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INDIAN POINT UNIT 3 ELECTRIC POWER SYSTEM

A. SUMMARY

A.1 INTRODUCTION

The Indian Point Unit 3 electric power system provides a source of motive, control, and instrumentation power to those components of the plant safeguards systems whose operation is necessary for the mitigation of any abnormal event affecting the reactor core, its heat removal systems, or systems which could affect the release of radioactivity to the environment. This function is normally accomplished through the provision of a reliable offsite power supply network with fully redundant onsite emergency generation capacity available in the event . all offsite power sources are lost.

In order to explicitly illustrate the direct interfaces between this system and the plant safeguards systems components and to fully develop the interrelationships among its various subsystems, the electric power system is modeled in detail to the level of individual motor control centers and power distribution panels. However, the system failure quantification is limited to a determination of the power unavailability at the four 480V switchgear buses.

The Indian Point Unit 3 electric power system is analyzed as presently installed. Operating, testing, and maintenance procedures and practices impacting upon the electric power system are considered as they are currently implemented at the station.

Since all initiating events in this study result in a trip of the main generator, power supply to the electric power system from this source is not included in this analysis. Offsite power is defined in this study as the 345 kV and 138 kV normal offsite power sources to Unit 3. Manual operator actions for the recovery of any power source are excluded from this analysis. Therefore, the status of the offsite power supply, as applied herein, does not define the status of either the 13.8 kV offsite power supply from Buchanan Substation or the status of the three gas turbine generating units available to the site. Loss of offsite power defines the specific condition in which no power is available to Unit 3 from sources other than the onsite diesel generators, if no manual operator actions are taken for alternate supply recovery. Failures of the station auxiliary transformer are included in the analysis of onsite electric power system failures.

Because mitigation of many of the event categories considered in this study may be accomplished with less than the design basis power supply capabilities, the electric power system is analyzed within the context of the 16 operability states summarized in Table 1. Each of these states is developed further for the two following boundary conditions:

- Offsite power not available
- Offsite power available.

The system failure analysis is extended to 6 hours following the initiation of any of the event sequences considered in this study. No operator actions for the recovery of failed equipment are considered at any time during this period. Although this represents an extremely pessimistic evaluation of operator response, this approach is necessary to insure that the results of this analysis provide conservatively bounding values which are applicable to all of the initiating event sequences studied. These recovery factors must be included in any complete evaluation of the contribution of electric power system failures to overall public risk. However, the impacts of power recovery and the probability of successful operator response are both highly dependent upon the precise scenario during which the failures occur. For these reasons, recovery actions are not quantified in this system analysis and are applied only within the context of those event sequences in which the failures of electric power prove to be significant contributors to risk.

The system is considered to be in its normal configuration per plant operating procedures with all buses energized from their normal power sources immediately prior to event initiation.

A.2 RESULTS

Tables 2.1 and 2.2 summarize the quantification of the 16 mutually exclusive electric power system operability states for each of the analysis boundary conditions. (The mutually exclusive state "Failure of Power at Buses 2A and 5A" is defined by the conditions: no power at bus 2A, no power at bus 5A, and power is available at buses 3A and 6A.) The mutually exclusive failure frequencies have been developed from the unconditional power failure states through the application of basic Boolean logic as described in the main body of this report. It is important to note that these results do not include the effects of operator actions to recover failed equipment during the 6-hour study period following event initiation. This analysis approach is very conservative because the inclusion of these recoverability factors would significantly reduce the unavailability of power in several of the states analyzed.

The loss of offsite power is a unique initiating event from the standpoint of electric power system operation. Table 2.3a summarizes the operability state frequencies which are applicable to the event sequences developed for this initiator.

All initiating events analyzed in this study ultimately result in a trip of the main generator. For transients other than those initiated by the loss of offsite power, it is possible that transmission network perturbations produced by this sudden loss of generation could be sufficient to cause a loss of offsite power due to the Indian Point Unit trip. A conservatively bounding distribution with a median value

of 1.97 x 10^{-5} failures per unit trip has been assigned to this conditional event. The operability state frequencies summarized in Table 2.3b are composite probability distributions applicable to all initiating events other than the loss of offsite power. These states were obtained by combining the distributions in Tables 2.1 and 2.2 with the conditional probability distribution for the loss of offsite power as the result of a unit trip.

No direct comparison can be made between these results and those developed for electric power system unavailability in the WASH-1400 study. The principal reasons preventing this type of comparison are:

- The physical configuration and operation of the Indian Point Unit 3 electric power system are significantly different from those of either the PWR plant or the BWR plant electric power systems analyzed in WASH-1400.
- The analysis methodology applied in this study, while conceptually similar to the basic approach adopted in WASH-1400, explicitly quantifies each possible system operability state under two offsite power boundary conditons and for a broad range of events in addition to the LOCA initiators.
- The site-specific nature of this study impacts significantly upon the dominant contributors to electric power unavailability identified for the two plants analyzed in WASH-1400.

A.3 CONCLUSIONS

The Indian Point Unit 3 electric power system has been analyzed for a total of 16 independent operability states under two global offsite power boundary conditions. These states and boundary conditions have been combined to provide conservatively bounding distributions for the unavailability of electric power, which are applied to each of the initiating event scenarios investigated in this study. The dominant contributors to the failure of electric power for a given operability state are, of course, dependent upon the precise system configuration and boundary conditions applicable to that specific state. However, a few general observations may be made about the results presented above.

The more restrictive of the two boundary conditons is that in which offsite power remains unavailable for the entire 6-hour analysis period. The mean frequency of occurrence of the dominant electric power system operability states are:

- All four 480V switchgear buses remain energized: 89.9%
- One 480V switchgear bus is deenergized: 6.6%
- Two 480V switchgear buses are deenergized: 3.3%.

The unavailability of power for each of the system states analyzed under this boundary condition is dominated by failure of the power supply from the diesel generators. The unavailability of power from a diesel generator is attributable to the following three principal causes:

- Failure of the diesel generator to start on demand: 47% of diesel generator unavailabilty

- Unavailability of the diesel generator due to maintenance: 35% of diesel generator unavailability

- Failure of the diesel generator during operation for 6 hours: 18% of diesel generator unavailability.

If a unit trip occurs and offsite power remains available to the station auxiliary transformer, the mean frequency of occurrence of the dominant electric power system operability states is:

- All four 480V switchgear buses remain energized: 99.8%
- Bus 3A is deenergized: 0.14%
- Bus 2A is deenergized: 0.01%.

