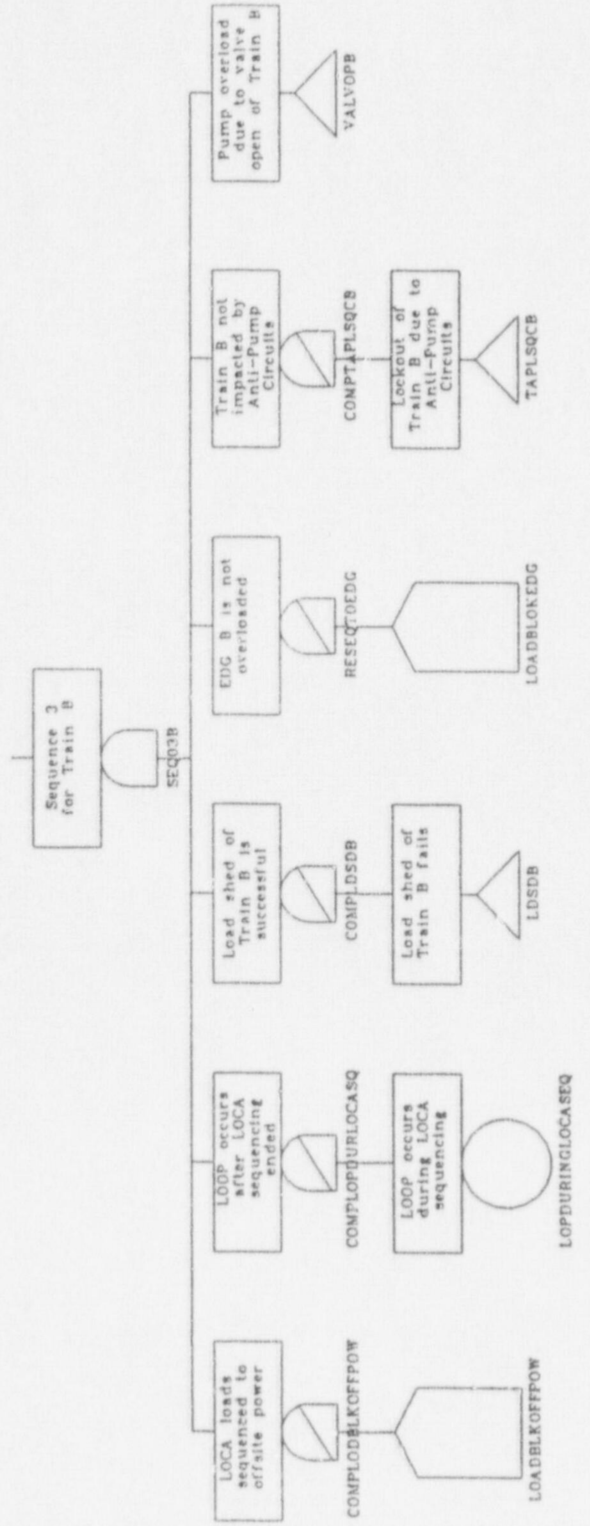


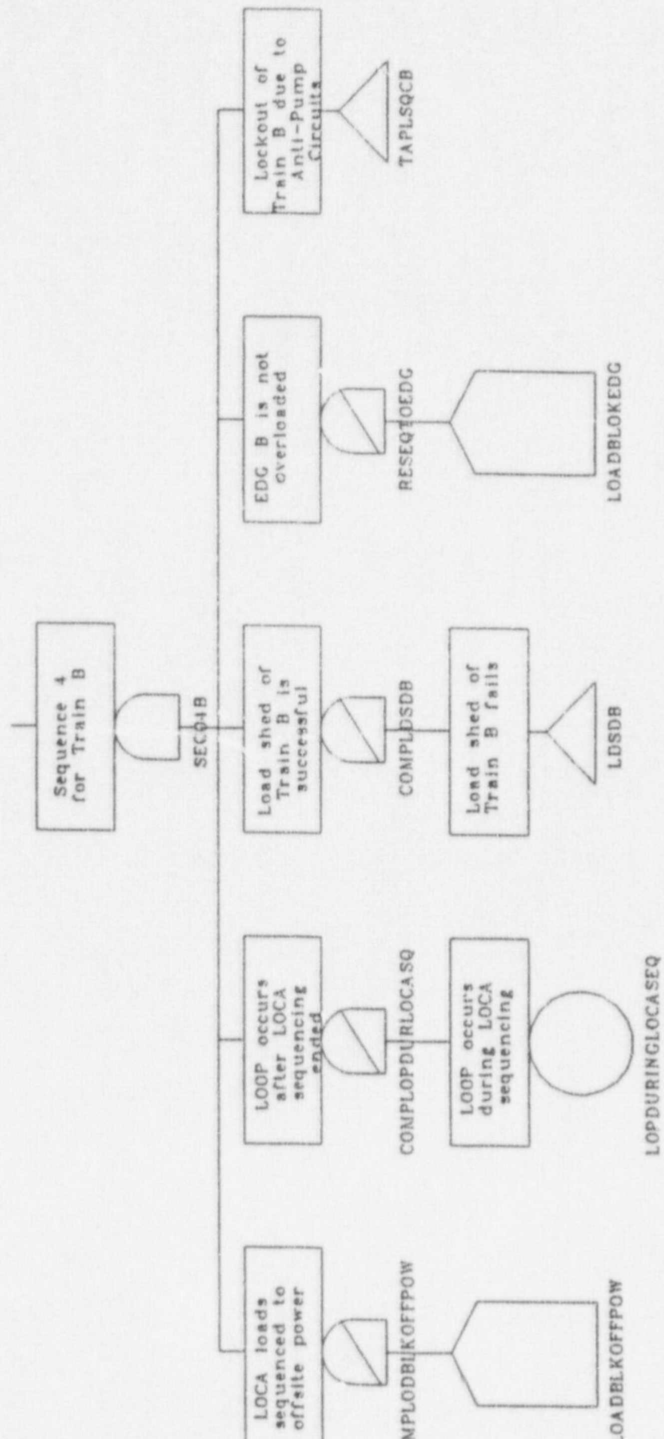
Irrecoverable overload of EDG of Train B
DGOVLOB
Recovery of overload of EDGs fails
DGOVLORECOVFAILS
Overload of EDG of Train B
Sequence 27 for Train B
Sequence 13 for Train B
Sequence 7 for Train B


Irrecoverable lockout of sequencers of Train B
SEQLOKB
Recovery of lockout of sequencers fails
SEQLOKRECOVFAILS
Lockout of Sequencers of Train B
SEQLOKB2
Sequence 12 for Train B
SEQ12B
Sequence 15 for Train B
SEQ15B
Sequence 18 for Train B
SEQ18B

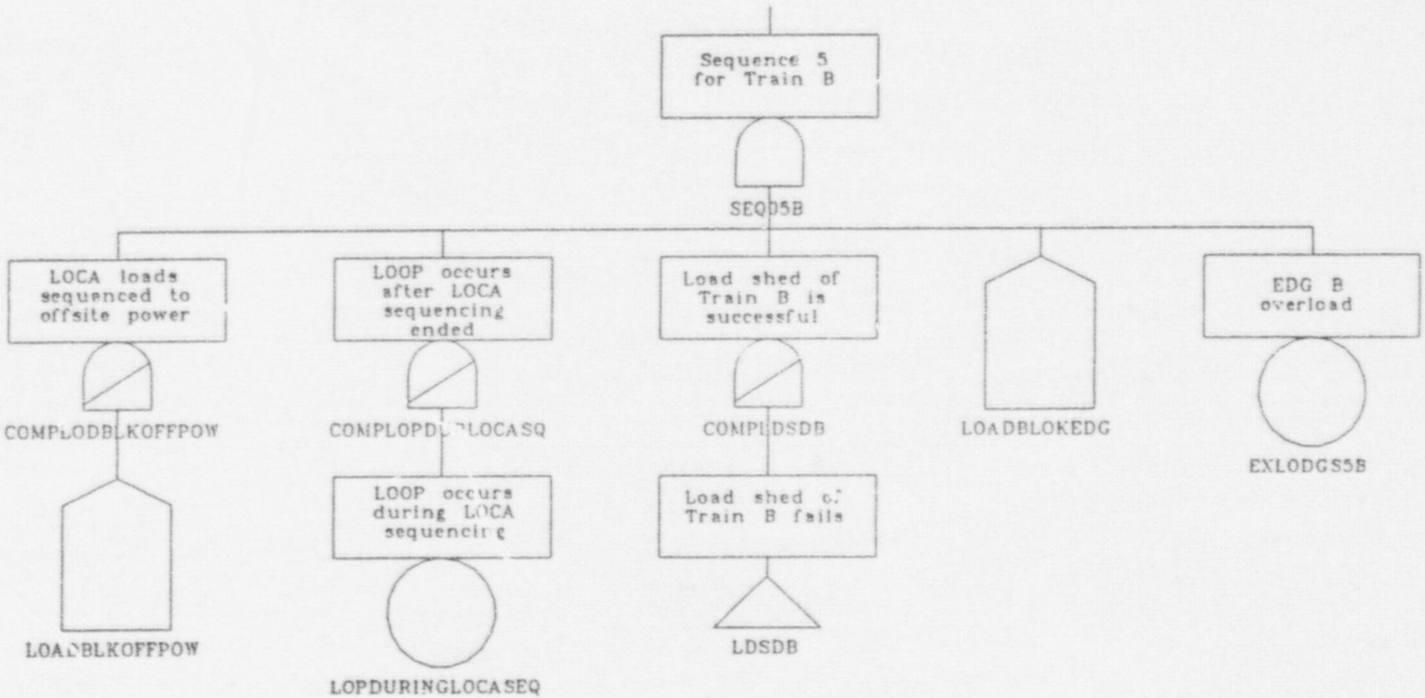

Irrecoverable lockout of CBs (Anti-pump circuits)
ANPLOKB
Recovery of lockout of CBs (Anti-pump circuits) fails
ANPLOKRECOVFAILS
Lockout of CBs of pumps of Train B (Anti-Pump Circuits)
ANPLOKB2
Sequence 4 for Train B
SEQ04B
Sequence 11 for Train B
SEQ11B
Sequence 24 for Train B
SEQ24B

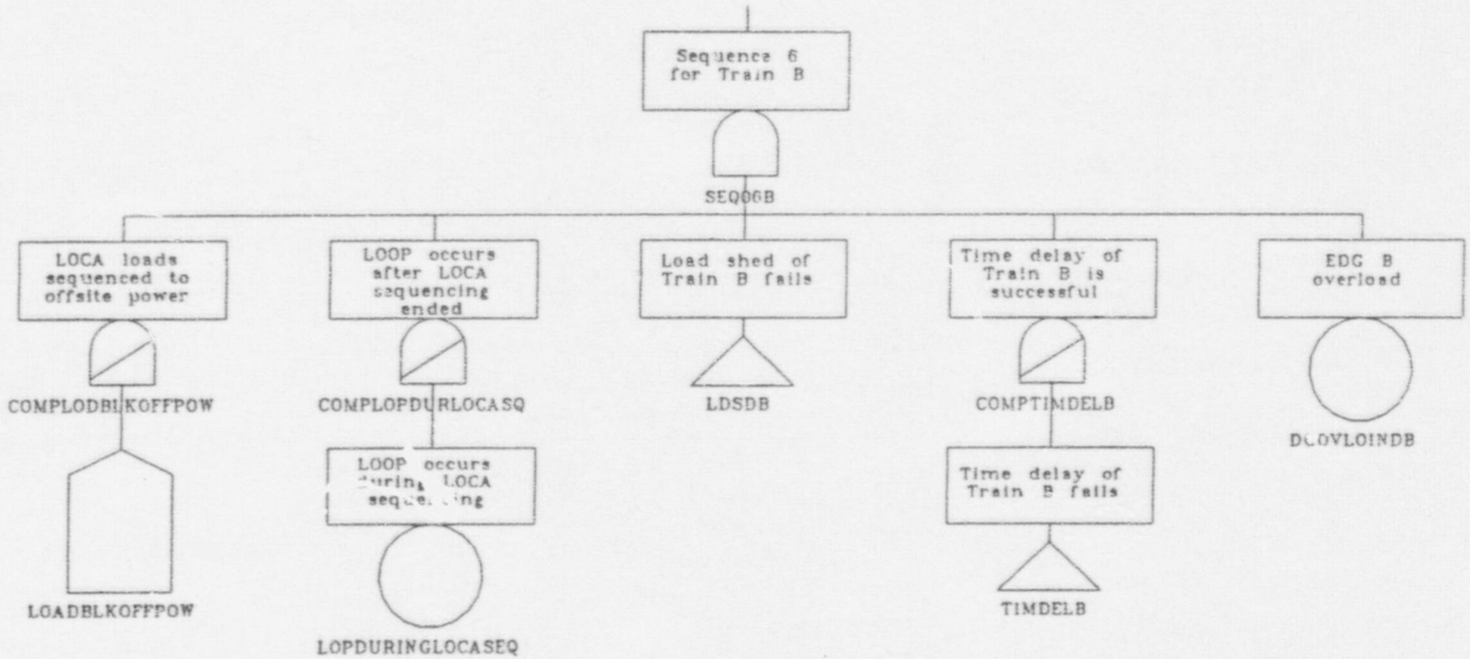

Irrecoverable overload of pumps of Train B
PUOVLOB
Recovery of overload of pumps fails
PUOVLORECOVFAILS
Overload of pumps of Train B
PUOVLOB2
Sequence 3 for Train B
SEQ03B
Sequence 10 for Train B
SEQ10B
Sequence 23 for Train B
SEQ23B

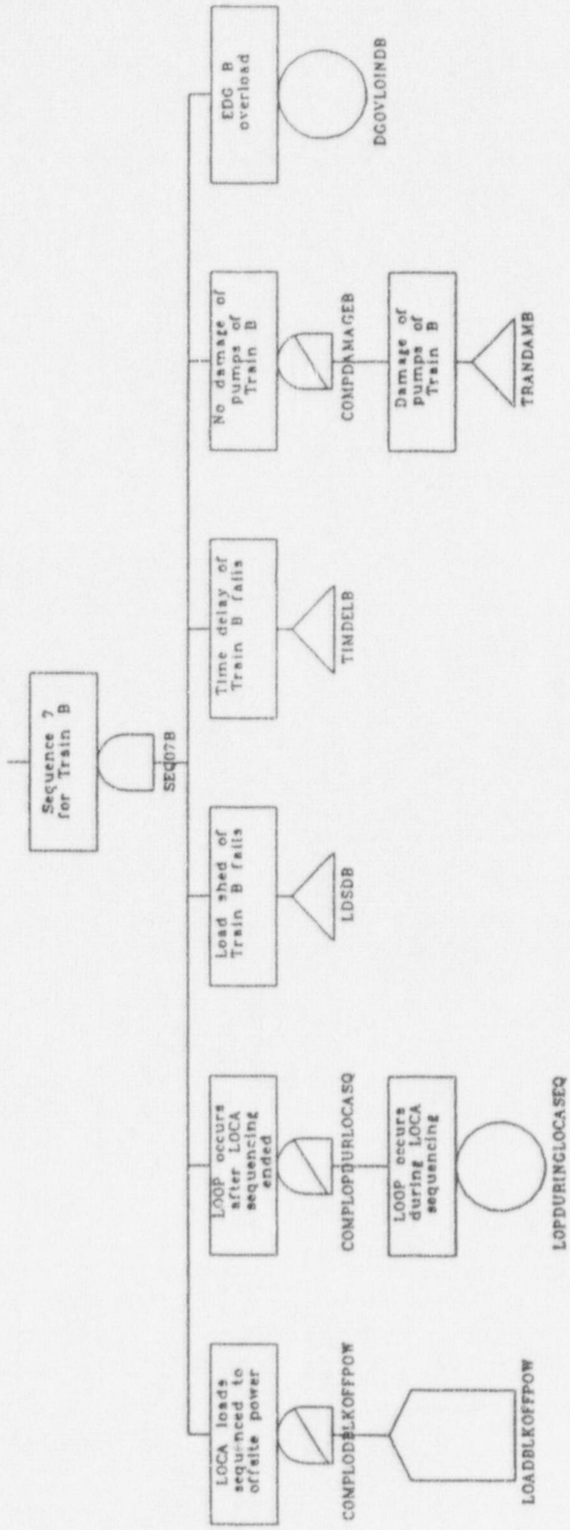

Sequence 3 for Train B
SEQ03B
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASQ
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train B is successful
COMPLDSDB
Load shed of Train B fails
LDSDB
EDG B is not overloaded
RESEQTOEDG
LOADBLOKEDG
Train B not impacted by Anti-Pump Circuits
COMPTAPLSQCB
Lockout of Train B due to Anti-Pump Circuits
TAPLSQCB
Pump overload due to valve open of Train B
VALVOPB

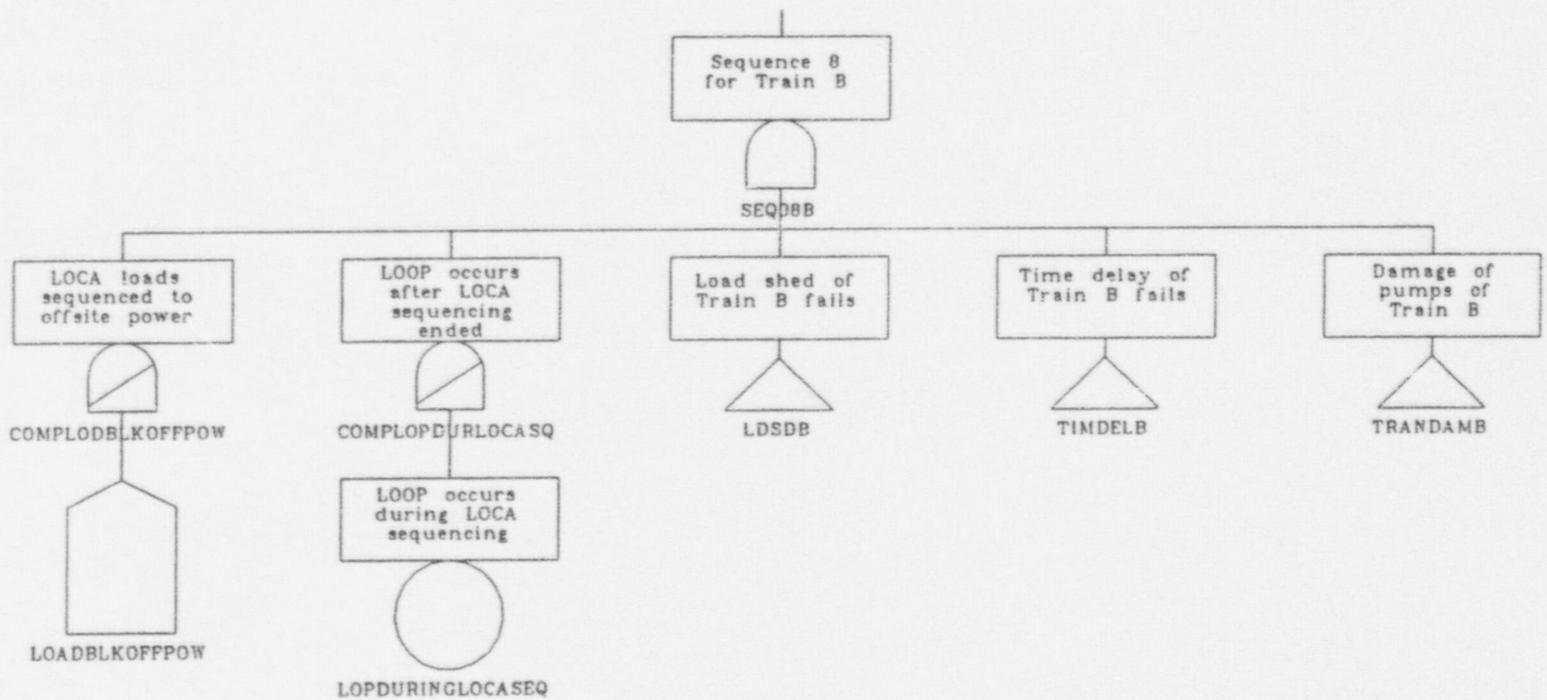


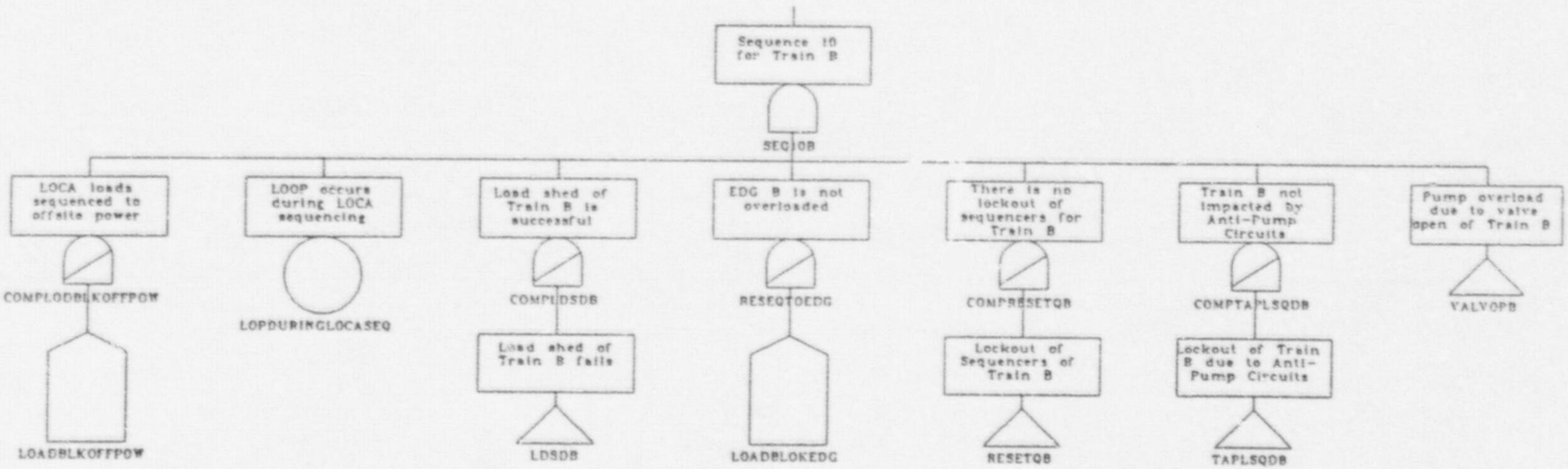
Sequence 4 for Train B
SEC04B
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASQ
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train B is successful
COMPLLDSDB
Load shed of Train B fails
LDSDB
EDG B is not overloaded
RESEQTOEDG
LOADBLOKEDG
Lockout of Train B due to Anti-Pump Circuits
TAPLSQCB