The failure of power at bus 2A is dominated by the failure of breaker UT2/ST5 to close following a unit trip, with subsequent failure or unavailability of diesel generator 31. Since the breaker 2AT3A will not automatically close if bus 2A is energized from its normal power source, the single failure to close of breaker UT3/ST6 represents the dominant contributor to the loss of power at only bus 3A. Failures of the common supplies to buses 2A and 5A from 6.9 kV bus 5 and to buses 3A and 6A from 6.9 kV bus 6 are the dominant contributors to the loss of normal power to these specific pairs of buses. Failure of the station auxiliary transformer is the single most important contributor to the loss of power at more than two buses.

It cannot be emphasized too strongly that these analysis results have been developed as very conservative bounding values to be applied to a broad spectrum of initiating event sequences. The exclusion of system recovery factors and the analysis of system failures over a nominal 6-hour operating period lead to extreme conservatism in many of these results. The results of this analysis are, therefore, directly applicable only to the identification of those specific event sequences contributing significantly to public risk. Once these sequences have been identified through the use of these bounding analysis failure states, specific recovery actions will be defined and quantified within the context of entire plant recovery

B. SYSTEM DESCRIPTION

B.1 SYSTEM FUNCTION

Within the context of this study, the primary functions of the electric power system are to:

- Provide a reliable electrical power supply to those components whose operation is necessary for the mitigation of any abnormal event affecting the reactor core, its heat removal systems, or systems which could affect the release of radioactivity to the environment.

- Provide a reliable control power supply for the operation of these systems and for the initiation of safeguards systems actuation signals.

- Provide a reliable source of power to instrumentation necessary for the monitoring of emergency system functions, for the monitoring of key plant parameters, and for inputs to safeguards systems actuation logic matrices.

These functions are normally accomplished through the provision of a reliable offsite power supply network connected to the station power system through redundant supply paths. In addition, one onsite gas turbine generator unit and two gas turbine generator units located at the Buchanan Substation may be connected to the station power system through the offsite power supply tielines, thereby providing additional redundancy of offsite power supply capabilities. In the event of complete failure of these offsite power sources, independent onsite power generation capabilities are provided by three redundant diesel generators, each capable of supplying 50% of the power requirements of the safeguards systems components. The DC power system, supplied from four onsite storage batteries, provides redundant power supplies to vital controls and instrumentation and provides the primary source of power to all safeguards actuation and reactor protection system circuits.

The extensive use of manual cross-tie interconnections within each of these systems provides plant personnel with additional capability to selectively energize subsystems and specific components in the event of multiple redundant power supply failures.

The Indian Point Unit 3 essential power s .ply subsystem is a unitized design consisting of three independent divisions, each provided with a dedicated emergency diesel generator, and each receiving its control power from a single DC power panel and battery. Figure 1 illustrates a simplified block diagram of the 480V essential power buses and their DC control power sources.

B.2 SYSTEM OPERATION

Figure 2 is a one-line diagram of the complete Indian Point Unit 3 electric power system. During normal operation, power is supplied to 6.9 kV buses 1, 2, 3, and 4 from the main generator output through the

unit auxiliary transformer, and power is supplied to 6.9 kV buses 5 and 6 from the offsite power grid through the 138 kV substation and the station auxiliary transformer. Following a trip of the main generator, automatic cross-tie-breakers operate to connect buses 1 and 2 to bus 5 and to connect buses 3 and 4 to bus 6, thereby maintaining all six 6.9 kV buses powered from the offsite grid. The redundant source of offsite power from the 13.8 kV substation and gas turbine generator unit 1 may be manually connected to buses 5 and 6 only if these buses are deenergized and their normal supply breakers from the station auxiliary transformer are open. Although no essential safeguards components are supplied directly from the 6.9 kV buses, buses 2, 3, 5, and 6 do supply power to the 480V essential power buses 2A, 3A, 5A, and 6A through their respective station service transformers.

B.2.1 OFFSITE POWER SUPPLY AND GAS TURBINE GENERATOR UNITS SUBSYSTEMS

Power produced by the Unit 3 main generator is stepped up in voltage from the 22 kV generator output to 345 kV through the two parallel main transformers 31 and 32. This 345 kV power is then transmitted via overhead transmission lines to the 345 kV substation at Buchanan. From the Buchanan ring bus, power is transmitted on three 345 kV feeders to Millwood and to Pennsylvania, New Jersey, and Maryland.

As shown in Figure 2, the Unit 3 station auxiliary transformer receives power from the Consolidated Edison system through a 138 kV switching station located adjacent to the Unit 3 primary auxiliary building. This switching station also supplies 138 kV power to the Unit 2 station auxiliary transformer. Two 138 kV overhead transmission lines tie the switching station to the Buchanan 138 kV substation, which has connections to the Consolidated Edison Millwood Switching Station and the Lovett Station of the Orange and Rockland System. The two-bus tie-breakers, BT4-5 and BT5-6, at the 138 kV switching station are normally closed. This arrangement allows Buchanan feeders 95331 and 95332 to supply power to both the Unit 2 and the Unit 3 station auxiliaries without requiring any manual switching operations. These bus tie-breakers are operated from the Unit 1 control panels.

Two separate underground feeders from the Buchanan 13.8 kV substation (13W92 and 13W93) are also available to provide a backup source of offsite power to both Unit 2 and Unit 3 through interconnections at the Unit 1 gas turbine generator installation and at the onsite 13.8 kV substation located between Unit 1 and Unit 3. In order to connect Unit 3 6.9 kV buses 5 and 6 to either of these 13.8 kV power supplies, the buses must first be deenergized and the normal feed breakers from the Unit 3 station auxiliary transformer (ST5 and ST6) must be open.

A gas turbine generator unit is located onsite and may be connected to either Unit 2 or Unit 3 through the 13.8 kV switchgear located at the gas turbine installation at Unit 1. During normal plant operation, breaker GT/BT is open and breaker GT/2F is closed. This breaker alignment maintains the Unit 1 gas turbine and 13.8 kV feeder 13W92 available for service to Unit 2. These supplies may also be aligned to

Unit 3 through manual operation of breaker GT/3T. The gas turbine is started and operated from the Unit 1 control panels. Two additional gas turbine generator units are located at the Buchanan Substation and may be connected to either Unit 2 or Unit 3 through the 138 kV or 13.8 kV tie lines. Gas turbine generator unit #2 at Buchanan is normally aligned for service to Indian Point Unit 3 through 13.8 kV feeder 13W93 and breakers GT-35 and GT-36. The third gas turbine generator may be aligned to either of the Indian Point units. Remote starting capability for these gas turbines is available in the common Unit 1/Unit 2 control room. Breakers GT/2F, GT/B1, GT-35 and GT-36 are all operated from the Unit 3 control room.

B.2.2 480V ELECTRICAL AUXILIARY AND EMERGENCY POWER SUPPLY SUBSYSTEM

B.2.2.1 Station Auxiliary Transformer

The normal source of offsite power to Unit 3 from the Buchanan 138 kV substation is stepped down to 6.9 kV through the station auxiliary transformer, which is connected to 6.9 kV buses 5 and 6 through supply breakers ST5 and ST6, respectively. The transformer is rated at 43,000 kVA and is oil-filled, with a 2 to 5 psig nitrogen cover pressure and forced air oil coolers.

The protective relays for the station auxiliary transformer are activated from the following conditons:

- Transformer differential current
- Transformer overcurrent
- Transformer neutral ground overcurrent
- Failure of breaker ST5 or ST6 to clear a fault at 6.9 kV bus 5 or 6
- Failure of breaker BT5-6 to clear a fault at the 138 kV switchyard
- Transfer trip signal from the pilot wire protection relays for Buchanan 138 kV feeder 95331.

When activated, the transformer protective relays trip and lockout 6.9 kV breakers ST5 and ST6, trip 138 kV breaker BT5-6, trip breaker BT2-6 at Buchanan Substation from the pilot wire relays for feeder 95331, and provide trip annuciation in the Unit 3 control room.

B.2.2.2 Gas Turbine Generator/13.8 kV Substation Supply

A backup source of offsite power from the Buchanan 13.8 kV substation and gas turbine generator Units 2 and 3 is available to 6.9 kV buses 5 and 6 through supply breakers GT-35 and GT-36. These breakers are interlocked with the normal supply breakers ST5 and ST6 to prevent both breakers for a given bus from being closed at the same time. The transfer from the normal to the reserve supply (or vice versa) must be

accomplished manually and is a "dead bus" transfer (i.e., the normal supply breaker must be opened before the reserve breaker is closed). The controls for breakers GT-35 and GT-36 are located at the Unit 3 control panels.

B.2.2.3 6.9 kV System

The six 6.9 kV station buses provide a source of power to auxiliary equipment rated at 400 horsepower and above and do not directly supply any safety-related system components. Buses 1, 2, 3, and 4 are normally supplied from the Unit 3 main generator during power operation through the unit auxiliary transformer. Actuation of the main generator trip relays results in an automatic "fast transfer" of the supply to these buses to the station auxiliary transformer through operation of cross tie-breakers connecting buses 1 and 2 to bus 5 and buses 3 and 4 to bus 6 (refer to Figure 2). This relaying scheme provides a transfer which is rapid enough to prevent voltage and current supply fluctuations from affecting any of the equipment powered from these four buses. Buses 5 and 6 are normally supplied from the station auxiliary transformer and are thus unaffected by the operating status of the main generator. An overcurrent condition on any of the 6.9 kV buses actuates the associated bus protection lockout relays, which isolate the bus by tripping and locking out both the normal supply breaker and the 6.9 kV tie-breaker for that bus.

Buses 2, 3, 5, and 6 provide the normal power supplies to 480V essential power buses 2A, 3A, 5A, and 6A through individual station service transformers. These are dry-type transformers, each rated at 2,666 kVA and are designed for natural convection cooling. Automatic fans are provided for supplementary cooling if the natural air circulation is insufficient. The supply breakers from the 6.9 kV buses to the individual station service transformers trip automatically on either an overcurrent condition at the associated transformer or an undervoltage condition at the supply bus. If tripped, these breakers must be closed manually from the Unit 3 control panels.

The 6.9 kV buses are housed in two metal-enclosed switchgear units located at the 15' elevation of the Unit 3 turbine building. Buses 1, 2, and 5 are contained in switchgear enclosure 31; buses 3, 4, and 6 constitute switchgear enclosure 32.

B.2.2.4 480V Switchgear Buses

Components rated between 100 and 400 horsepower are supplied directly from the station 480V switchgear buses 2A, 3A, 5A, and 6A; individual loads of 100 horsepower and below are supplied from 480V motor control centers (MCCs) fed from the 480V switchgear buses. The normal power supply to each of the 480V buses is from its associated 6.9 kV bus through a station service transformer. If this normal power source becomes unavailable, an independent source of emergency onsite power is provided to each of these buses from the three emergency diesel generator units. (As illustrated in Figure 2, diesel generator 33

supplies bus 5A, diesel generator 32 supplies bus 6A, and diesel generator 31 supplies buses 2A and 3A through its output breaker to bus 2A and bus tie-breaker 2AT3A between buses 2A and 3A.)

The station safeguards systems components are distributed among the four 480V switchgear buses in a manner such that, with coincident loss of all offsite power sources and failure of any one of the diesel generators, power will remain available to the minimum number of components required for the mitigation of any of the design basis accident scenarios evaluated in the Indian Point Unit 3 final safety analysis report. (Under many situations less restrictive than these limiting design basis events, full accident mitigation may be provided with less than this nominal power supply availability.) The loads supplied from each of the 480V switchgear buses are summarized in Table 3.

If a fault occurs on one of the 480V switchgear buses, lockout relays are actuated which trip and prevent reclosure of all breakers associated with the bus. The bus lockout relays must be manually reset after the fault is cleared to allow the tripped breakers to be reclosed.

The normal feed breaker to each bus from the station service transformer may be operated from either the Unit 3 control panels or from a local panel in the diesel generator building. The breaker may be closed from the main control room only if the associated bus is deenergized; the breaker may be closed from the diesel generator panel with the bus energized through the use of the local synchronizing scope interlock, to allow paralleling of the diesel generator and normal supplies during testing and other transfer operations. The normal feed breakers trip automatically on either of the following conditions:

- Undervoltage at the associated 480V bus
- Overcurrent.