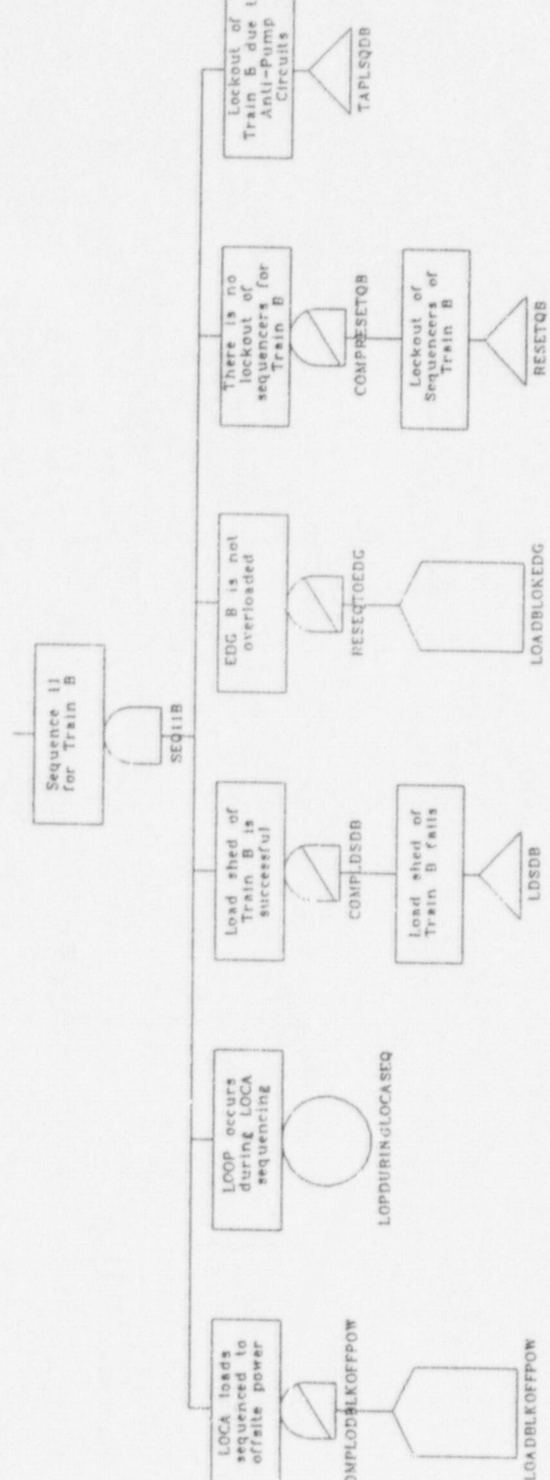

Sequence 5
for Train B
SEQ05B
LOCA loads
sequenced to
offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs
after LOCA
sequencing
ended
COMPLOPDURLOCASQ
LOOP occurs
during LOCA
sequencing
LOPDURINGLOCASEQ
Load shed of
Train B is
successful
COMPLDSDB
Load shed of
Train B fails
LDSDB
LOADBLOKEDG
EDG B
overload
EXLODGS5B

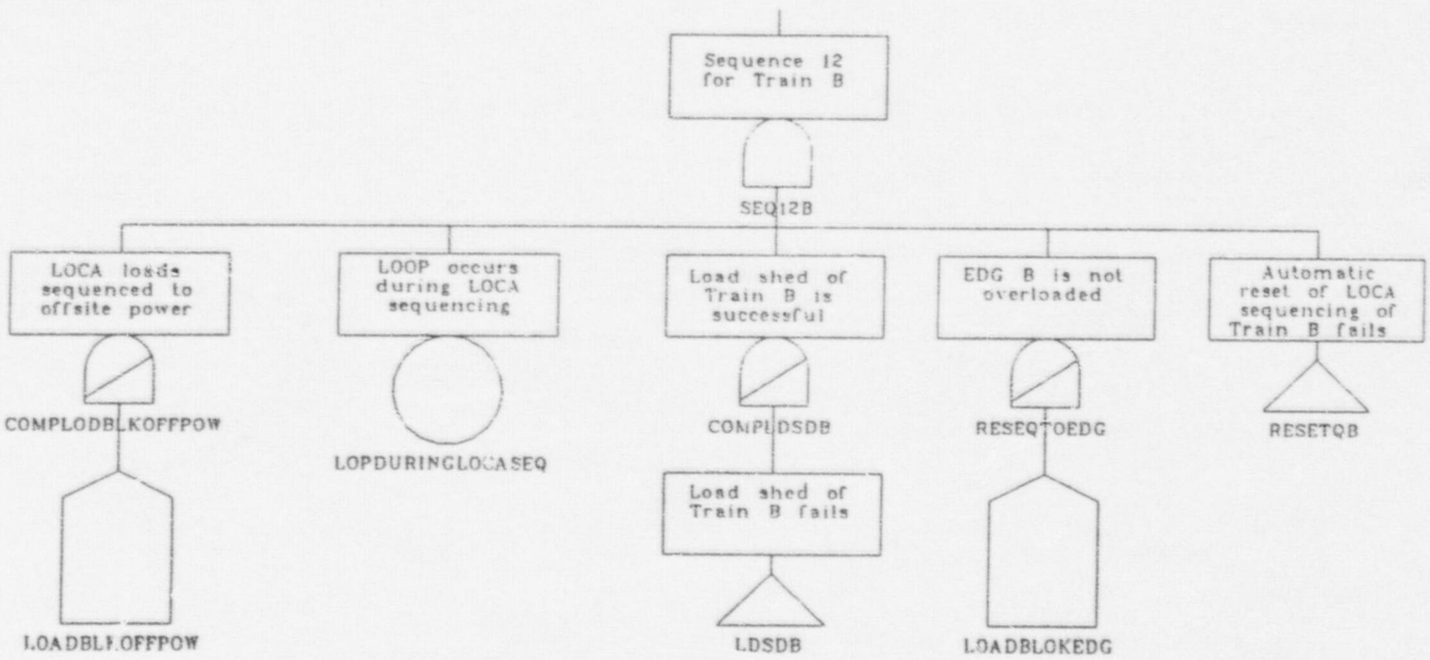

Sequence 6 for Train B
SEQ06B
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASQ
LOOP occurs
LOCA
LOPDURINGLOCASEQ
Load shed of Train B fails
LDSDB
Time delay of Train B is successful
COMPTIMDELB
Time delay of Train B fails
TIMDELB
EDG B overload
DCOVLOINDB

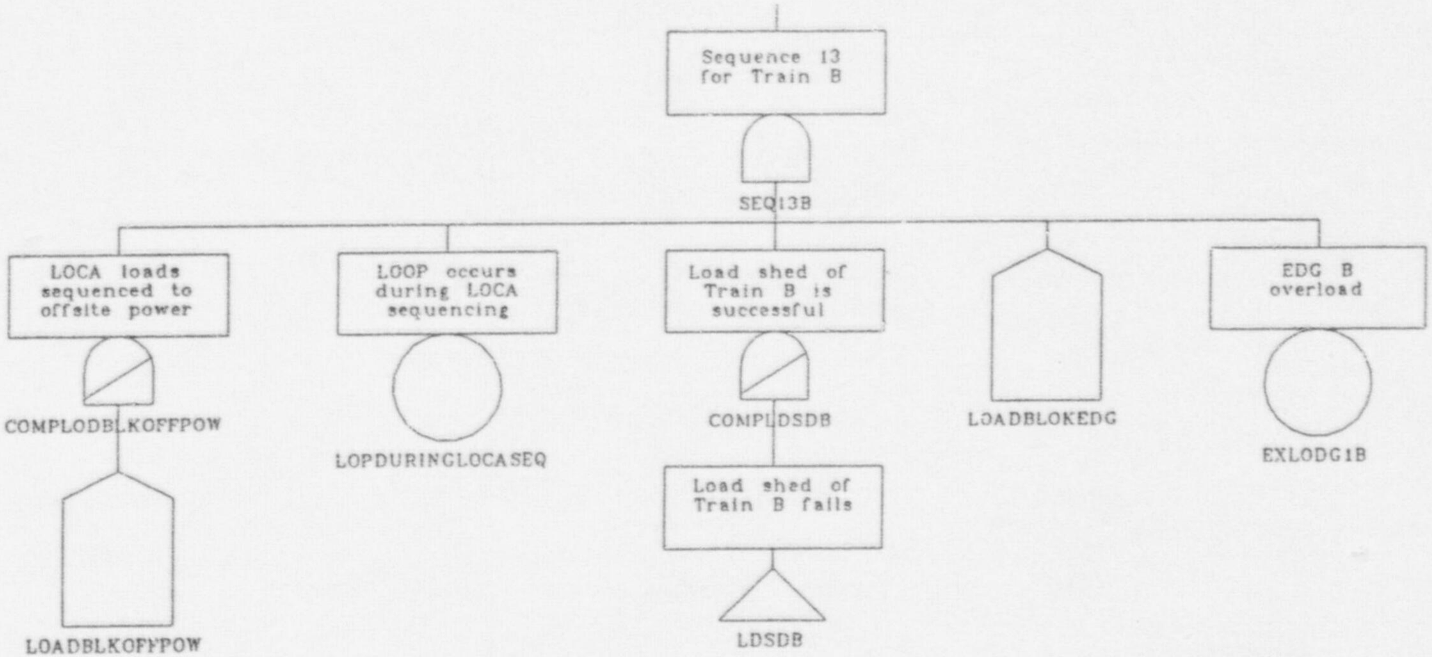

Sequence 7 for Train B
SEQ07B
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASQ
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train B fails
LDSDB
Time delay of Train B fails
TIMDELB
No damage of pumps of Train B
COMPDAMAGEB
Damage of pumps of Train B
TRANDAMB
EDG B overload
DGOVLOINDB


Sequence 8 for Train B
SEQ8BB
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASQ
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train B fails
LDSDB
Time delay of Train B fails
TIMDELB
Damage of pumps of Train B
TRANDAMB

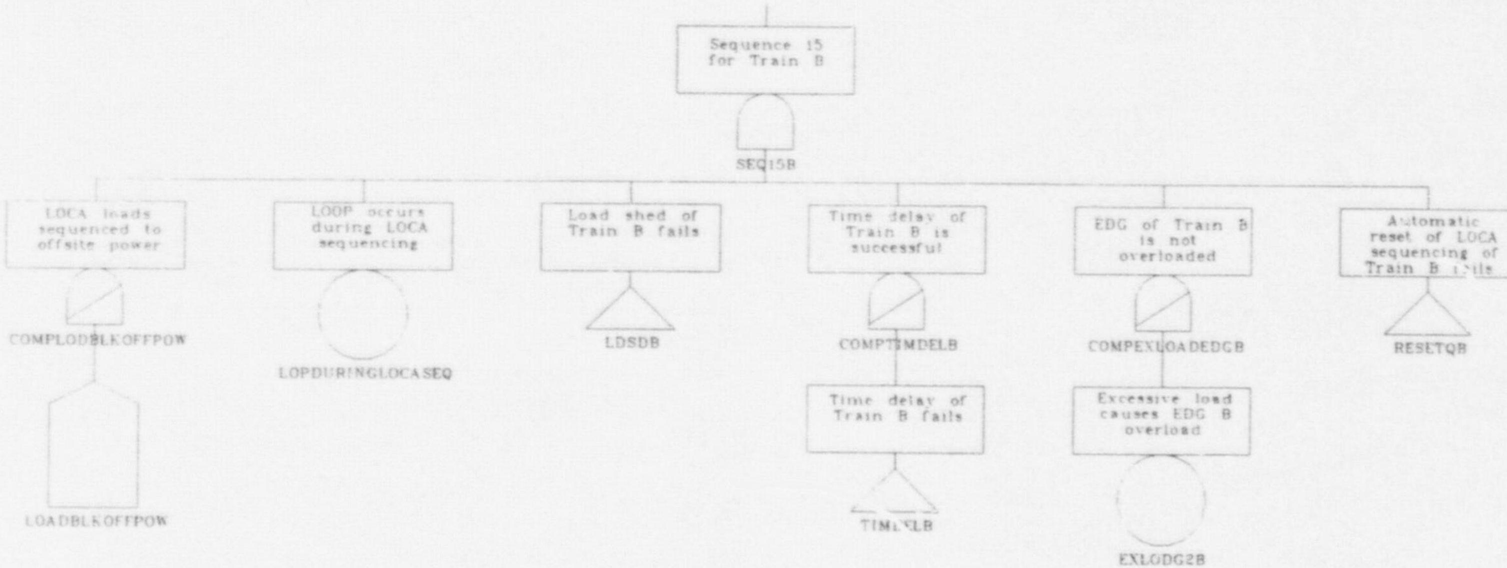

Sequence 10 for Train B
SEQ10B
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train B is successful
COMPLDSDB
Load shed of Train B fails
LDSDB
EDG B is not overloaded
RESEQTOEDG
LOADBLOKEDG
There is no lockout of sequencers for Train B
COMPRESETQB
Lockout of Sequencers of Train B
RESETQB
Train B not impacted by Anti-Pump Circuits
COMPTAPLSQDB
Lockout of Train B due to Anti-Pump Circuits
TAPLSQDB
Pump overload due to valve open of Train B
VALVOPB


Sequence 11 for Train B
SEQ11B
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train B is successful
COMPLDSDB
Load shed of Train B fails
LDSDB
EDG B is not overloaded
RESEQTOEDG
LOADBLOKEDG
There is no lockout of sequencers for Train B
COMPRESETQB
Lockout of Sequencers of Train B
RESETQB
Lockout of Train B due to Anti-Pump Circuits
TAPLSQDB

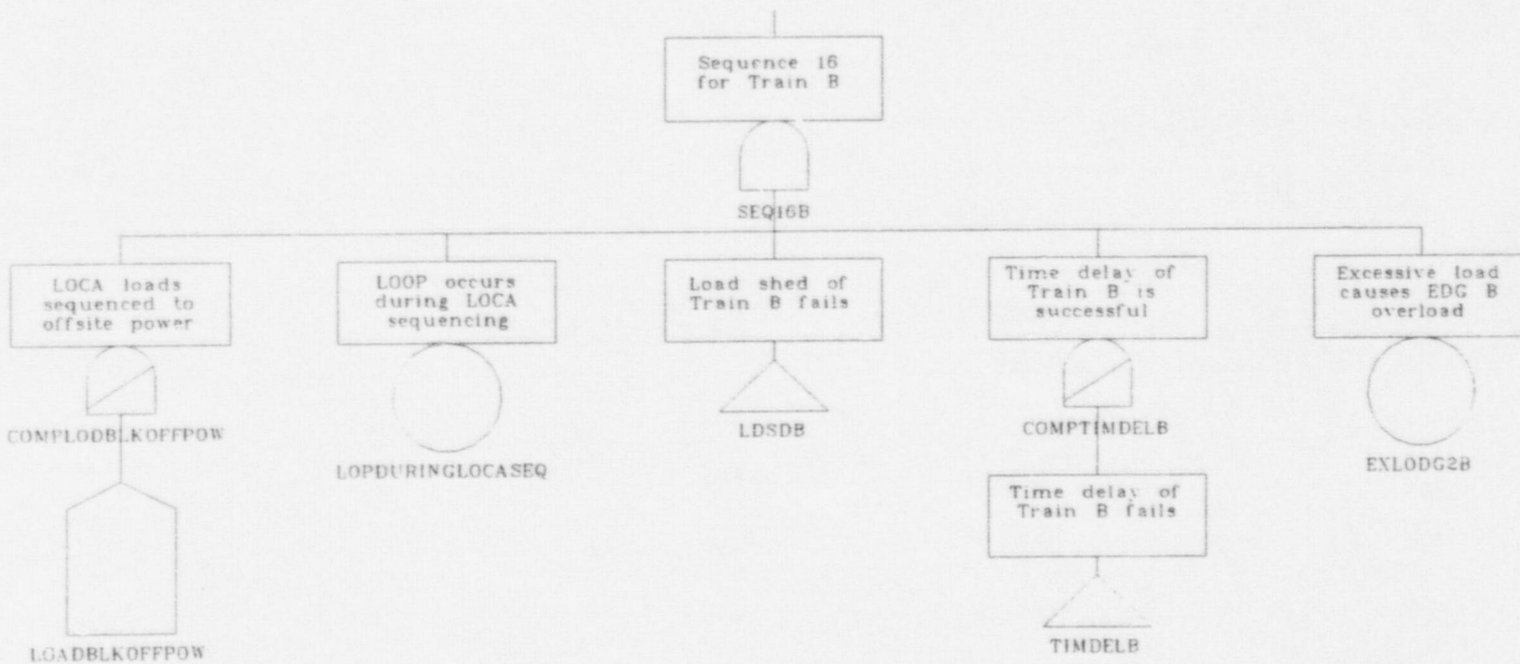

Sequence 12 for Train B
SEQ12B
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train B is successful
COMPLDSDB
Load shed of Train B fails
LDSDB
EDG B is not overloaded
RESEQTOEDG
LOADBLOKEDG
Automatic reset of LOCA sequencing of Train B fails
RESETQB

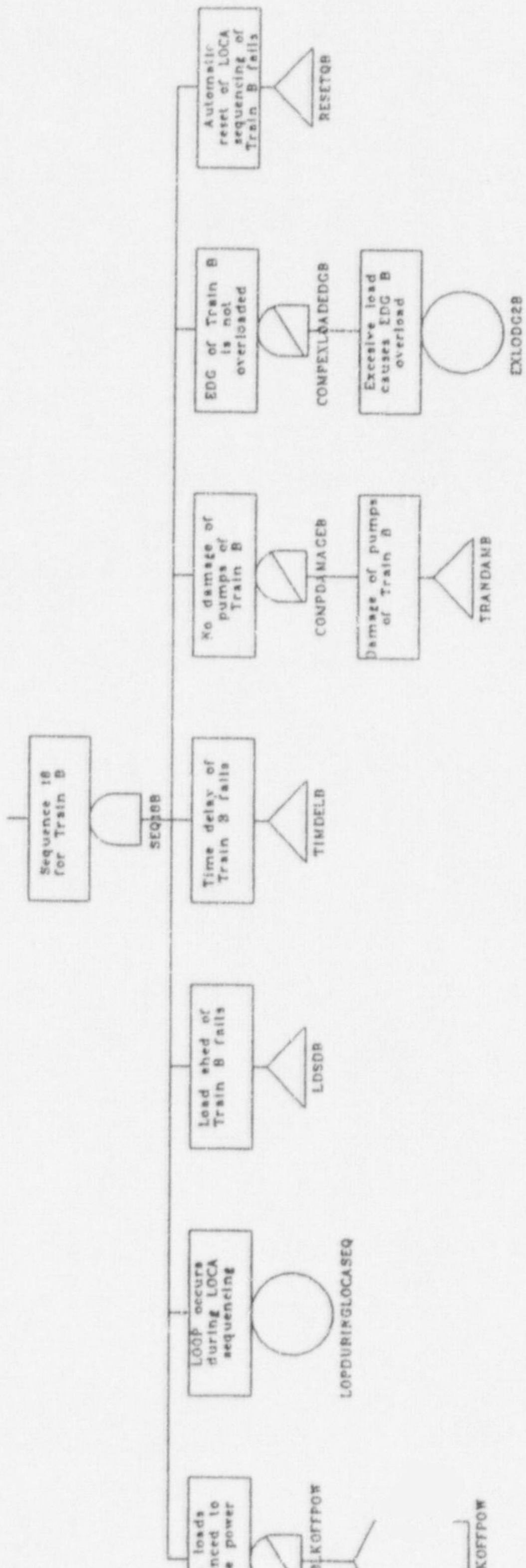


Sequence 13 for Train B
SEQ13B
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train B is successful
COMPLDSDB
Load shed of Train B fails
LDSDB
LOADBLOKEDG
EDG B overload
EXLODG1B