The supply breaker from a diesel generator to its associated 480V bus cannot be closed unless all of the following conditions exist:

- No fault on the 480V bus
- Diesel generator output voltage normal
- Either the synchronizing scope on <u>or</u> an undervoltage condition existing on the 480V bus.

The breakers can be closed manually from either the Unit 3 control panels or from local control switches at the associated diesel generator control panels in the diesel generator building. The breakers will close automatically if the above conditions are satisfied at the affected bus and both of the following additional requirements are met:

- The normal feed breaker to the bus is open

- The associated 480V bus tie-breaker is open (except that breaker 2AT3A need not be open for diesel generator 31 breaker EG1 to close automatically).

The diesel generator feed breaker to a 480V bus trips automatically on any of the following conditions:

- Bus lockout relay actuation
- Trip of the associated diesel generator
- Overcurrent.

Cross tie-breaker 2AT3A between buses 2A and 3A is administratively controlled to remain in the open position during normal unit operation. To allow bus 3A to be automatically energized from diesel generator 31, breaker 2AT3A receives an automatic closing signal if the following requirements are met:

- Undervoltage on bus 3A
- Tie breaker 3AT6A open
- Normal feed breaker to bus 3A open
- Diesel generator 31 output breaker EG1 closed
- No faults on either bus 2A or bus 3A.

It should be noted that breaker 2AT3A will not close automatically if bus 3A is deenergized and bus 2A remains energized through its normal supply breaker 2A. A synchronizing scope interlock is provided at a redundant control switch for breaker 2AT3A in the diesel generator building to allow manual closure of the breaker without an undervoltage condition on either bus 2A or bus 3A. Breaker 2AT3A is tripped only by the bus lockout or overcurrent condition at either bus 2A or bus 3A. An alarm is actuated at the Unit 3 control panels if the control switch for breaker 2AT3A is placed in the pullout position (preventing automatic breaker closure).

In addition to the normal and emergency power supplies to each of the 480V switchgear buses, the capability for manually interconnecting these buses is provided through the use of cross-tie-breakers between buses 2A and 5A and between buses 3A and 6A (refer to Figure 2).
Cross-tie-breakers 2AT5A and 3AT6A are administratively controlled to remain in the open position during normal unit operation. These breakers may be closed manually from the control room only if no fault exists on either of the associated buses and one of the buses is deenergized. Breakers 2AT5A and 3AT6A trip automatically on any of the following conditions:

- Bus lockout relay actuation on either associated bus
- Undervoltage on either associated bus
- Safety injection signal
- Overcurrent.

If an undervoltage condition is detected at any of the 480V buses, the normal feed breaker to that bus receives an automatic trip signal, the associated diesel generator receives a signal to start, and the diesel

generator output breaker receives an automatic closing signal. (Diesel generator 31 receives an automatic starting signal from undervoltage at bus 2A only.) The diesel generator output breaker will not close until diesel generator voltage is normal and all other interlocks are satisfied, as discussed previously. All load breakers from the bus are tripped, with the exceptions of the breakers supplying MCCs 36A, 36B, and 36C. After the diesel generator has closed onto the bus, auxiliary feedwater, service water, and component cooling pumps (as applicable to the affected bus) are sequentially reenergized through the operation of a series of automatic time delay bus loading relays. Nonessential MCCs remain stripped until manually reenergized at the local switchgear breaker controls. All other nonessential components may be manually restarted after switchgear power is restored.

Following a safety injection, all three diesel generators receive automatic starting signals and all nonessential loads are stripped from the 480V buses and are locked out. (MCCs 34, 39, 36A, 36B, and 36C remain energized.) With normal voltage present on a bus, the running safeguards equipment remains energized and all other safeguards components are automatically started. Under these conditions, the diesel generators continue to run unloaded as long as the buses remain energized from the offsite power supply. If an undervoltage condition is then detected at any bus, all loads, except MCCs 36A, 36B, and 36C, are shed from the bus, the normal feed breaker receives a signal to open, and the diesel generator output breaker closes. (Breaker EG1 closes on undervoltage at bus 2A only.) The safeguards components are then sequentially reenergized as described above. The diesel generators associated with the unaffected buses continue to run unloaded and the safeguards equipment supplied from those buses remains energized continuously as long as normal voltage is present. Nonessential components may be manually restarted after the safeguards actuation signal is reset.

The 480V buses are housed in two metal-enclosed switchgear units located at the 15' elevation of the Unit 3 control building. Buses 5A and 2A are contained in switchgear enclosure 31; buses 6A and 3A are contained in switchgear enclosure 32.

B.2.2.5 <u>Diesel Generators</u>

Each of the emergency diesel generators is powered by a 16 cylinder, four cycle, turbo-charged diesel engine rated at 2,450 horsepower and 900 rpm. The generator driven by this engine is a self-excited, three phase, 60 Hertz, 480V unit rated at 2,188 kVA at 0.8 power factor. The output ratings of each diesel generator unit are 1,750 kW for continuous service and 1,950 kW for a maximum of 2,000 hours. Each unit is capable of supplying sufficient power to maintain the operation of at least 50% of the safeguards systems components required for the mitigation of any of the design basis accident scenarios analyzed in the Indian Point Unit 3 final safety analysis report.

Each diesel generator receives an automatic starting signal under either of the following conditions:

- Undervoltage at its associated 480V bus (diesel generator 31 starts automatically on undervoltage at bus 2A only)
- Safety injection signal.

In order for a diesel generator to be available for auto starting, however, the engine starting mode control switch located at the diesel generator control panel in the diesel generator building must be in the "Auto" position. (Two other positions are available: "Off," which prevents the engine from starting, and "Manual," which allows manual starting from the local panel start pushbutton only.) An alarm is received in the control room if the switch is removed from the "Auto" position. Each diesel generator has the capability to attain full speed and voltage within 10 seconds and can be fully loaded within 30 seconds from the time of the starting signal. A fast acting electro-hydraulic governor maintains a constant diesel engine speed as load is applied to the unit. The generator output breaker will close automatically to load the diesel generator onto its associated bus only if an undervoltage condition is detected at that bus and the normal bus feed breaker is open.

The normal protective function trip signals provided for each diesel generator are:

- Local emergency stop pushbutton
- Generator overcurrent
- Generator reverse power
- Diesel engine overcrank (failure to attain speed within 37 seconds after start signal)
- Low lube oil pressure
- Diesel engine electrical overspeed trip relay
- Diesel engine mechanical overspeed trip.

An automatic start due to a safety injection signal causes the first three of these trips (pushbutton, overcurrent, and reverse power) to be blocked. These trips are automatically reinstated following clearance of the safety injection signal. Following any trip of the diesel generator, the trip lockout relay must be manually reset at the local diesel generator control panel before the engine can be restarted.

Successful starting and continued operation of the diesel generators requires the availability of four auxiliary systems: the diesel engine starting air system, the diesel fuel oil transfer system, the station

service water system, and 125 VDC control power. Each diesel engine is provided with a 53 ft^3 starting air receiver, which is normally maintained at a pressure of 300 psig by a starting air compressor. The power supplies for these compressors are listed in Table 4. When fully charged, the receiver volume is sufficient to provide air pressure for three or four normal diesel engine starts without recharging. Although normally isolated, an equalizing line is available to connect all three receivers together, in the event of failure of any of the air compressors. Each receiver discharges to two engine starting air motors through separate discharge lines and pressure reduction valves. DC solenoid-operated starting air valves are located in each line to admit air pressure to the starting motors. Either of the two starting motors alone will provide sufficient torque to start the diesel engine rolling.

Each diesel engine is provided with a 175 gallon fuel oil day tank, which serves as an immediate source of fuel for engine starting and short term operaton. (The diesel generator consumes approximately 115 gallons of fuel oil during 55 minutes of full load operation.) Fuel flows by gravity from the day tank to a booster pump driven from the free end of the diesel engine crankshaft and then to the individual cylinder fuel injection pumps. The primary storage capacity for the diesel generator fuel is provided by three 7,700 gallon underground fuel tanks located on the south side of the diesel generator building. The three tanks, when full, provide sufficient fuel for approximately 72 hours of continuous operaton of all three diesel generators at full load. The tanks are filled through a common truck hose connection and fill header. A fuel oil transfer pump is mounted on each tank and can be aligned to discharge into the common normal or emergency makeup line to all three diesel generator fuel oil day tanks. The pump power supplies are listed in Table 4. If a low level is detected in the day tank for diesel generator 31, transfer pump 31 will automatically start to refill the tank to approximately 158 gallons. In a similar manner, transfer pump 32 starts on a low level in the day tank for diesel generator 32, and transfer pump 33 starts for diesel generator 33. If the primary fuel oil transfer pump for a given diesel generator fails, no automatic signals are available from the affected diesel generator to start either of the remaining two pumps. A control room annunciator alerts the operators if any day tank level decreases to the low-low alarm setpoint of approximately 52 gallons, and local operators can manually start each of the transfer pumps from switches located in the diesel generator rooms. Once running, any of the pumps can supply fuel to all three day tanks through the common fill piping.

The station service water system provides cooling water for the diesel engine jacket water cooling system heat exchangers and for the engine lube oil coolers. Two service water supply lines to each diesel generator are available: one from the service water nuclear services header, and one from the conventional services header. During normal plant operation, the diesel generators are aligned to the nuclear services header. A more detailed discussion of the plant's service water supply system is contained in the service water system analysis section of this report.

The diesel generators utilize 125 VDC control power for several auxiliary functions during starting and loading. In order to admit air pressure from the starting air receiver to the engine starting motors, the DC solenoid-operated starting air valves must be energized from the engine starting control circuitry. If DC power is not available to these valves, they may be opened manually by means of a mechanical pushbutton mounted on the valve body, thereby admitting air to the starting motors and allowing the engine to start rolling. DC power is also used to provide automatic field flashing for the generator exciter and is required for automatic or remote closure of the generator output breaker. For the purpose of this study, it is assumed that a diesel generator cannot be started and loaded onto its associated bus if its DC control power source is unavailable. Once started and loaded, a diesel generator does not require DC power for continued operation. The DC control power source for each diesel generator and its output breaker is also listed in Table 4.

The diesel generators, fuel oil day tanks, starting air compressors and receivers, and local control panels are all located in the diesel generator building adjacent to the Unit 3 control building. Each diesel generator and its associated control panels and auxiliaries is contained in a separate room in this building to minimize the potential for a fire involving all three units. The fuel oil transfer pumps and the fill connection for the underground storage tanks are housed in a structure built over the storage tanks.

It should be noted that the Indian Point Unit 3 technical specifications require that a minimum of 5,676 gallons of diesel generator fuel oil be available in each underground storage tank and that 26,300 additional gallons of fuel be available onsite at all times. The additional storage capacity for this fuel is provided by the two Unit 1 gas turbine fuel oil storage tanks and the oil storage tank at Buchanan Substation.

B.2.3 DC POWER SUBSYSTEM

The Indian Point Unit 3 DC power system consists of four independent battery installations, each connected to a DC power panel and each maintained under continuous charge by a self-regulating battery charger. The system is ungrounded, with the positive and negative legs each maintained at a potential of approximately 129 volts with respect to ground. Ground detection is provided for each battery division, with a common alarm in the control room.

Following the unitized system design approach, three of the DC power panels each supply control power to an associated essential AC power division as illustrated in Figure 1. The fourth DC power panel provides the normal source of power to AC instrument bus 34. The DC system also provides the source of power for all safeguards actuation and reactor protection logic matrices. The major loads supplied from each of the DC power panels are listed in Table 5. A bus-tie-breaker is available to

connect power panel 31 to power panel 32 in the event of failure of the battery or battery charger for either of these panels; this breaker is administratively controlled to remain open during normal operation to maintain the separation and independence of these DC power divisions.

Each of the battery installations is composed of 60 individual lead antimony storage cells connected so as to provide a nominal terminal voltage of 129 VDC. Battery 31 is rated at 1,320 ampere hours, battery 32 is rated at 960 ampere hours, battery 33 is rated at 425 ampere hours, and battery 34 is rated at 440 ampere hours (each at an 8-hour discharge rate). Batteries 31 and 32 are connected to their respective power panels through 800 ampere fuses; battery 33 utilizes a 600 ampere fuse, and battery 34 has a 600 ampere circuit breaker.