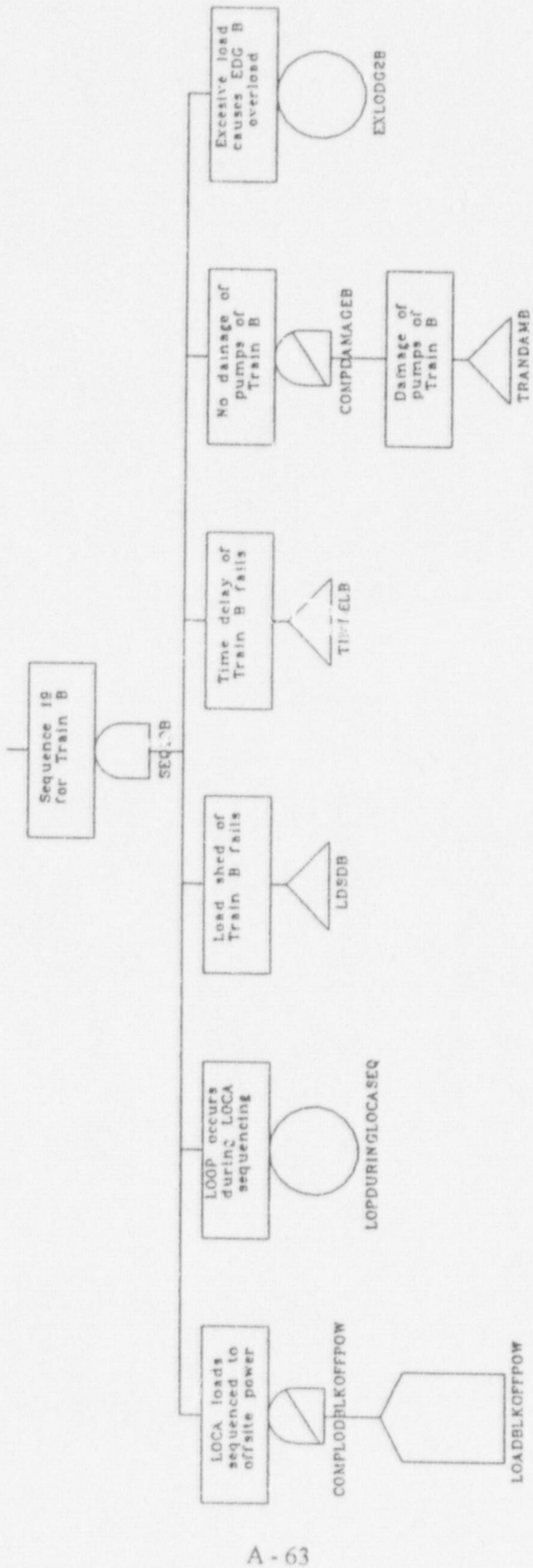


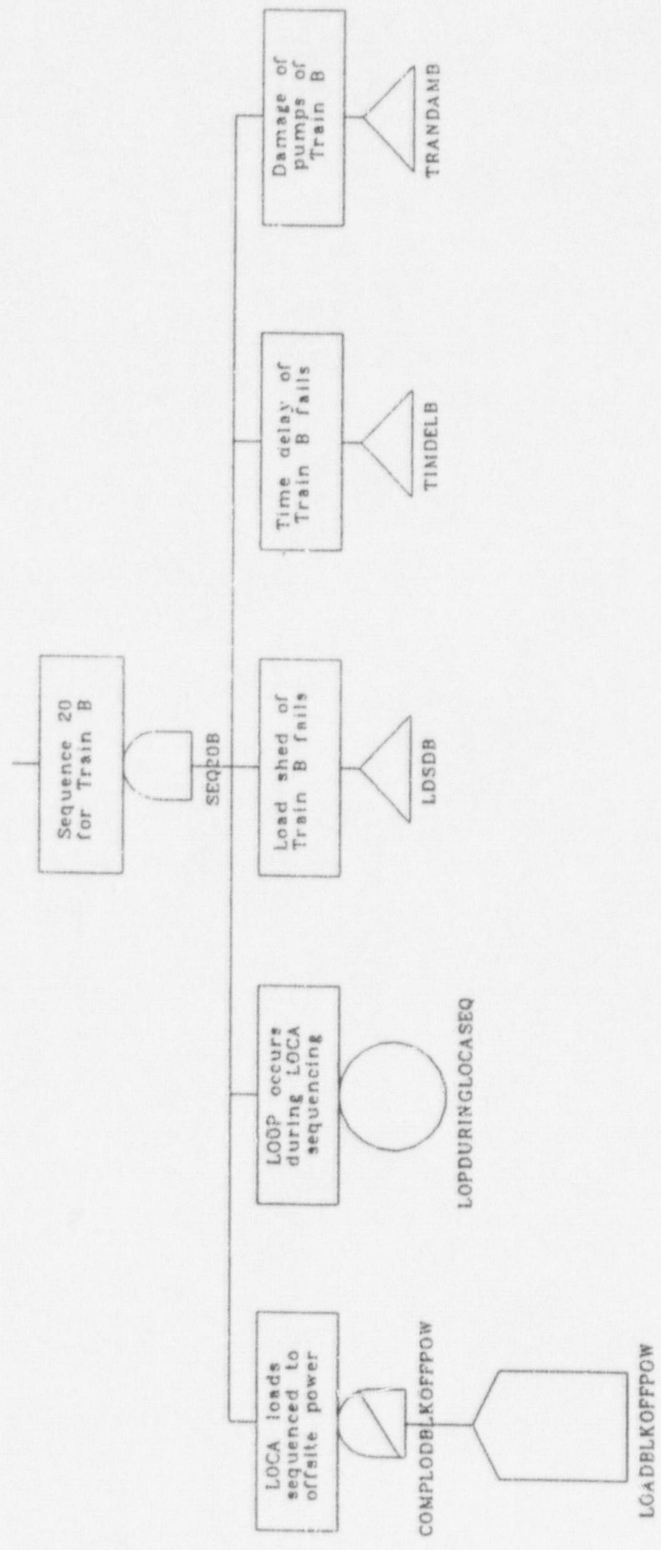
Sequence 15 for Train B
SEQ15B
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train B fails
LDSDB
Time delay of Train B is successful
COMPTIMDELB
Time delay of Train B fails
EDG of Train B is not overloaded
COMPEXLOADEDGB
Excessive load causes EDG B overload
EXLODG2B
Automatic reset of LOCA sequencing of Train B
RESETQB

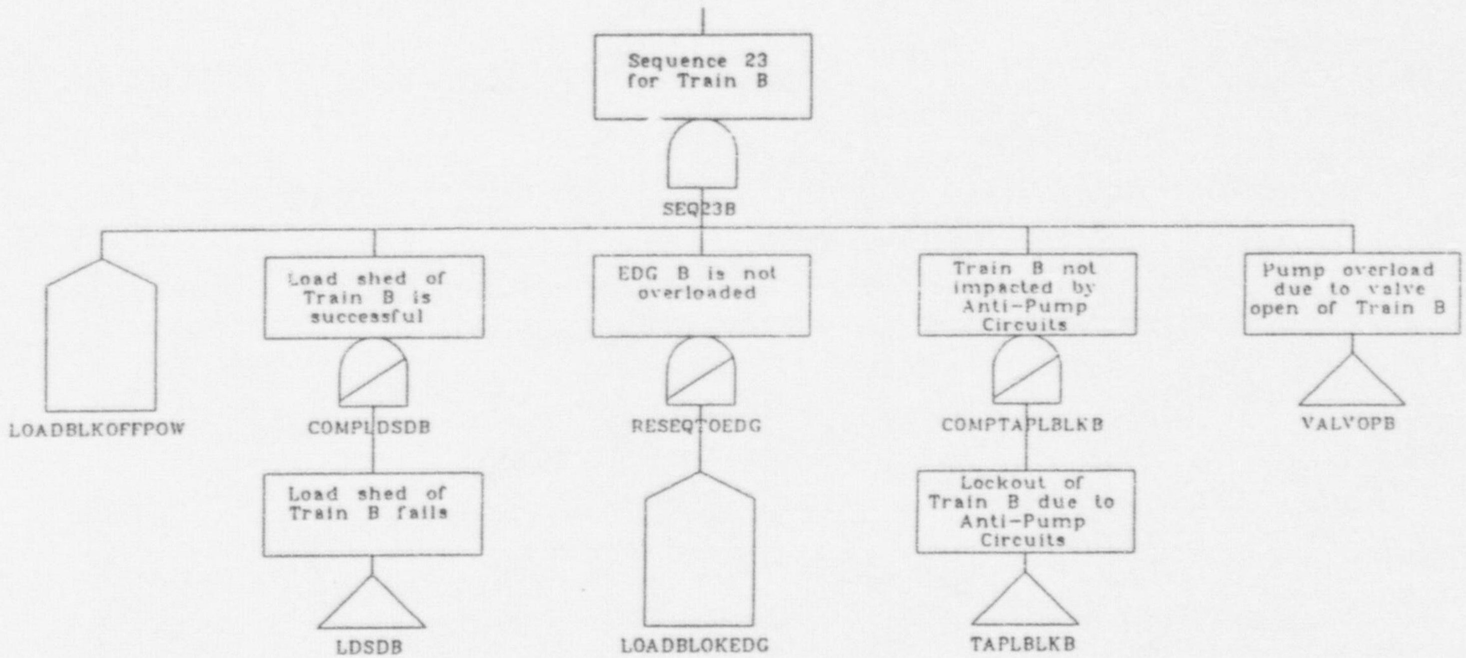

Sequence 16 for Train B
SEQ16B
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LGADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train B fails
LDSDB
Time delay of Train B is successful
COMPTIMDELB
Time delay of Train B fails
TIMDELB
Excessive load causes EDG B overload
EXLODG2B



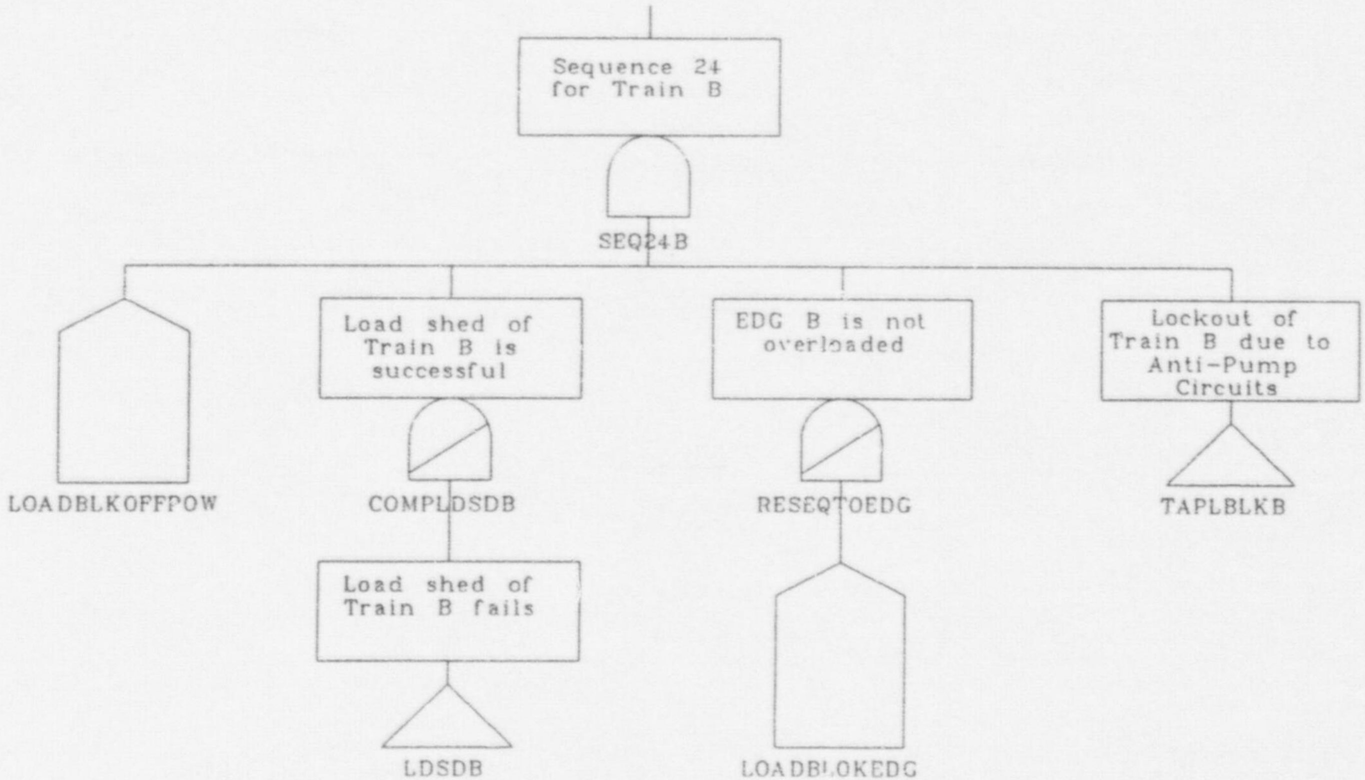
Sequence 18 for Train B
SEQ18B
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train B fails
LDSDB
Time delay of Train B fails
TIMDELB
No damage of pumps of Train B
COMPDAMAGEB
Damage of pumps of Train B
TRANDAMB
EDG of Train B is not overloaded
COMPEXLOADEDGB
Excessive load causes EDG B overload
EXLODG2B
Automatic reset of LOCA sequencing of Train B fails
RESETQB

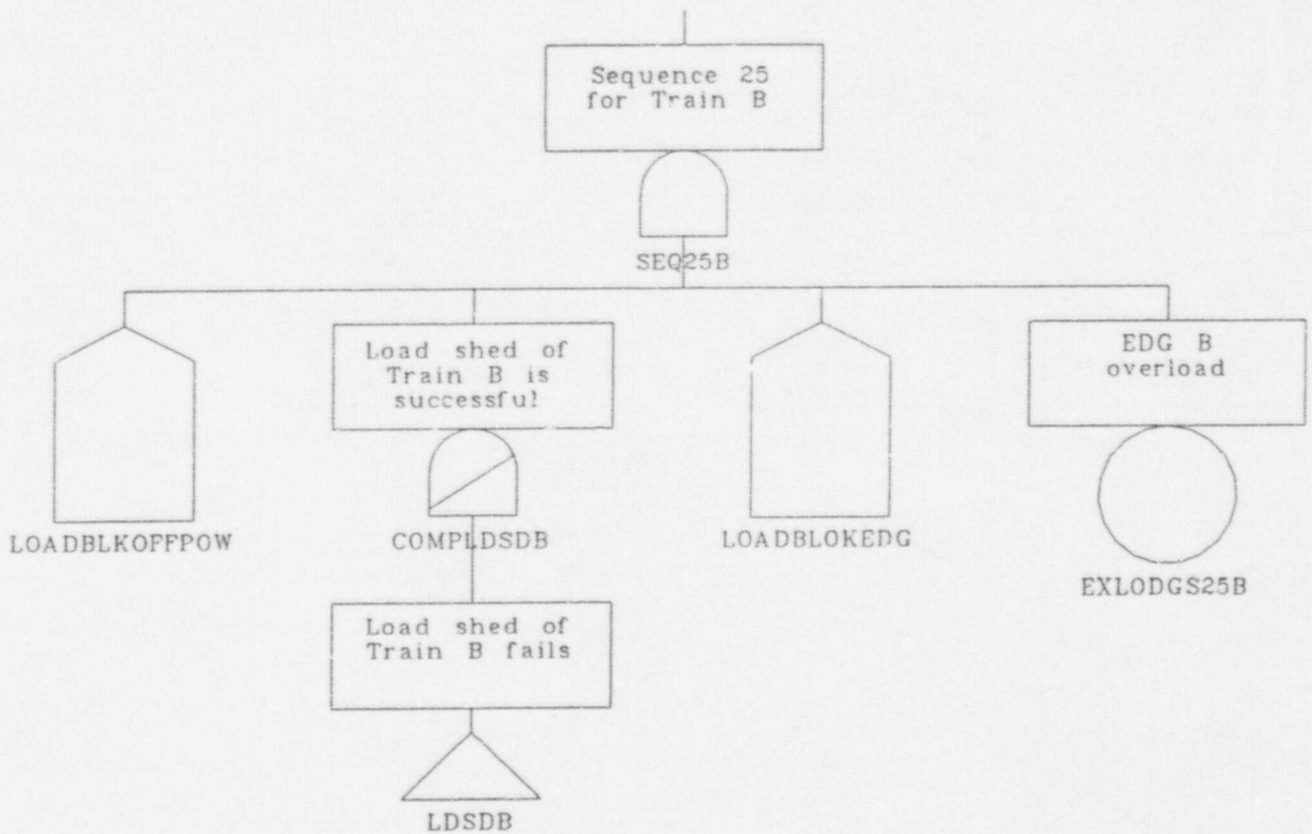

Sequence 19 for Train B
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train B fails
LDSDB
Time delay of Train B fails
No damage of pumps of Train B
COMPDAMAGEB
Damage of pumps of Train B
TRANDAMB
Excessive load causes EDG B overload
EXLODG2B


Sequence 20 for Train B
SEQ20B
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train B fails
LDSDB
Time delay of Train B fails
TIMDELB
Damage of pumps of Train B
TRANDAMB

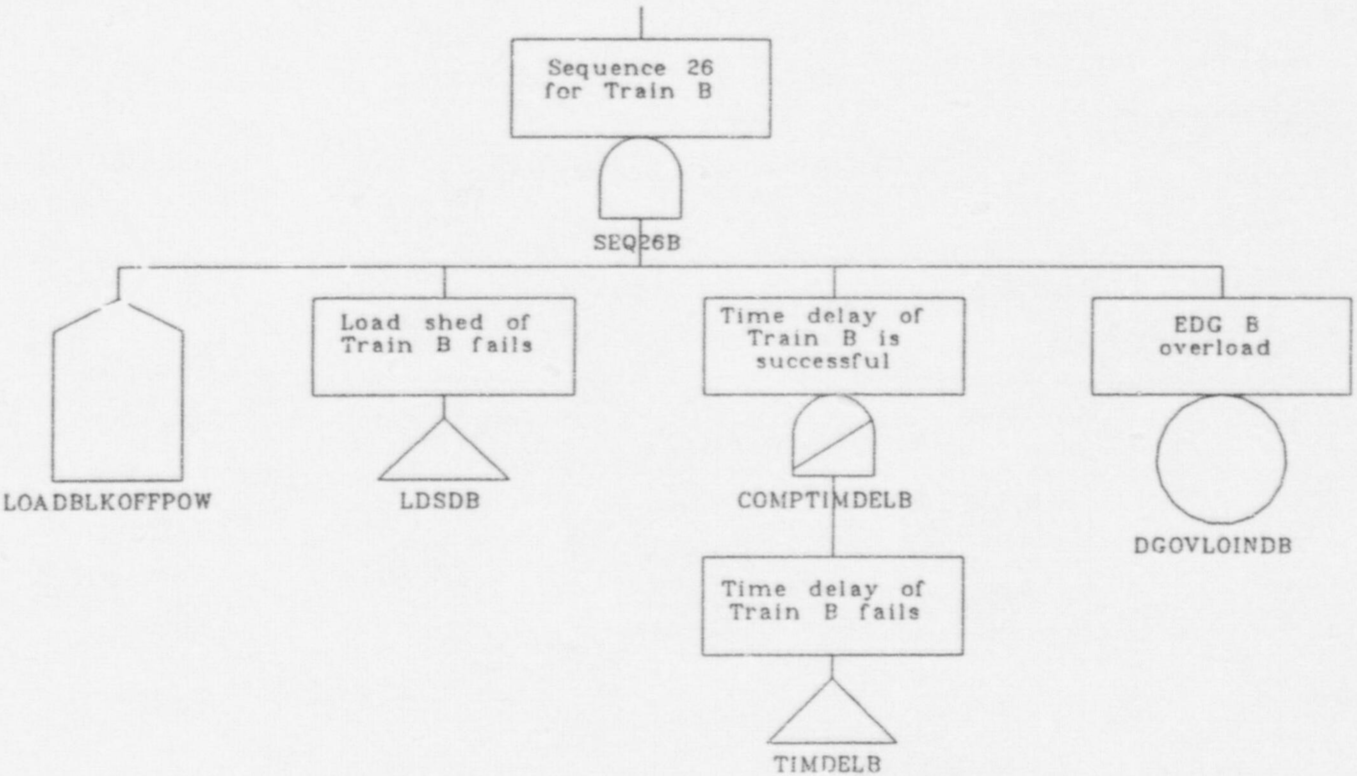


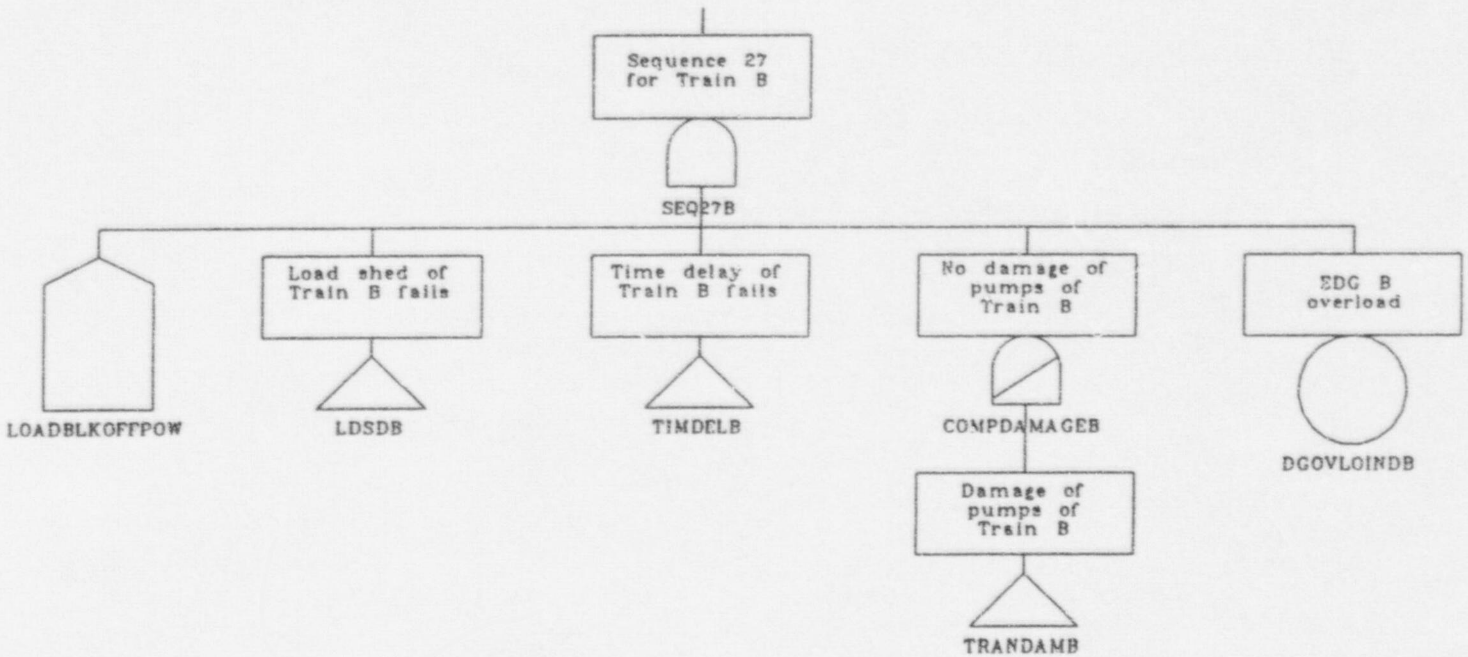
Sequence 23 for Train B
SEQ23B
LOADBLKOFFPOW
Load shed of Train B is successful
COMPLDSDB
Load shed of Train B fails
LDSDB
EDG B is not overloaded
RESEQTOEDG
LOADBLOKEDG
Train B not impacted by Anti-Pump Circuits
COMPTAPLBLKB
Lockout of Train B due to Anti-Pump Circuits
TAPLBLKB
Pump overload due to valve open of Train B
VALVOPB


Sequence 24
for Train B
SEQ24B
LOADBLKOFFPOW
Load shed of
Train B is
successful
COMPLDSDB
Load shed of
Train B fails
LDSDB
EDG B is not
overloaded
RESEQTOEDG
LOADBLOKEDG
Lockout of
Train B due to
Anti-Pump
Circuits
TAPLBLKB

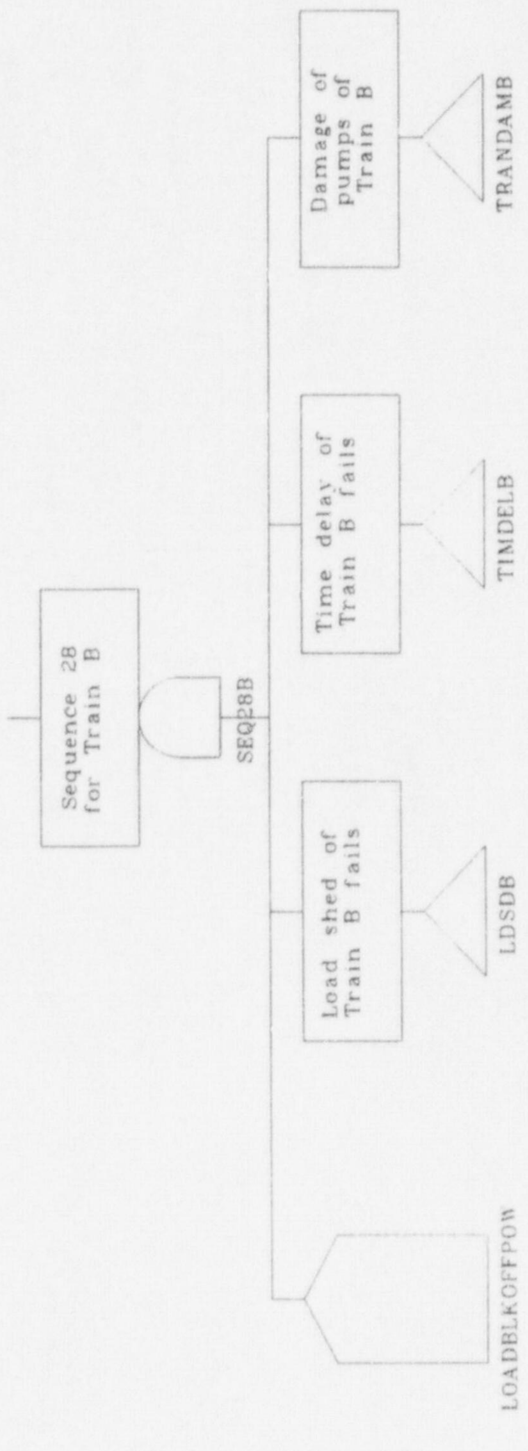


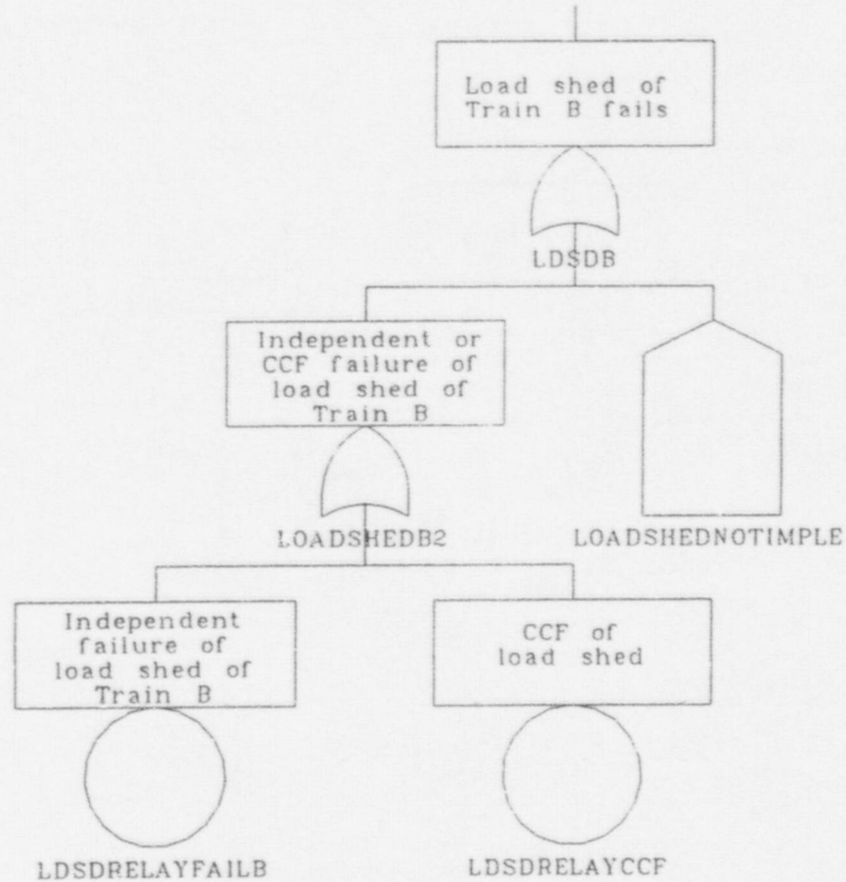
Sequence 25 for Train B
SEQ25B
LOADBLKOFFPOW
Load shed of Train B is successful
COMPLDSDB
Load shed of Train B fails
LDSDB
LOADBLOKEDG
EDG B overload
EXLODGS25B

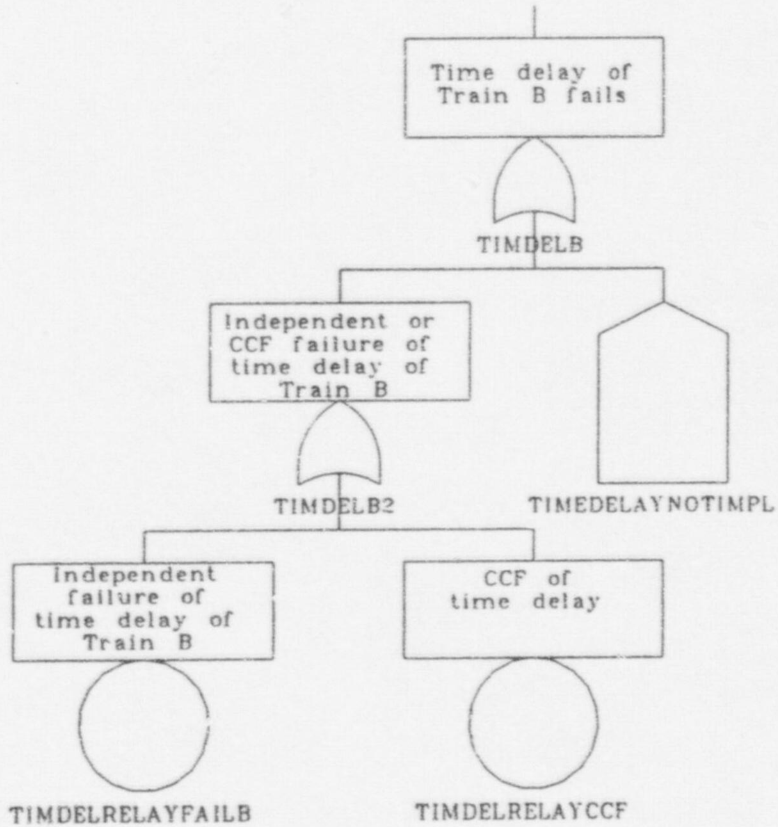

Sequence 26 for Train B
SEQ26B
LOADBLKOFFPOW
Load shed of Train B fails
LDSDB
Time delay of Train B is successful
COMPTIMDELB
Time delay of Train B fails
TIMDELB
EDG B overload
DGOVLOINDB

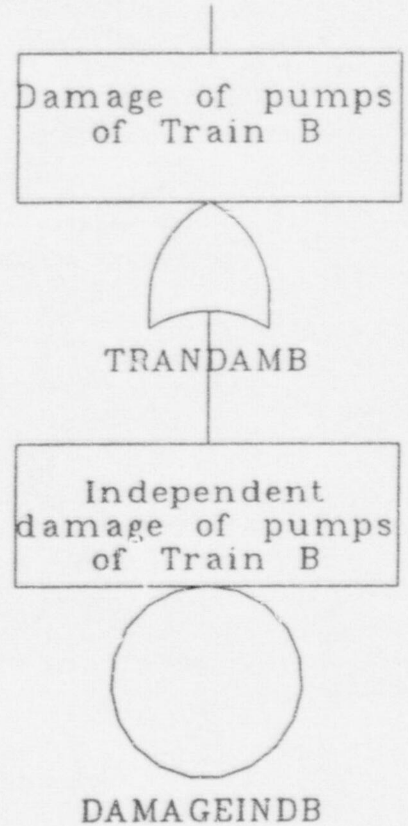


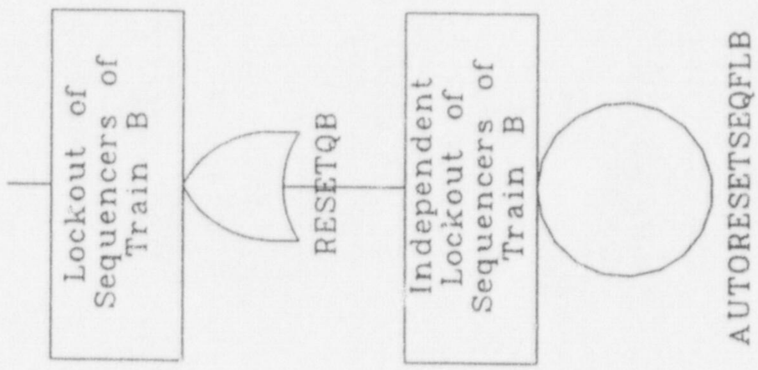
Sequence 27 for Train B
SEQ27B
LOADBLKOFFPOW
Load shed of Train B fails
LDSDB
Time delay of Train B fails
TIMDELB
No damage of pumps of Train B
COMPDAMAGEB
Damage of pumps of Train B
TRANDAMB
EDG B overload
DGOVLOINDB

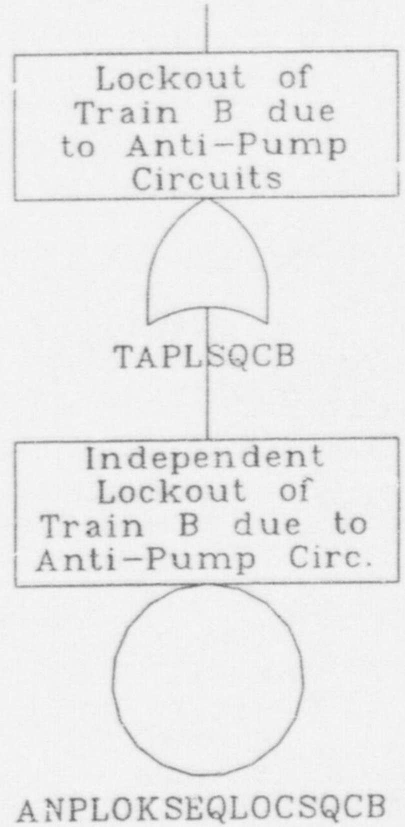

Sequence 28 for Train B
SEQ28B
Load shed of Train B fails
LDSDB
Time delay of Train B fails
TIMDELB
Damage of pumps of Train B
TRANDAMB
LOADBLKOFFPOW

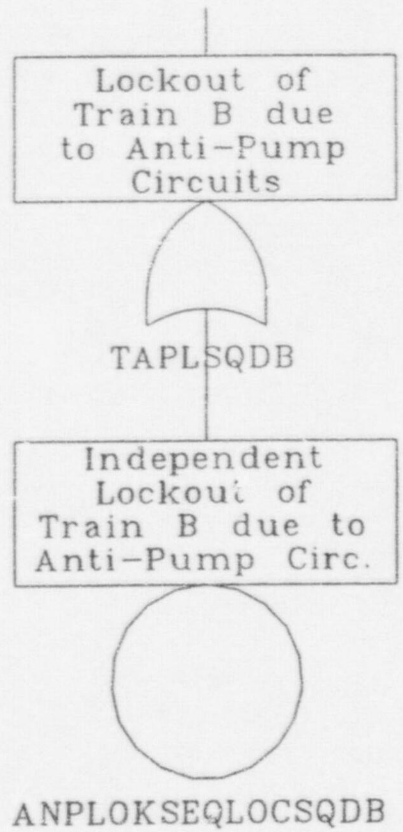

Load shed of Train B fails
LDSDB
Independent or CCF failure of load shed of Train B
LOADSHEDB2
LOADSHEDNOTIMPLE
Independent failure of load shed of Train B
CCF of load shed
LDSDRELAYFAILB
LDSDRELAYCCF

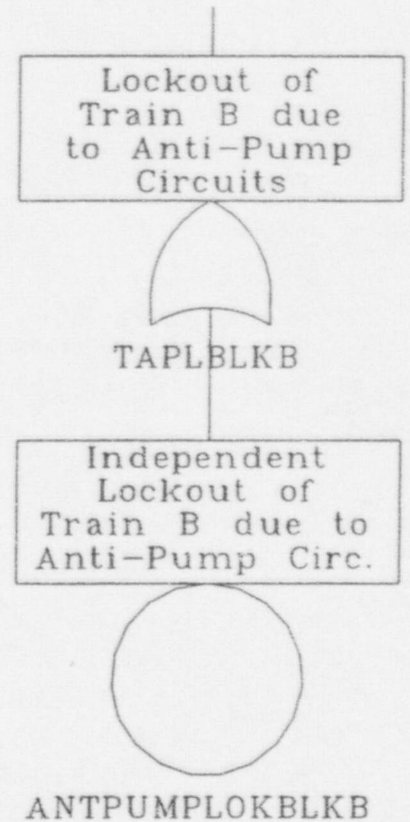

Time delay of Train B fails
TIMDELB
Independent or CCF failure of time delay of Train B
TIMDELB2
TIMEDELAYNOTIMPL
Independent failure of time delay of Train B
CCF of time delay
TIMDELRELAYFAILB
TIMDELRELAYCCF

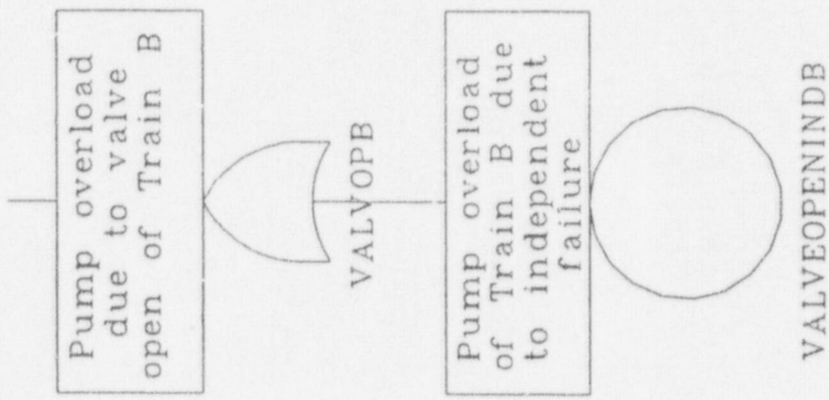

Damage of pumps of Train B
TRANDAMB
Independent damage of pumps of Train B
DAMAGEINDB

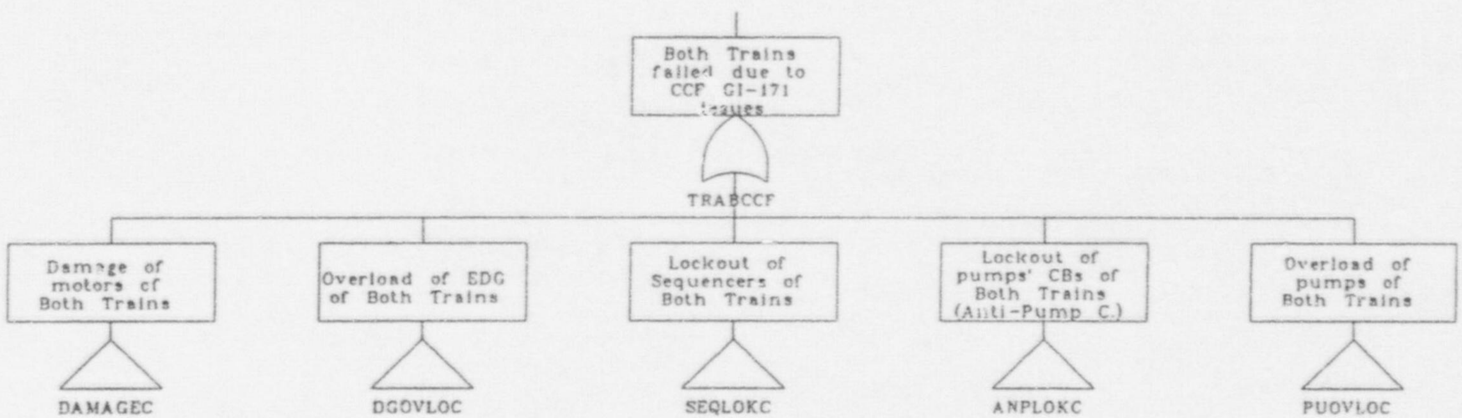

Lockout of Sequencers of Train B
RESETQB
Independent Lockout of Sequencers of Train B
AUTORESETSEQFLB

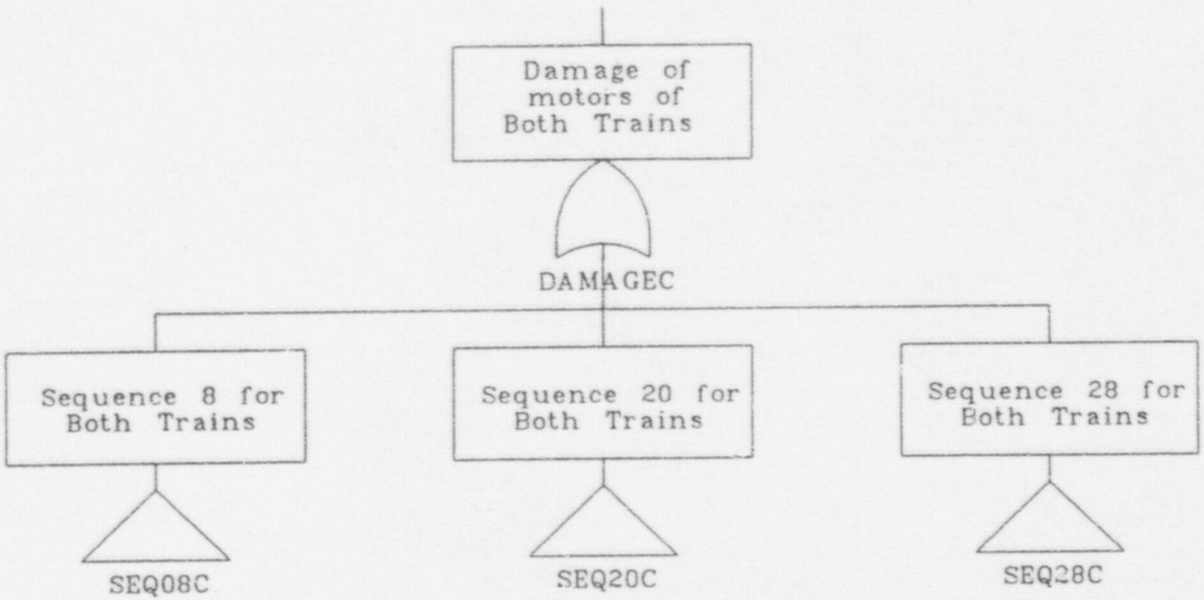

Lockout of Train B due to Anti-Pump Circuits
TAPLSQCB
Independent Lockout of Train B due to Anti-Pump Circ.
ANPLOKSEQLOCSQCB