During normal operation, the loads from each of the power panels are supplied from the output of the associated battery charger, which also provides a constant trickle charge to maintain the battery in a fully charged condition. Each of the battery chargers is a silicon-controlled rectifier self-regulating unit cooled by forced air circulation. Protective relays will trip the charger input circuit breaker to prevent the unit from overheating if either the cooling fan fails or if inadequate cooling air flow is detected by an internally mounted differential pressure sensor. Each battery charger is connected directly to its associated power panel through the battery charger output supply breaker. An equalizing charge may be applied to the battery at 139 VDC for up to 24 hours during normal operation without removing either the battery or the battery charger from service. The power supply to each of the battery chargers is provided from a source associated with the 480V bus for which that charger supplies DC control power. Battery charger 31 is powered from MCC 39 (which is supplied from bus 5A), battery charger 32 is powered from MCC 37 (bus 6A), battery charger 33 from MCC 36C (bus 2A), and battery charger 34 from MCC 32 (bus 3A). As described in Section B.2.2.4, the supplies to battery chargers 31, 32, and 34 are stripped following a safety injection or 480V bus undervoltage signal. If automatically stripped, the MCCs must be reenergized by manually closing their supply breakers at the 480V switchgear.

Batteries 31, 32, and 34 are located in individual battery rooms of the 33' elevation cable spreading area of the Unit 3 control building. Battery 33 is located in a battery enclosure separated from diesel generator 31 in the diesel generator building. Battery chargers 31, 32, and 34 are located in the cable spreading area at elevation 33' in the control building; battery charger 33 is located in the switchgear room on the 15' elevation of the control building.

B.2.4 AUXILIARY AC POWER SUBSYSTEMS

B.2.4.1 480V Motor Control Centers

All station 480V loads rated at 100 horsepower and below are supplied from motor control centers (MCCs) powered from the 480V switchgear buses as shown in Figure 2 and Table 3. All safeguards system motor-operated

valves are powered from either MCC 36A or MCC 36B, which remain energized wherever their associated supply buses (5A and 6A, respectively) are energized. The supply breakers to MCCs 36A, 36B, and 36C receive automatic closing signals on any safety injection actuation and may be operated from the Unit 3 control panels. The supply breakers to all other MCCs are operated locally at the 480V switchgear by manual close and trip pushbuttons.

As described in Section B.2.2.4, various MCCs are stripped from the associated supply buses by safety injection and bus undervoltage signals. Following this automatic stripping, the affected MCC's must be manually reenergized at the 480V switchgear. The MCCs affected by each of these conditions are:

- Safety injection: strips all MCC feeds except those to MCCs 34, 39, 36A, 36B, and 36C
- Bus undervoltage: strips all MCC feeds from the affected bus only, except those to MCCs 36A, 36B, and 36C, as applicable.

MCC 31 is located outdoors at the Unit 3 intake structure and supplies intake auxiliaries such as the traveling screens. MCCs 32 to 35 are located at the 15' elevation in the turbine building and supply auxiliaries associated with the conventional plant. MCCs 36A, 36B, and 37 are located at the 55' elevation of the primary auxiliary building; MCCs 36A and 36B supply safeguards systems components, and MCC 37 supplies nonessential primary plant auxiliaries outside of the containment. MCC 36C is located in the switchgear room at the 15' elevation of the control building and supplies auxiliaries for diesel generator 31. MCC 38 is located inside the Unit 3 containment at elevation 68' and supplies auxiliaries such as the control rod drive cooling fans and the reactor coolant pump bearing lift pumps. MCC 39 is located at elevation 33' in the control building and supplies equipment associated with the building ventilation systems and transformer auxiliaries.

B.2.4.2 118 VAC Instrument Power Buses

All instrumentation monitoring vital plant parameters and providing input signals to the reactor protection and safeguards actuation systems is supplied from 118 VAC instrument power buses. Instruments providing redundant input signals to the reactor trip and safety injection logic matrices are supplied from separate buses so that failure of any one bus will neither prevent a protection function from actuating nor cause an inadvertent trip.

Because these instruments require an extremely stable and reliable source of power, all four instrument buses are normally supplied by static inverters, which convert DC power into a very smooth, noise-free AC power signal. Each inverter is rated at 7.5 kVA with an output voltage of 118 VAC at 60 Hertz. This output will be maintained over a range of input voltage fluctuations from 105 VDC to 140 VDC.

A reserve power supply for each of the instrument buses is provided from 120 VAC lighting bus 32 through a manual transfer switch located at each instrument bus. These transfer switches are provided with mechanical interlocks to prevent both supplies to a given bus from being connected in parallel. The transformer supplying lighting bus 32 is sized such that only one instrument bus may be supplied from the reserve power source at any given time. Table 6 lists the normal and reserve power supplies to each of the instrument buses.

The instrument bus panels are located in the Unit 3 control room behind the logic cabinets. The static inverters are located at the 33' elevation in the control building cable spreading area.

B.3 INTERFACING AND SUPPORT SYSTEMS

The station electric power system provides AC and DC motive, control, and instrumentation power to all electrically operated components in the plant. The Consolidated Edison transmission network provides the normal source of power to the station through tielines with the Buchanan 138 kV and 13.8 kV substations. One onsite and two near-site gas turbine generator units also provide independent sources of power to the station through these offsite tielines and onsite switchyard.

In the event that all offsite and gas turbine power supplies are unavailable, the Unit 3 electric power system can be powered from three independent onsite diesel generator units. The diesel generator starting air compressors and air receivers provide the compressed air supply necessary for diesel engine starting, and the diesel fuel oil transfer and station service water systems provide sources of fuel and engine cooling for continued operation.

The safeguards actuation, reactor protection, main turbine generator protection, and offsite tieline fault protection systems provide signals to the station electric power system for the initiation of automatic bus transfer operations, bus load shedding, diesel generator starting, and automatic bus load sequencing under a variety of transient conditions.

Within the system itself, the AC and DC subsystems are strongly dependent upon one another through the AC-powered battery chargers and the DC control power supplies to the diesel generators and the 6.9 kV and 480V switchgear.

The control room and local plant operators interface directly with the electric power system for remote and local manual circuit breaker operations and manual operation of the diesel generators. Although the system is designed to automatically provide a reliable source of onsite power during a wide range of anticipated events, these manual operations provide added flexibility for realignment of the power supply flowpaths as conditions require and provide the means by which individual components and subsystems may be recovered following severe system transients.

3.4 TECHNICAL SPECIFICATIONS

The Indian Point Unit 3 technical specifications require the following electric power system components to be operable before the unit can be brought above the cold shutdown condition.