Lockout of Train B due to Anti-Pump Circuits
TAPLSQDB
Independent Lockout of Train B due to Anti-Pump Circ.
ANPLOKSEQLOCSQDB

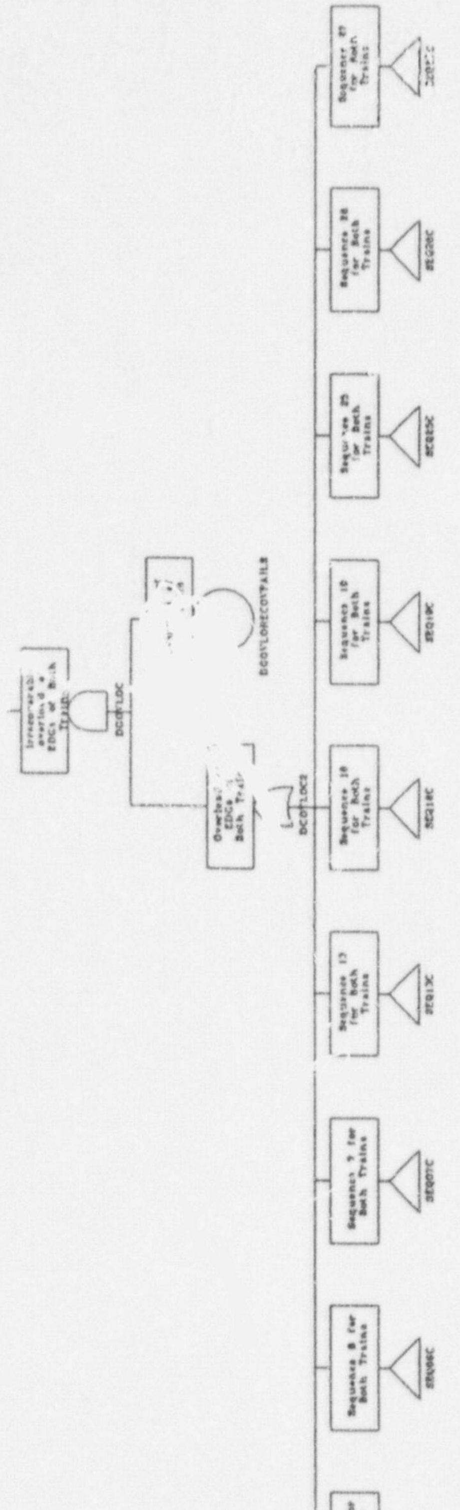

Lockout of Train B due to Anti-Pump Circuits
TAPLBLKB
Independent Lockout of Train B due to Anti-Pump Circ.
ANTPUMPLOKBLKB

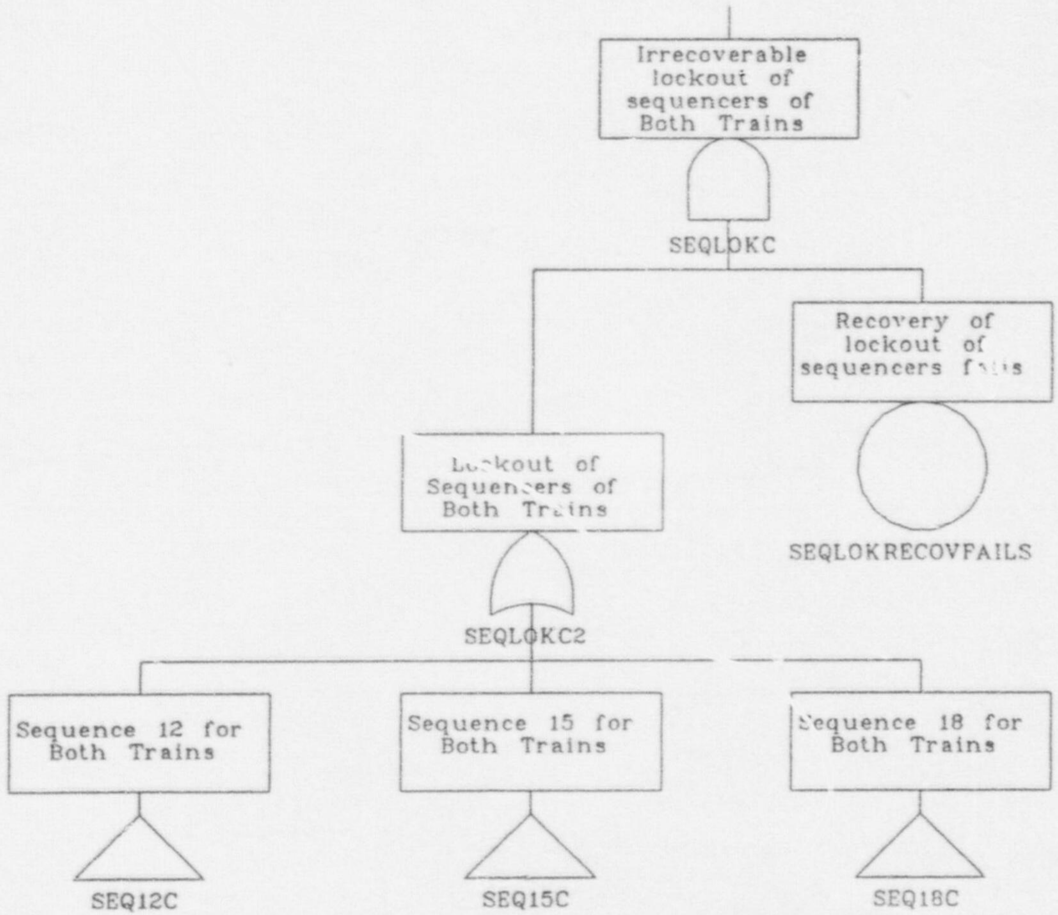

Pump overload due to valve open of Train B
VALVOPB
Pump overload of Train B due to independent failure
VALVEOPENINDB

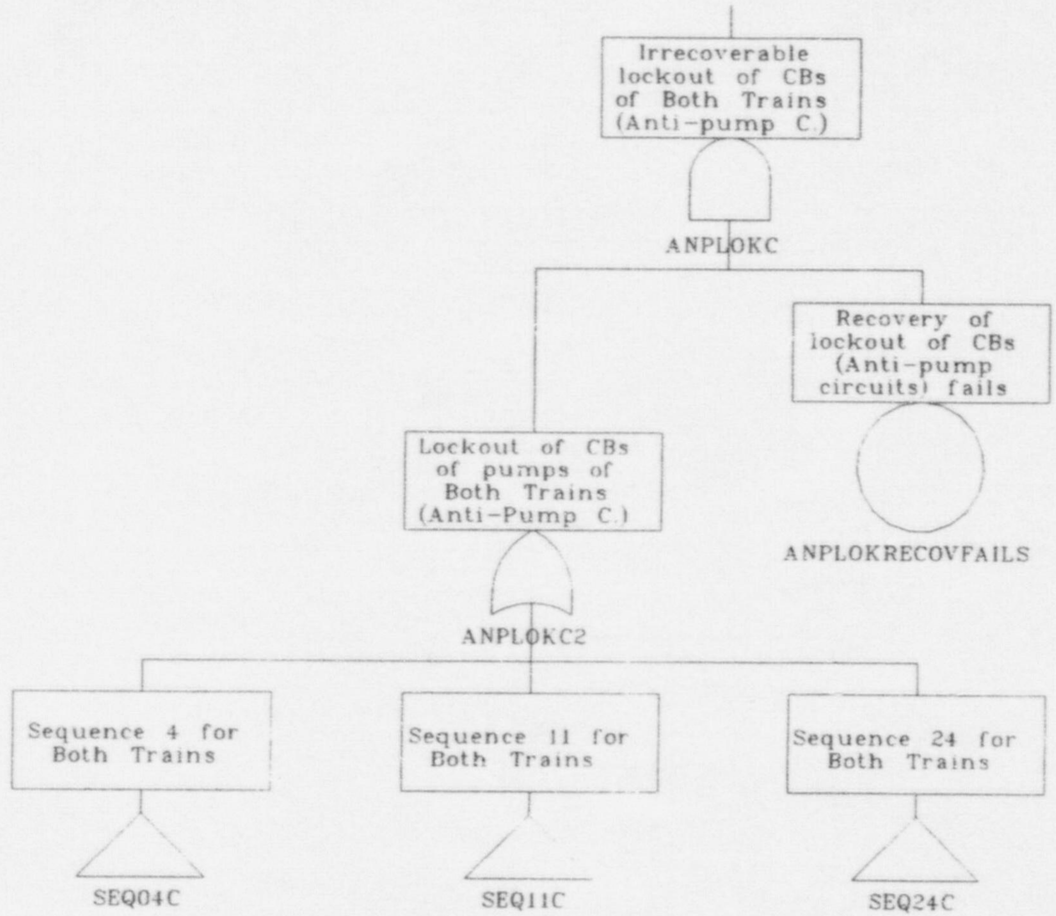

Both Trains failed due to CCF GI-171 Issues
TRABCCF
Damage of motors of Both Trains
DAMAGEC
Overload of EDG of Both Trains
DGOVLOC
Lockout of Sequencers of Both Trains
SEQLOKC
Lockout of pumps' CBs of Both Trains (Anti-Pump C.)
ANPLOKC
Overload of pumps of Both Trains
PUOVLOC

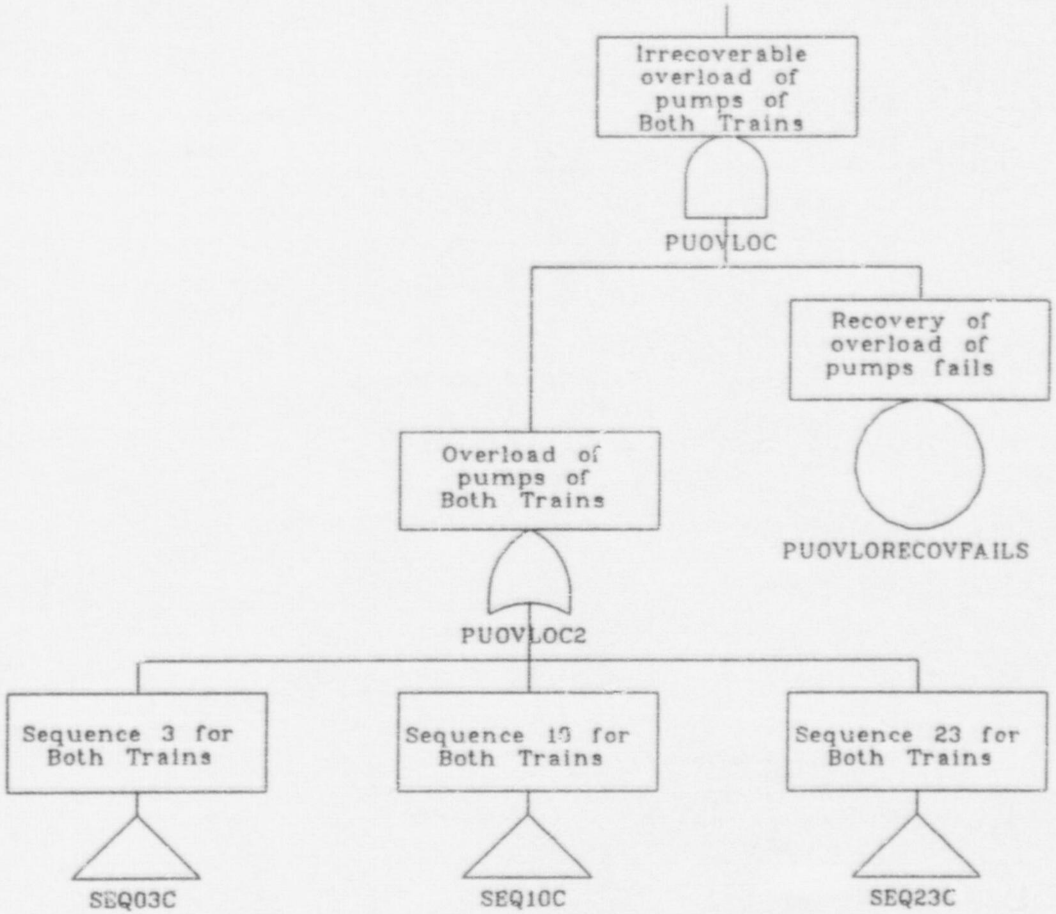


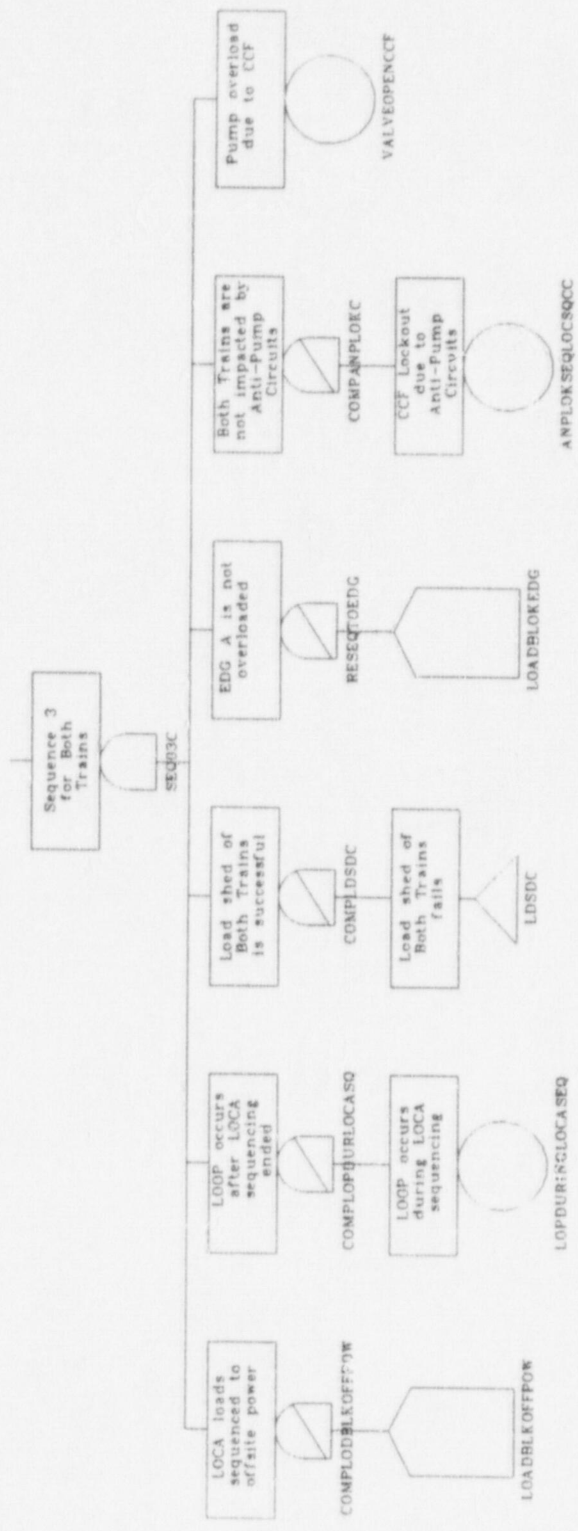
Damage of motors of Both Trains
DAMAGEC
Sequence 8 for Both Trains
Sequence 20 for Both Trains
Sequence 28 for Both Trains
SEQ08C
SEQ20C
SEQ28C

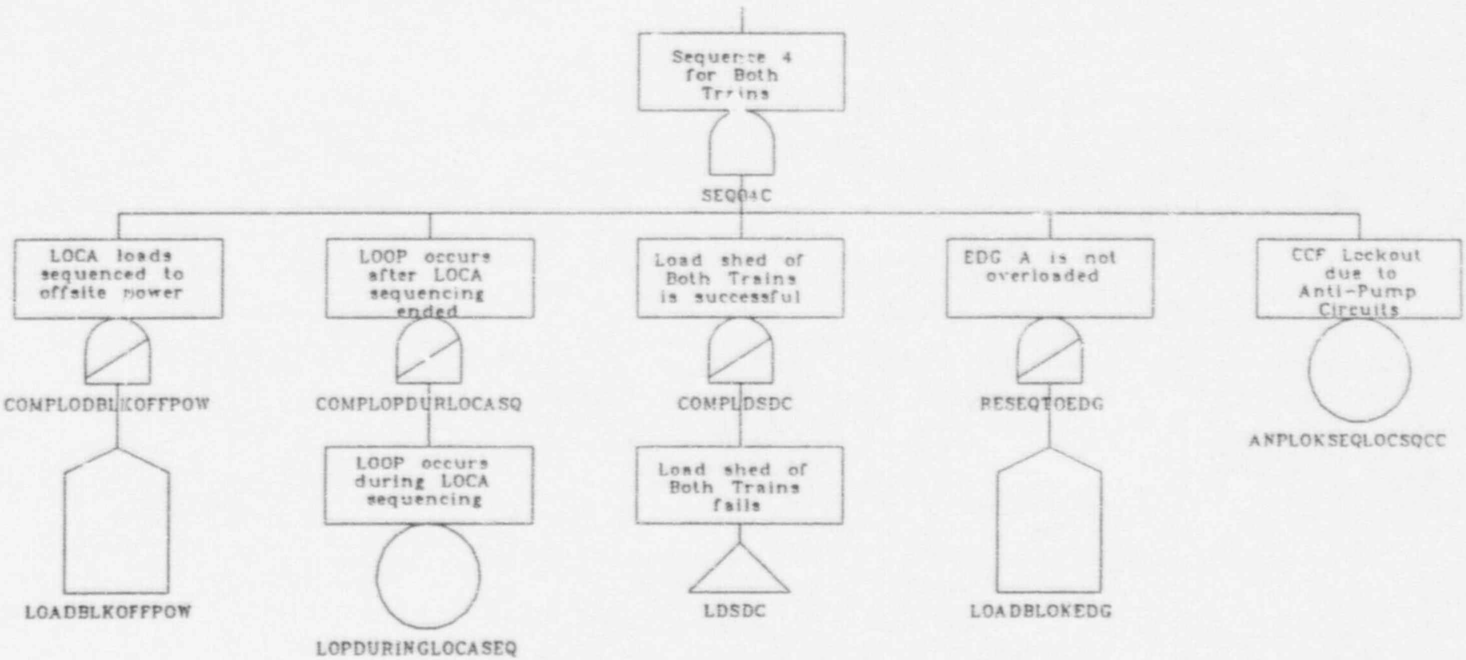


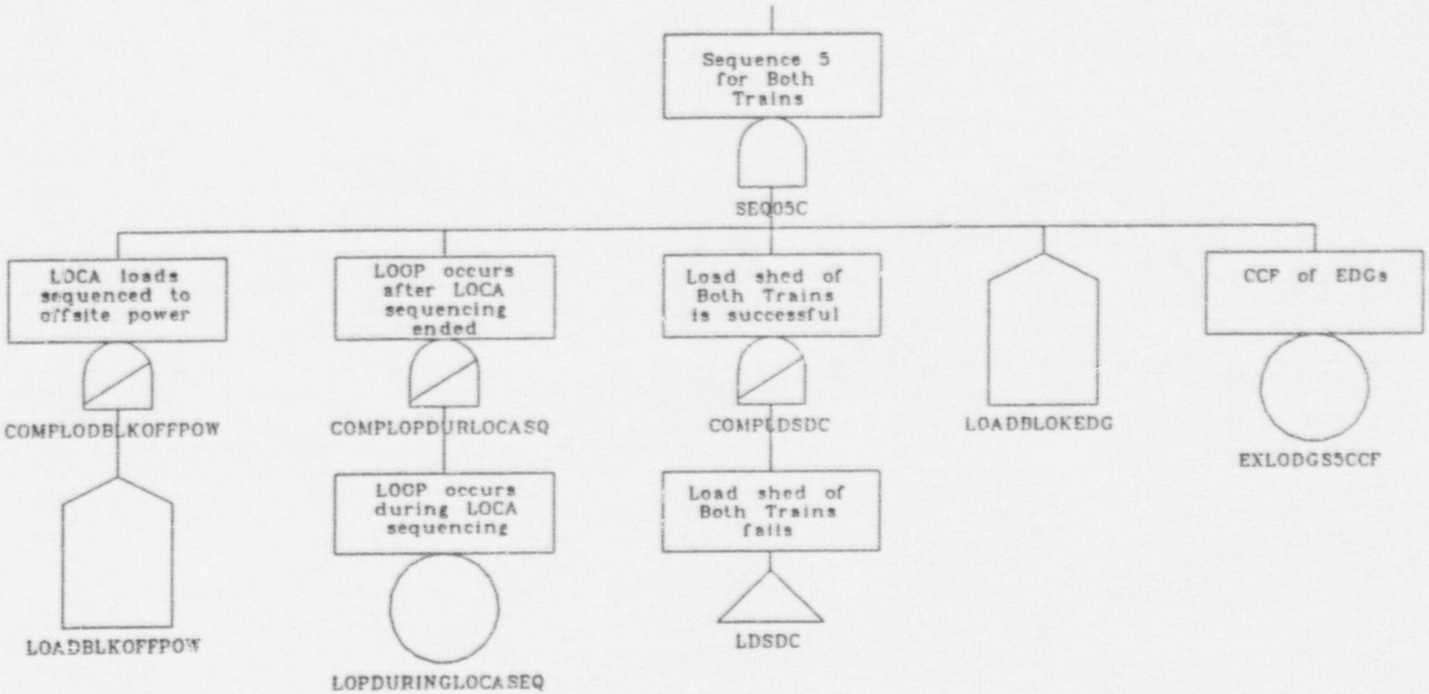

Irrecoverable lockout of sequencers of Both Trains
SEQLOKC
Recovery of lockout of sequencers fails
SEQLOKRECOVFAILS
Lockout of Sequencers of Both Trains
SEQLOKC2
Sequence 12 for Both Trains
Sequence 15 for Both Trains
Sequence 18 for Both Trains
SEQ12C
SEQ15C
SEQ18C


Irrecoverable lockout of CBs of Both Trains (Anti-pump C.)
ANPLOKC
Recovery of lockout of CBs (Anti-pump circuits) fails
ANPLOKRECOVFAILS
Lockout of CBs of pumps of Both Trains (Anti-Pump C.)
ANPLOKC2
Sequence 4 for Both Trains
SEQ04C
Sequence 11 for Both Trains
SEQ11C
Sequence 24 for Both Trains
SEQ24C

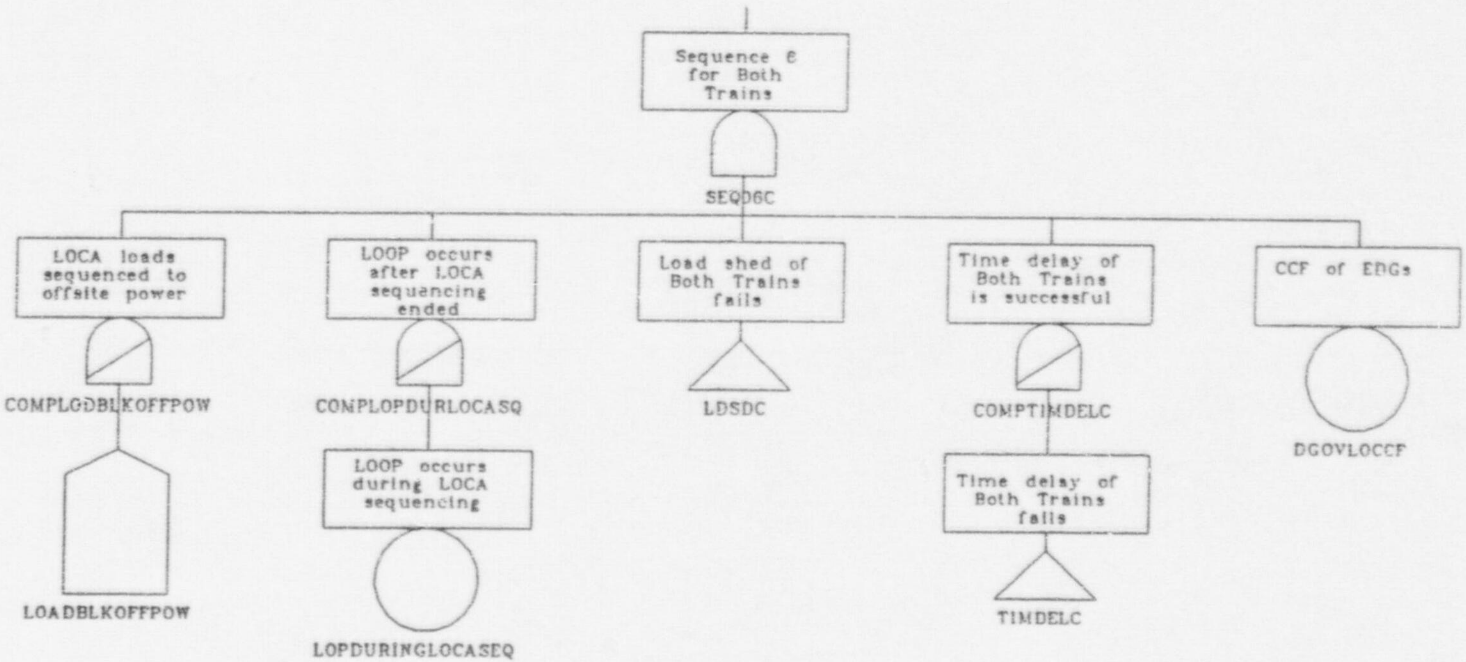

Irrecoverable overload of pumps of Both Trains
PUOVLOC
Recovery of overload of pumps fails
PUOVLORECOVFAILS
Overload of pumps of Both Trains
PUOVLOC2
Sequence 3 for Both Trains
SEQ03C
Sequence 10 for Both Trains
SEQ10C
Sequence 23 for Both Trains
SEQ23C

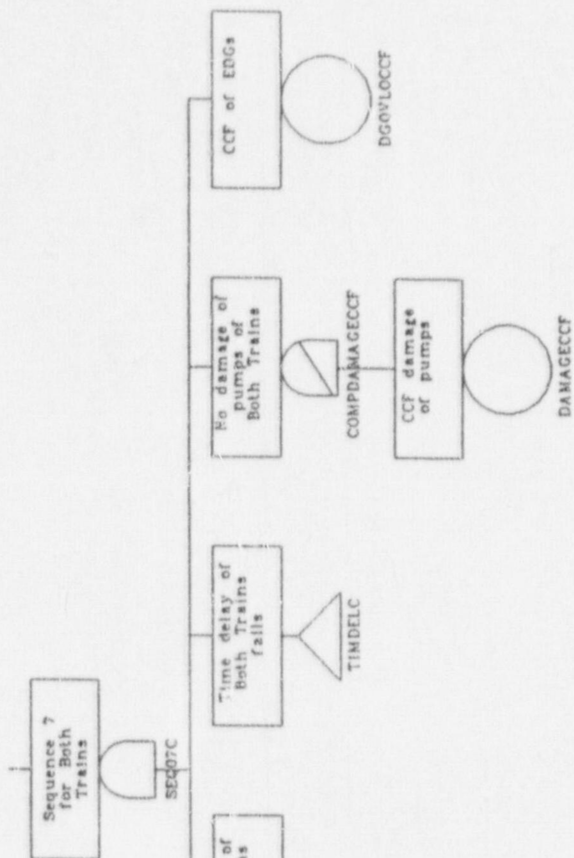

Sequence 3 for Both Trains
SEQ3C
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASQ
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Both Trains is successful
COMPLDSDC
Load shed of Both Trains fails
LDSDC
EDG A is not overloaded
RESEQTOEDG
LOADBLOKEDG
Both Trains are not impacted by Anti-Pump Circuits
COMPANPLOKC
CCF Lockout due to Anti-Pump Circuits
ANPLOKSEQLOCSQCC
Pump overload due to CCF
VALVEOPENCCF

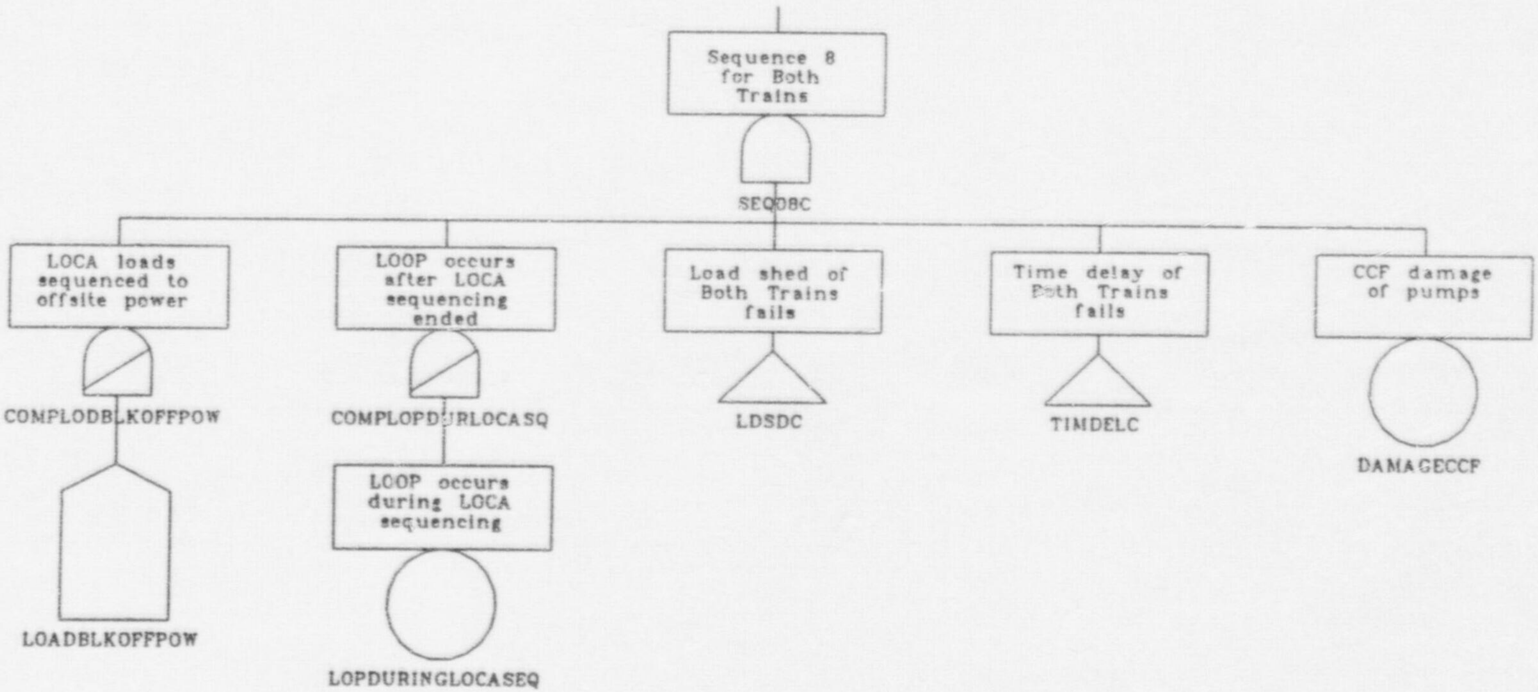

Sequence 4 for Both Trains
SEQ04C
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASQ
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Both Trains is successful
COMPLDSDC
Load shed of Both Trains fails
LDSDC
EDG A is not overloaded
RESEQTOEDG
LOADBLOKEDG
CCF Lockout due to Anti-Pump Circuits
ANPLOKSEQLOCSQCC

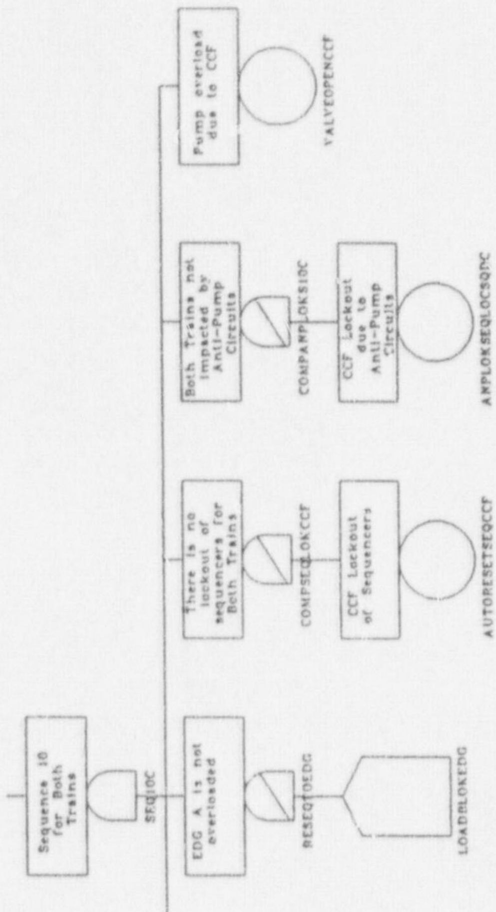


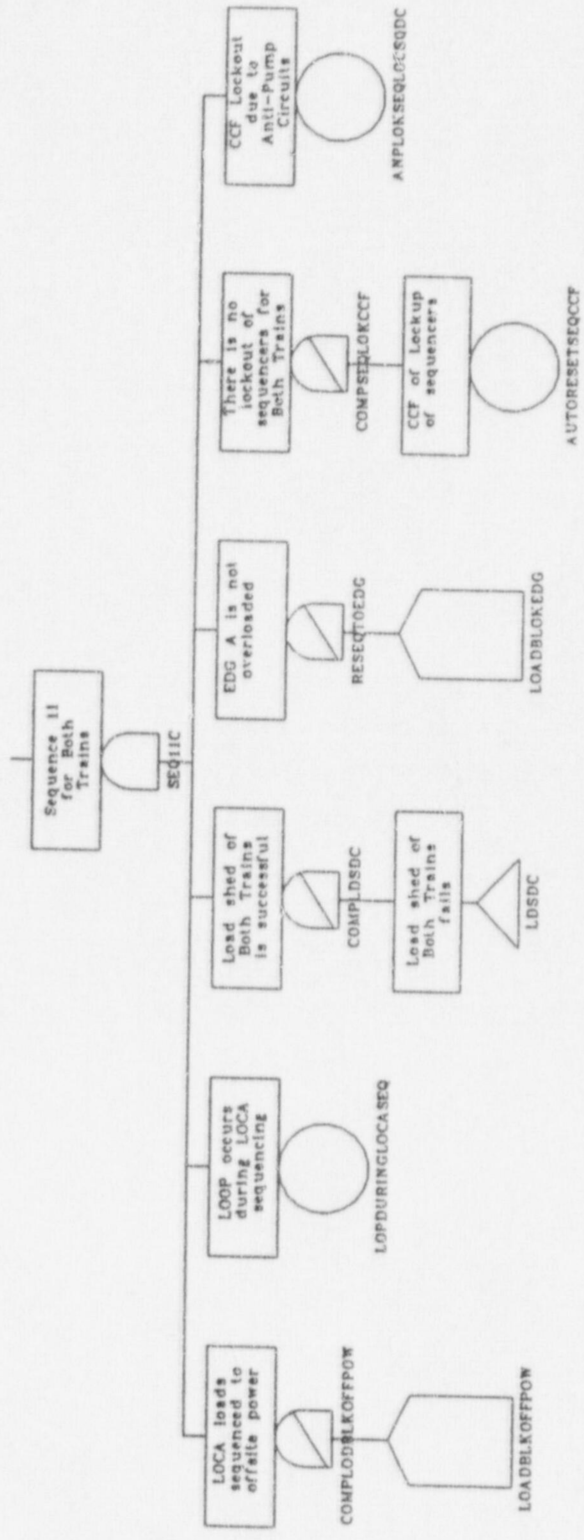
Sequence 5 for Both Trains
SEQ05C
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASQ
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Both Trains is successful
COMPLDSDC
Load shed of Both Trains fails
LDSDC
LOADBLOKEDG
CCF of EDGs
EXLODGS5CCF

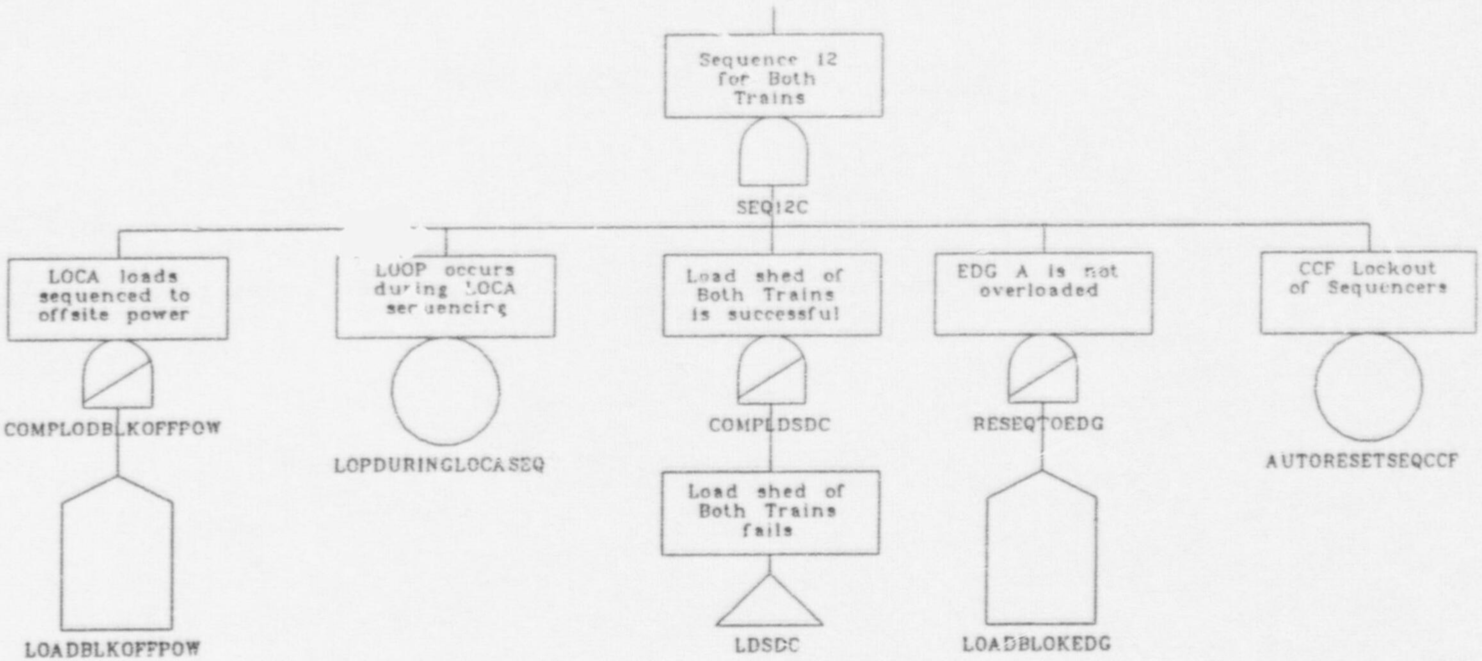

Sequence 6 for Both Trains
SEQ06C
LOCA loads sequenced to offsite power
COMPLGDBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASQ
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Both Trains fails
LDSDC
Time delay of Both Trains is successful
COMPTIMDELC
Time delay of Both Trains fails
TIMDELC
CCF of EDGs
DGOVLOCCF

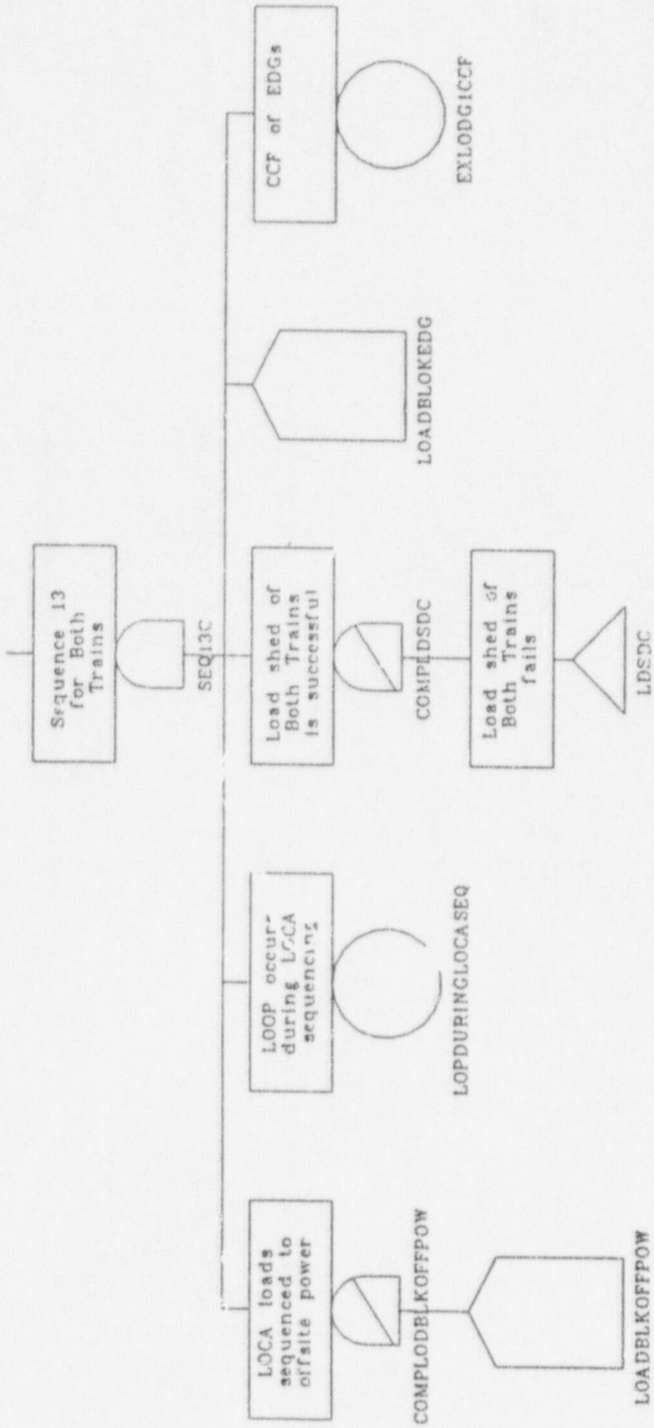

Sequence 7 for Both Trains
SEQ07C
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASQ
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Both Trains fails
LDSDC
Time delay of Both Trains fails
TIMDELC
No damage of pumps of Both Trains
COMPDAMAGECCF
CCF damage of pumps
DAMAGECCF
CCF of EDGs
DGOVLOCCF