- At least two transmission circuits to Buchanan Substation.
- 6.9 kV buses 5 and 6 energized through the station auxiliary transformer from either 138 kV feeder 95331 or feeder 95332.
- 13.8 kV feeder 13W92 or feeder 13W93 available.
- All four 480V switchgear buses energized with cross-tie-breakers 2AT5A and 3AT6A open.
- All three diesel generators operable.
- A minumum of 5,676 gallons of diesel fuel in each of the three underground storage tanks, with an additional 26,300 gallons of fuel available onsite.
- All four batteries, DC power panels, and battery chargers operable.
- A maximum of one of the 118 VAC instrument buses supplied from the backup lighting bus.

The technical specifications allow the following limited inoperability conditions during unit power operation.

- One diesel generator may be removed from service for a period of up to seven days, provided the remaining two diesel generators are verified to be operable daily and both the 138 kV and 13.8 kV sources of offsite power are available during this inoperability period.
- Unit operation may continue for 48 hours if either the 138 kV or the 13.8 kV source of offsite power is unavailable, provided all three diesel generators are operable. Operation may continue beyond 48 hours in this condition if the NRC is notified of the specific plans in effect for the restoration of the offsite power supply.
- One battery may be removed from service for 24 hours, provided the remaining batteries and all four battery chargers are operable. The DC power panel for the unavailable battery must be energized from one of the battery chargers during this period.

If any of these conditions cannot be met, the unit must be shut down immediately. If the degraded operability condition persists for longer than 48 hours with the unit at hot shutdown, the unit must be brought to cold shutdown.

8.5 TESTING REQUIREMENTS

In order to minimize the unavailability of electric power system components during unit operating periods, all periodic testing at Indian Point Unit 3 which requires any electrical system component to be removed from normal service is performed during cold shutdown or refueling periods. The major periodic tests performed on the electric power system are summarized below; the numbers in parentheses refer to the specific Indian Point Unit 3 procedure under which the given test is performed.

- A visual inspection of each diesel generator is performed weekly to verify and record satisfactory lube oil level, check for jacket water, fuel oil and lube oil system leaks, verify operation of the starting air compressor, and to record the volume of fuel in the underground storage tanks and reserve fuel oil tanks onsite (3PT-W1).
- The terminal voltage, individual cell voltage, pilot cell electrolyte specific gravity, and electrolyte level are measured and recorded once per month for each station battery (3PT-M21).
- Each diesel generator is started manually and loaded onto its associated 480V bus in parallel with the normal bus power supply once each month. The diesel generator is operated at a load of approximately 500 kW for between 1 and 2 hours (3PT-M22) (The testing has been recently changed in conformance with NRC Regulatory Guide 1.108).
- Each station battery is inspected and placed on an equalizing charge at 134.4 volts for 24 hours once each quarter (3PT-Q1).
- The mechanical overspeed trip setpoint of each diesel generator is functionally tested once each quarter (3PT-Q7).
- A safety injection with blackout signal is simulated during each refueling to verify the automatic starting of each diesel generator and the operation of the 480V bus load shedding and associated load sequencing control circuits (3PT-R3D).
- Each diesel generator is started manually and loaded onto its associated 480V bus in parallel with the normal bus power supply once each refueling. The diesel generator is operated for at least 4 hours at its rated load of 1,750 kW (3PT-R16).
- Each battery is disconnected from its power panel and discharged into a load resistance bank for a period of 8 hours to verify its ampere hour capacity once each refueling (3PT-R29A).
- If one of the diesel generators is unavailable for service during unit operation, the remaining two diesel generators are started daily to verify their continued operability (for a maximum allowable period of 7 days). The diesel generators are not loaded onto their buses during these nonroutine operability checks.

3.6 MAINTENANCE REQUIREMENTS

Routine preventive maintenance performed on components of the electric power system, with the exception of the diesel generators, is generally scheduled for cold shutdown periods during which the electrical load on the system is reduced and the technical-specification component inoperability time limitations are relaxed. Repairs of failed or degraded components during unit operating periods must conform with the applicable technical specifications system operability criteria, or the unit must be shutdown until the failed components are returned to service. Most maintenance performed on individual 6.9 kV and 480V switchgear circuit breakers is done with the breaker removed from its cubicle. During these periods, a spare breaker is normally installed, and the associated buswork remains energized. Maintenance on other system components can also generally be performed without affecting the flow of power to the station loads through the use of the manual bus-tie interconnections and installed reserve power supplies.

The diesel generators, because of their complexity, frequent testing, and vital status as emergency power supplies, are subject to more frequent nonroutine and scheduled preventive maintenance than are most other components in the plant. Routine maintenance performed on the diesel generators during unit operation includes preventive maintenance items such as the repair of minor cooling water and oil leaks, replacement of oil filters, calibration of electrical and mechanical control systems, etc. The technical specifications also require a major inspection and general overhaul of each diesel generator to be performed periodically in accordance with the manufacturer's recommendations.

C. LOGIC MODEL

C.1 TOP EVENTS DEFINITION

The Indian Point Unit 3 electric power system is analyzed for the 16 operability states listed in Table 1. Each of these states is developed for the two general boundary conditions of offsite power available and offsite power not available.

The event trees developed for Indian Point Unit 3 analyze the loss of offsite power as an initiating event which causes a unit trip. This condition, therefore, requires failure of the 345 kV transmission system to the extent necessary to cause an automatic generator trip or to necessitate manual operator action to trip the unit. Because the 138 kV supply from Buchanan Substation provides the normal source of offsite power to Unit 3, the loss of offsite power also requires failure of this supply. The analysis of the Unit 3 electric power system described in this report has been developed as a conservatively bounding failure quantification for the purposes of identifying the dominant event sequence contributors to public risk. As such, manual operator actions are excluded from this analysis and will be included during the assessment of recovery from the dominant failure sequences during event tree quantification. Since the 13.8 kV power supply from Buchanan and the three gas turbines require the performance of manual switching operations before they can energize any of the Unit 3 buses, the status of these supplies does not affect the condition of "offsite power" as it is applied in this analysis. (Their status does significantly affect the time required to recover power to the essential buses from a source other than the diesel generators and is, therefore, vital to the quantification of failure recovery.) For the purposes of this study, "offsite power" is thus defined as specifically including the following two items:

- The 345 kV transmission system from Unit 3, to the extent that failures will necessarily result in a unit trip
- The 138 kV supply to Unit 3 from Buchanan Substation.