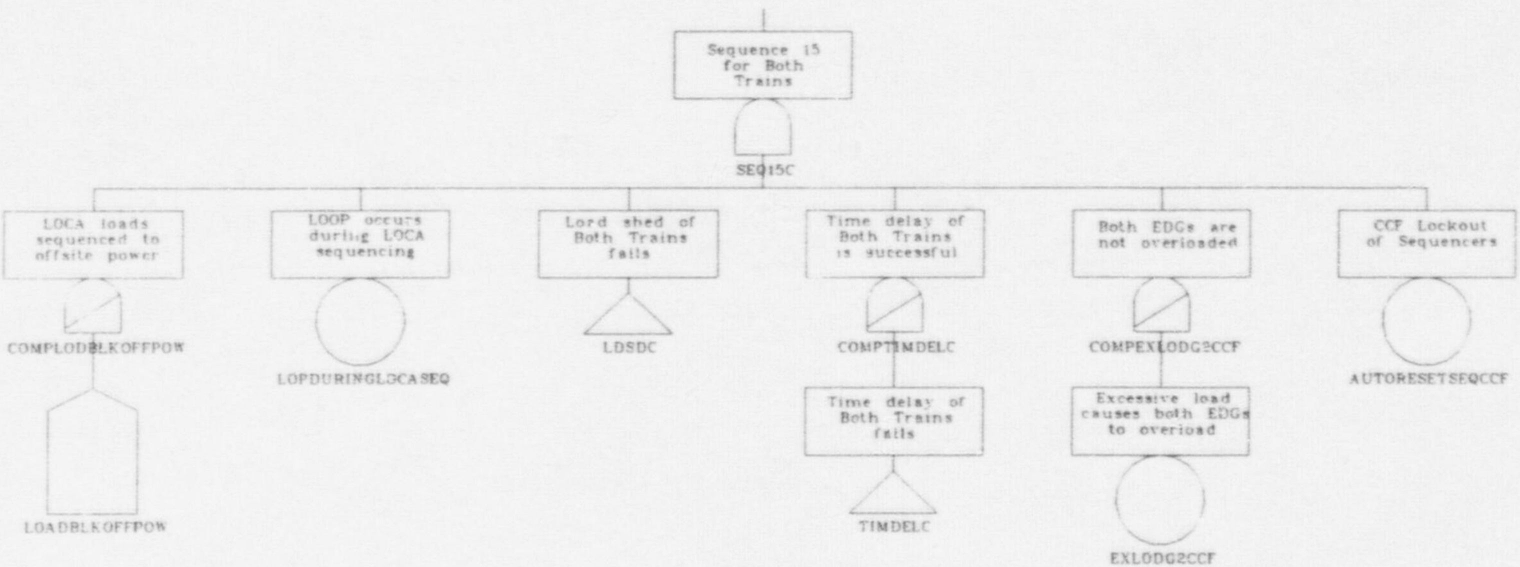

Sequence 8 for Both Trains
SEQ08C
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs after LOCA sequencing ended
COMPLOPDURLOCASQ
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Both Trains fails
LDSDC
Time delay of Both Trains fails
TIMDELC
CCF damage of pumps
DAMAGECCF


Sequence 10 for Both Trains
SEQ10C
LOCA loads sequenced to offsite power
CONPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Train A is successful
CONPLDSDC
Load shed of Train A fails
LDSDC
EDG A is not overloaded
RESEQTOEDG
LOADBLOKEDG
There is no lockout of sequencers for Both Trains
COMPSEQLOKCCF
CCF Lockout of Sequencers
AUTORESETSEQCCF
Both Trains not impacted by Anti-Pump Circuits
COMPANPLOKS10C
CCF Lockout due to Anti-Pump Circuits
ANPLOKSEQLOCSQPC
Pump overload due to CCF
VALVEOPENCCF

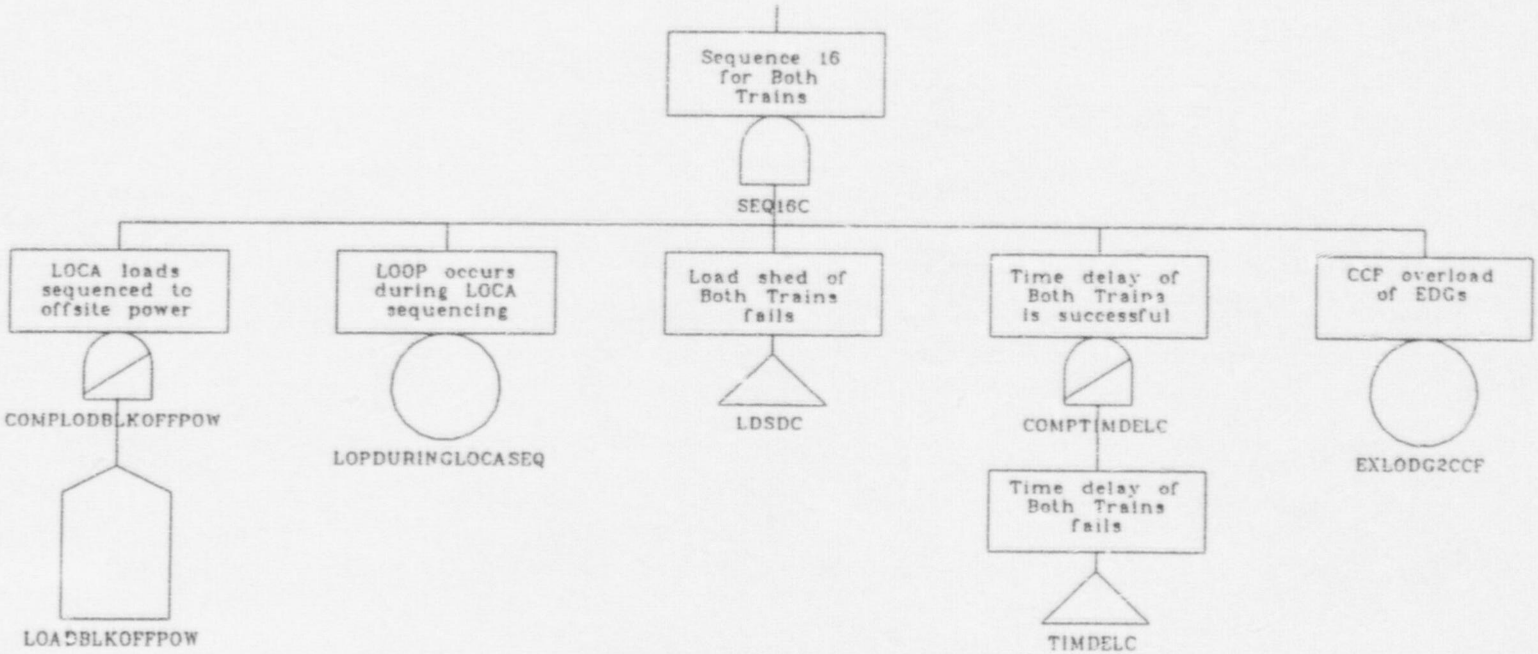

Sequence 11 for Both Trains
SEQ11C
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Both Trains is successful
COMPLDSDC
Load shed of Both Trains fails
LDSDC
EDG A is not overloaded
RESEQTOEDG
LOADBLOKEDG
There is no lockout of sequencers for Both Trains
COMPSEQLOKCCF
CCF of Lockup of sequencers
AUTORESETSEQCCF
CCF Lockout due to Anti-Pump Circuits
ANPLOKSEQLOCSQDC

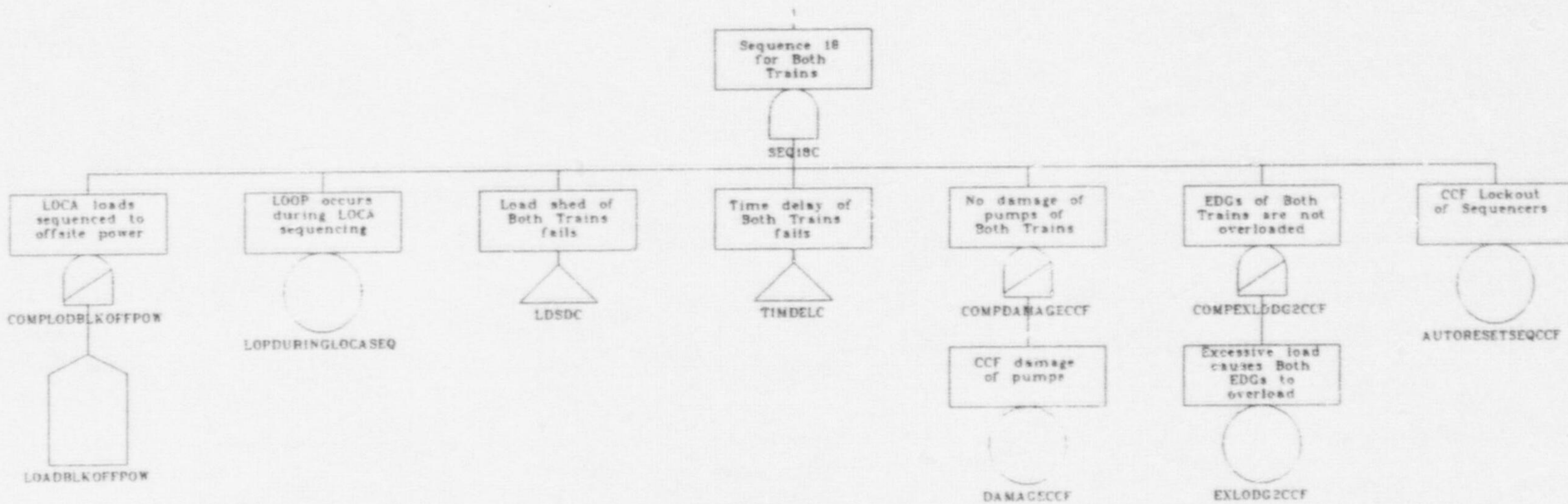

Sequence 12 for Both Trains
SEQ12C
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LUOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Both Trains is successful
COMPLDSDC
Load shed of Both Trains fails
LDSDC
EDG A is not overloaded
RESEQTOEDG
LOADBLOKEDG
CCF Lockout of Sequencers
AUTORESETSEQCCF


Sequence 13 for Both Trains
SEQ13C
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Both Trains is successful
COMPLDSDC
Load shed of Both Trains fails
LDSDC
LOADBLOKEDG
CCF of EDGs
EXLODGICCF

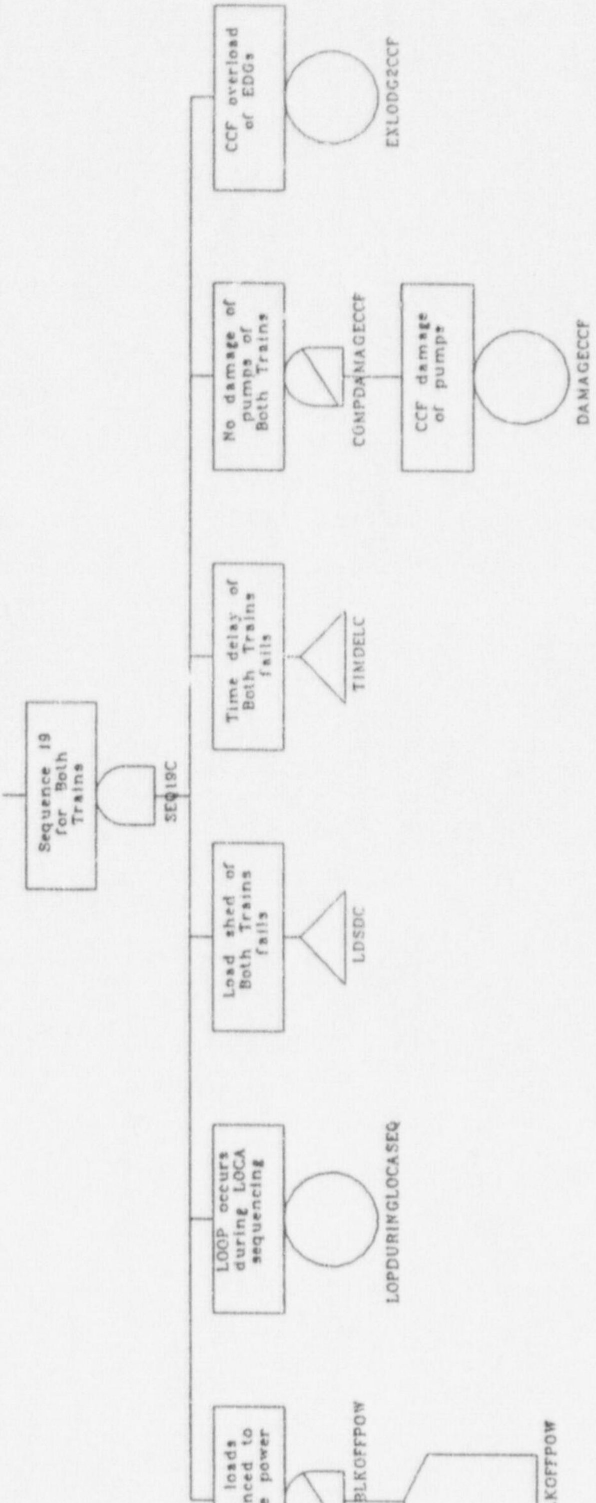


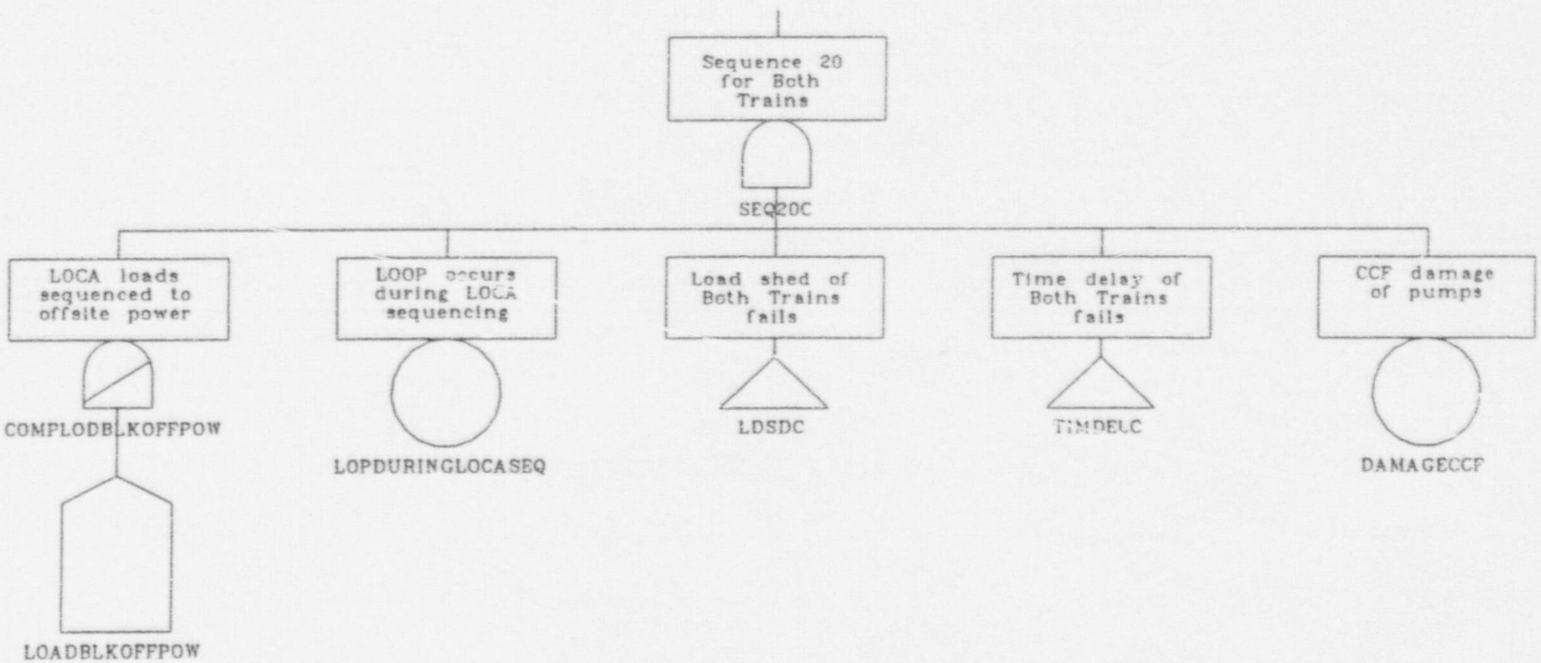
Sequence 15 for Both Trains
SEQ15C
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Lord shed of Both Trains fails
LDSDC
Time delay of Both Trains is successful
COMPTIMDELC
Time delay of Both Trains fails
TIMDELC
Both EDGs are not overloaded
COMPEXLODG2CCF
Excessive load causes both EDGs to overload
EXLODG2CCF
CCF Lockout of Sequencers
AUTORESETSEQCCF

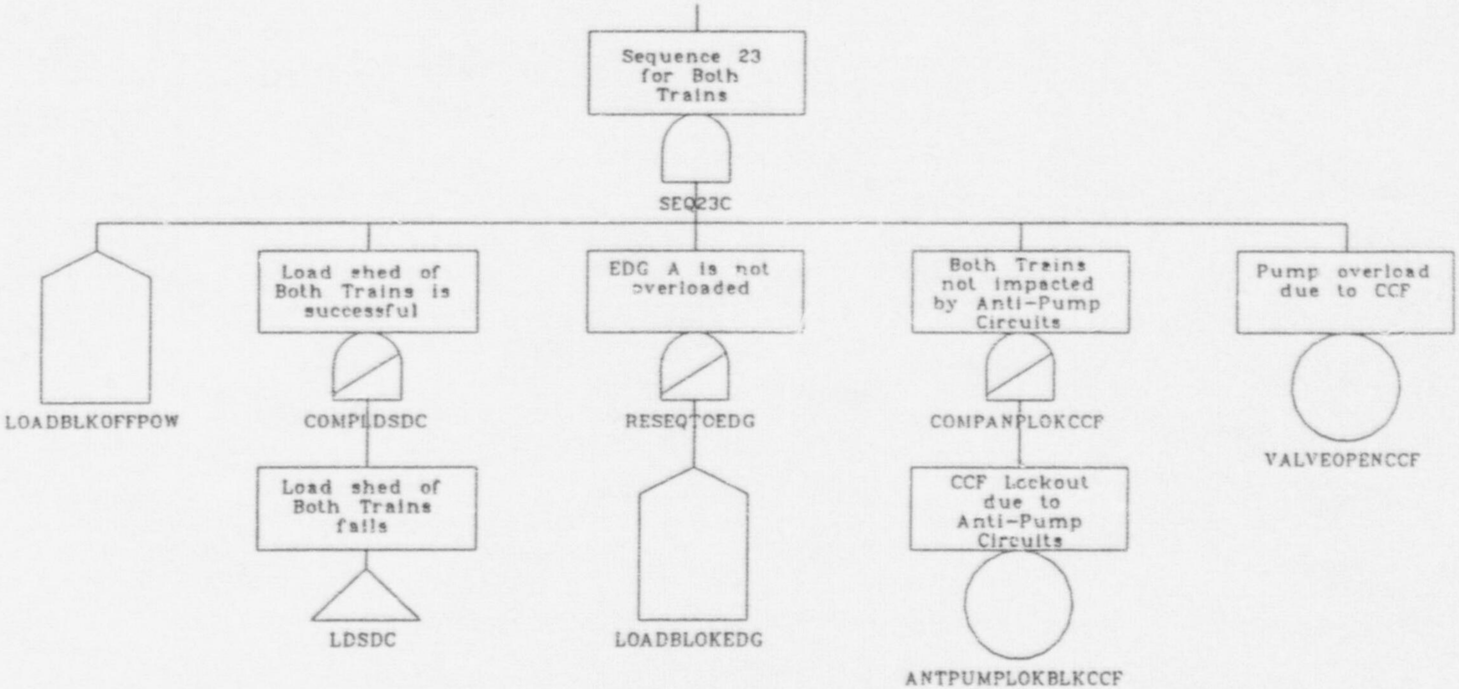

Sequence 16 for Both Trains
SEQ16C
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Both Trains fails
LDSDC
Time delay of Both Trains is successful
COMPTIMDELC
Time delay of Both Trains fails
TIMDELC
CCF overload of EDGs
EXLODG2CCF

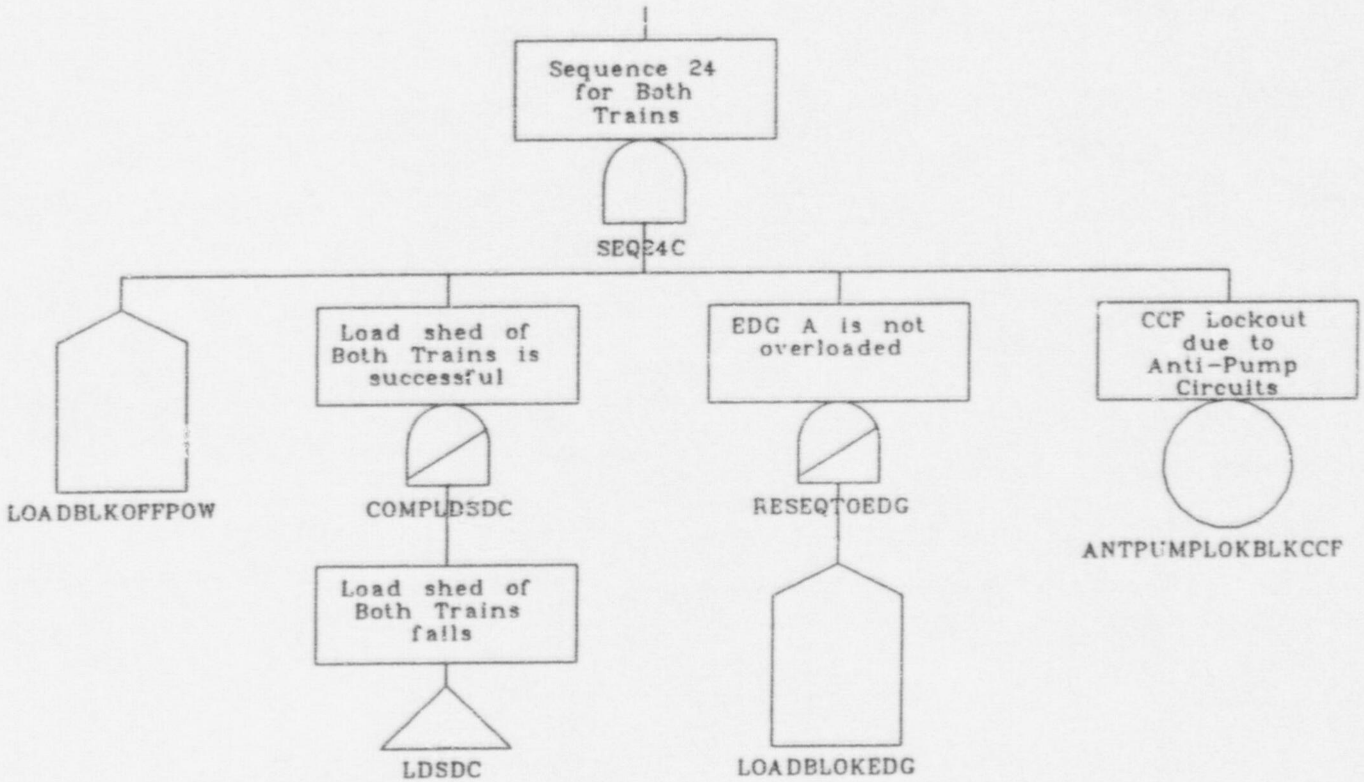


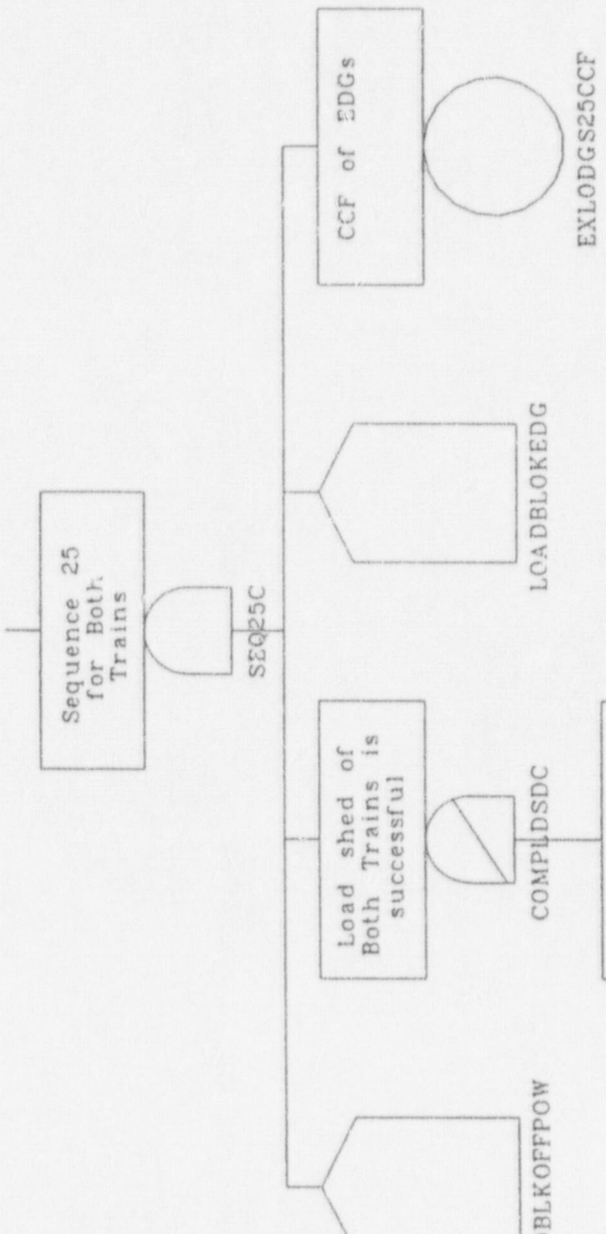
Sequence 18 for Both Trains
SEQ18C
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Both Trains fails
LDSDC
Time delay of Both Trains fails
TIMDELC
No damage of pumps of Both Trains
COMPDAMAGECCF
CCF damage of pumps
DAMAGECCF
EDGs of Both Trains are not overloaded
COMPEXLODG2CCF
Excessive load causes Both EDGs to overload
EXLODG2CCF
CCF Lockout of Sequencers
AUTORESETSEQCCF

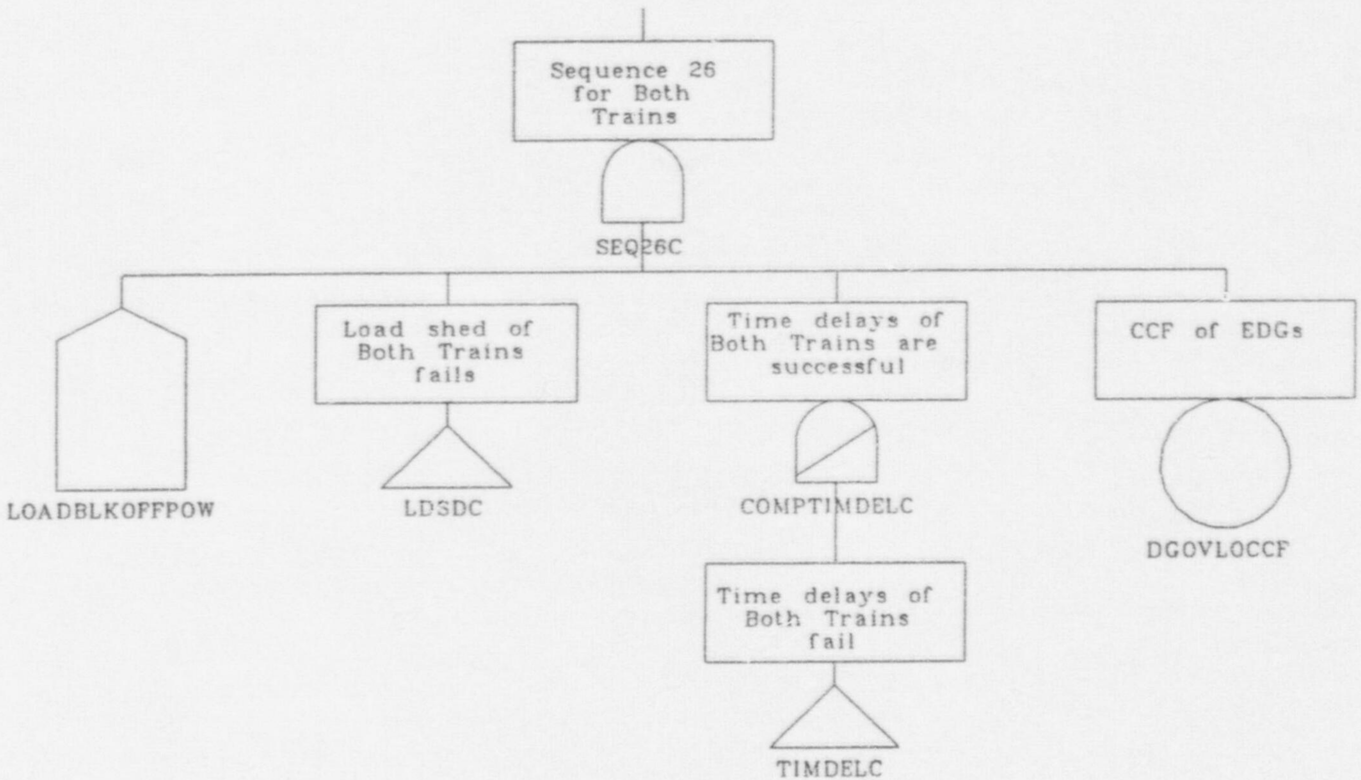

Sequence 19 for Both Trains
SEQ19C
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Both Trains fails
LDSDC
Time delay of Both Trains fails
TIMDELC
No damage of pumps of Both Trains
COMPDAMAGECCF
CCF damage of pumps
DAMAGECCF
CCF overload of EDGs
EXLODG2CCF

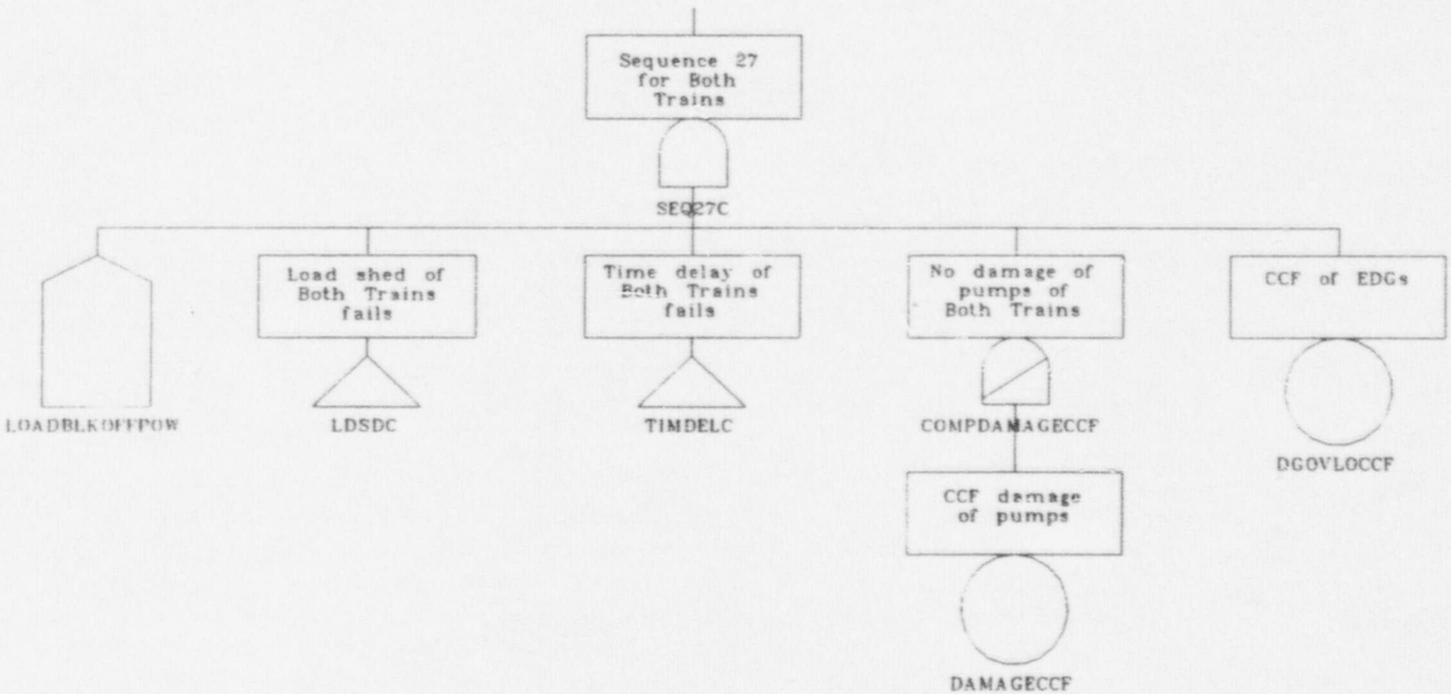

Sequence 20 for Both Trains
SEQ20C
LOCA loads sequenced to offsite power
COMPLODBLKOFFPOW
LOADBLKOFFPOW
LOOP occurs during LOCA sequencing
LOPDURINGLOCASEQ
Load shed of Both Trains fails
LDSDC
Time delay of Both Trains fails
TIMDELC
CCF damage of pumps
DAMAGECCF

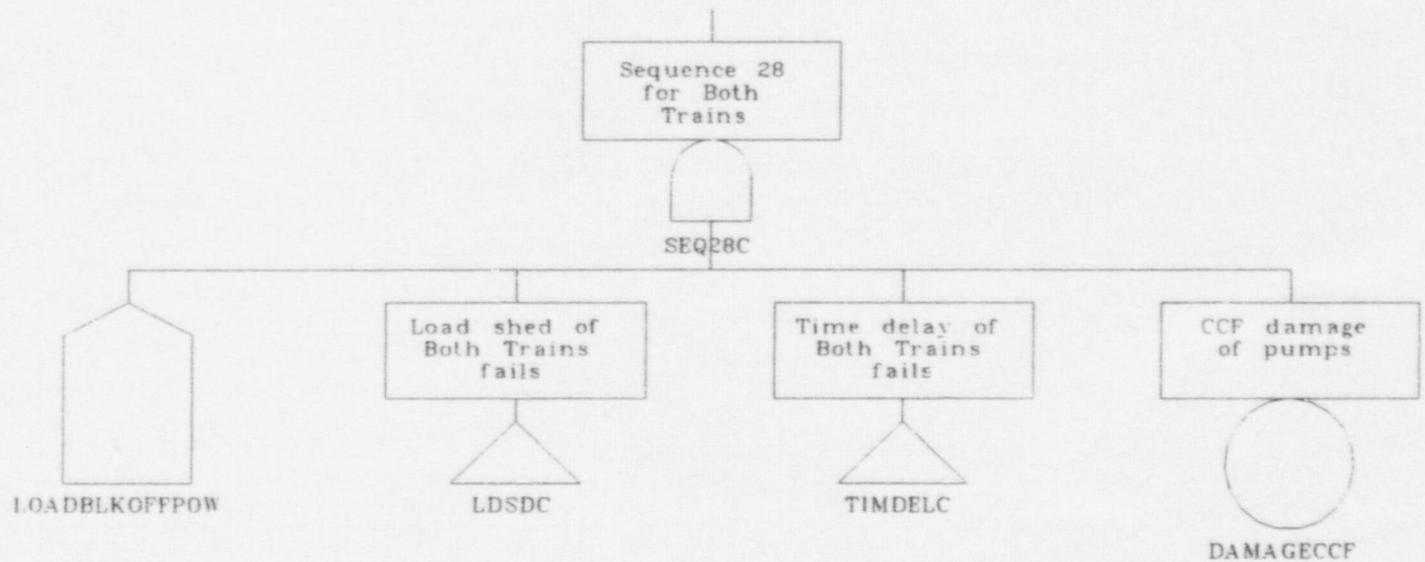

Sequence 23 for Both Trains
SEQ23C
LOADBLKOFFPOW
Load shed of Both Trains is successful
COMPLDSDC
Load shed of Both Trains fails
LDSDC
EDG A is not overloaded
RESEQTOEDG
LOADBLOKEDG
Both Trains not impacted by Anti-Pump Circuits
COMPANPLOKCCF
CCF Lockout due to Anti-Pump Circuits
ANTPUMPLOKBLKCCF
Pump overload due to CCF
VALVEOPENCCF

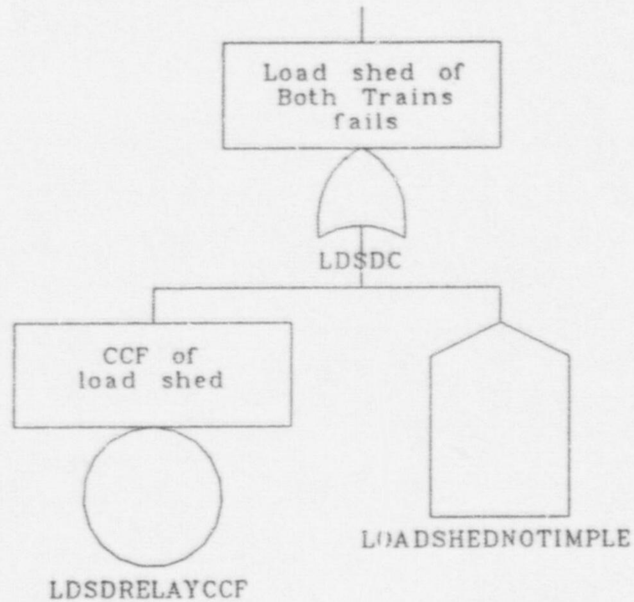

Sequence 24 for Both Trains
SEQ24C
LOADBLKOFFPOW
Load shed of Both Trains is successful
COMPLDSDC
Load shed of Both Trains fails
LDSDC
EDG A is not overloaded
RESEQTOEDG
LOADBLOKEDG
CCF Lockout due to Anti-Pump Circuits
ANTPUMPLOKBLKCCF

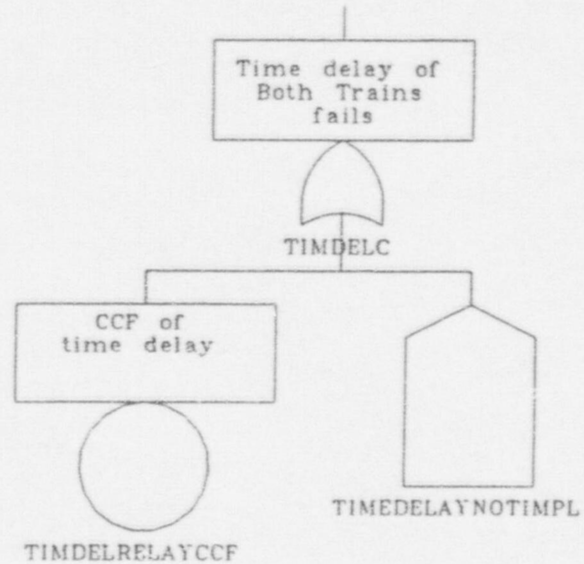

Sequence 25 for Both Trains
SEQ25C
CCF of EDGs
EXLODGS25CCF
LOADBLOKEDG
Load shed of Both Trains is successful
COMPLDSDC
Load shed of Both Trains fails
LDSDC
LOADBLKOFFPOW


Sequence 26 for Both Trains
SEQ26C
Load shed of Both Trains fails
Time delays of Both Trains are successful
CCF of EDGs
LOADBLKOFFPOW
LDSDC
COMPTIMDELC
DGOVLOCCF
Time delays of Both Trains fail
TIMDELC


Sequence 27 for Both Trains
SEQ27C
LOADBLKOFFPOW
Load shed of Both Trains fails
LDSDC
Time delay of Both Trains fails
TIMDELC
No damage of pumps of Both Trains
COMPDAMAGECCF
CCF damage of pumps
DAMAGECCF
CCF of EDGs
DGOVLOCCF


Sequence 28 for Both Trains
SEQ28C
Load shed of Both Trains fails
Time delay of Both Trains fails
CCF damage of pumps
LOADBLKOFFPOW
LDSDC
TIMDELC
DAMAGECCF


Load shed of Both Trains fails
LDSDC
CCF of load shed
LDSDRELAYCCF
LOADSHEDNOTIMPLE


Time delay of Both Trains fails
TIMDELC
CCF of time delay
TIMDELRELAYCCF
TIMEDELAYNOTIMPL

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10. SUPPLEMENTARY NOTES

A. W. Serkiz, NRC Project Manager

11. ABSTRACT *(200 words or less)*

Generic Safety Issue 171 (GSI-171), Engineered Safety Features (ESF) Failure from a Loss Of Offsite Power (LOOP) subsequent to a Loss Of Coolant Accident (LOCA), deals with an accident sequence in which a LOCA is followed by a LOOP. This issue was later broadened to include a LOOP followed by a LOCA. Plants are designed to handle a simultaneous LOCA and LOOP. In this report, we address the unique issues that are involved in LOCA with delayed LOOP (LOCA/LOOP) and LOOP with delayed LOCA (LOOP/LOCA) accident sequences, and determine that such sequences and the specific concerns raised as part of GSI-171 are not fully addressed in Individual Plant Examination (IPE) submittals. The determination is based on our review of selected IPE Submittals. LOOP/LOCA accidents are addressed more fully by IPEs than are LOCA/LOOP ones. LOCA/LOOP accidents are analyzed further in this report by developing event-tree/fault-tree models to quantify their contributions to core-damage frequency (CDF) in a pressurized water reactor and a boiling water reactor (PWR and a BWR). Engineering evaluation and judgements are used during quantification to estimate the unique conditions that arise in a LOCA/LOOP accident. The results show that the CDF contribution of such an accident can be a dominant contributor to plant risk, although BWRs are less vulnerable than PWRs.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

BWRs, PWRs, Loss of Coolant, Loss of Offsite Power, engineered safety systems, failure mode analysis, fault tree analysis, reactor accidents, reactor core disruption, reactor safety, risk assessments

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