Failure of "offsite power" requires failure of both of these elements as a minumum condition. The failure of "offsite power" to Unit 3 does not define the status of either of the 13.8 kV supply lines from Buchanan or of any of the gas turbine units. Failure of "offsite power" may include failure of any, all, or none of these additional power sources. The status of these sources is important only in the quantification of the time required for onsite electric power recovery, and the effects of the unavailability of these supplies will be quantified explicitly as they impact upon recovery from the dominant event sequences. The unit-specific electric power system model developed in this analysis includes the station auxiliary transformer. Failures of this component are, therefore, not included in the definition of failure of "offsite power" and are quantified separately in the unit power supply availability analysis.

The electric power system is normally in service during all modes of unit operation. For the purposes of this study, it is considered to be in its normal configuration (all buses energized from their normal power sources) immediately prior to the initiation of any of the event sequences presented in the event trees. Those electric power system failures which produce any of the plant transients analyzed in the event trees are identified and quantified in the initiating event analysis section of this report. A summary of these failures and the corresponding initiating events is presented in Table 7. Any failure causing loss of power which does not lead directly to an initiating event will be quickly detected by plant personnel due to its effects upon auxiliary equipment operation. These failures will either be quickly repaired, or the unit will be shut down in conformance with the technical specifications operability criteria or normal operating procedures and practices. The probability of any other initiating event not associated with the loss of power occurring during this recovery period is very small when compared with the probability of event initiation due to electric power failure. Therefore, the electric power system is analyzed for its unavailability conditional upon the following two criteria:

1. An initiating event has occurred

2. The electric power system was available in its normal configuration immediately prior to event initiation.

Although it is very desirable for the electric power system to remain in continuous operation for the duration of each of the event sequences analyzed in this study, there exists for each general initiating event category a time period during which failures are less tolerable and may be critical to overall plant recoverability. The duration of this period is determined by factors such as the magnitude and type of initiating event considered, the operation of automatic mitigation systems, the response times of plant personnel, characteristic periods associated with core nuclear physics, primary and secondary thermal hydraulics, etc. In principle, each sequence studied presents a unique time frame beyond which electric power failures are relatively more tolerable due to increased recovery times, the availablility of additional recovery personnel, reduced decay heat levels, and the establishment of a stable and well controlled core condition. For the purposes of developing electric power unavailability information to be applied to the entire spectrum of event sequences studied, this electric power system failure analysis is extended for a nominal time period of 6 hours following event initiation. This period is considered to be a conservative representation of the time required to place the unit in a stable configuration such that core nuclear and thermal transients are relatively slow and the available time frame for system and plant recovery is extended. It should be noted that for the majority of sequences analyzed, stable shutdown will be achieved within a significantly shorter time period, and application of the results of this 6-hour failure analysis provides a conservative estimate of system unavailability. For those event sequences in which the unavailability

of electric power provides a dominant contribution to overall public risk, the analysis will be refined to incorporate a more detailed time model of both failure and recovery phenomena within the context of each specific event scenario.

A second major factor in the overall conservatism of the electric power system analysis is that no credit is taken for manual operator action or general system recoverability over the entire duration of the 6-hour study period. The response of the plant operators to any failure is strongly dependent upon the specific conditions existing when the failure occurs. Failures may be massive and confusing or relatively minor. The operators may find themselves in the midst of a rapid sequence of events requiring almost immediate correct response or in a relatively slow transient during which even major component failures are tolerable. These event-specific constraints must also be coupled with the characteristic times required to effect recovery, as determined by the specific failure states analyzed. It is thus evident that the application of even the most simple recoverability factors for the electric power system cannot be taken out of the context of the event sequences during which the failures are postulated to occur. Assessment of the electric power system unavailability with no recovery provides a very conservative estimate of system response to be applied in the determination of the dominant contributors to public risk. As discussed above, once the dominant sequences are identified through the application of this analysis, the quantification of each of these sequences will include a detailed model of both time-dependent failure and recovery applied within the context of each specific postulated scenario.

The top event definition for each of the electric power system operability states is thus of the form "Failure to Maintain Bus(es) - Energized For a Period of 6 Hours Following Event Initiation," given the electric power system was available immediately prior to event initiation and no efforts are made to recover any failed equipment.

C.2 SYSTEM FAULT TREE

Fault tree logic is utilized in this analysis as an aid in the identification of those combinations of component failures which are necessary to produce overall system failure within the context of the specified operability state and boundary conditions imposed upon the system. Figure 3 shows the fault tree developed for the Indian Point Unit 3 electric power system. To facilitate the synthesis of the various system operability states analyzed in this study, the tree is drawn such that the failure of power at a single 480V switchgear bus can easily be extracted and combined with other buses to form a tree unique to each operability state.

The fault tree is developed for all components of the station 6.9 kV, 480 VAC, 120 VAC, and 125 VDC subsystems which provide motive and control power to each of the safeguards systems analyzed in this study. It extends to the level of detail necessary to illustrate the electrical

power supply components providing a direct interface with the corresponding mechanical system components (e.g., motor control centers and 120 VAC distribution panels). All available bus-ties and alternate power supply paths are specifically included to model the subsystem interdependencies. The fault tree does not include those components and subsystems which do not supply power to any systems analyzed in this study (e.g., 6.9 kV buses 1 and 4, several auxiliary motor control centers, etc.).

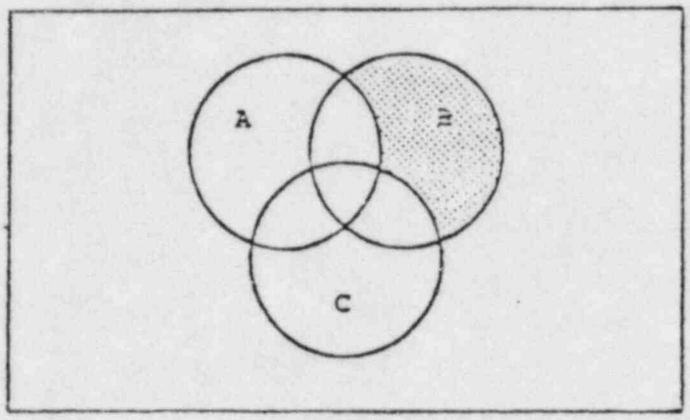
As shown, the system fault tree includes all component failure modes which contribute to system failure and, as such, is a complete representation of the system hardware failures which are both necessary and sufficient to achieve the top event for any of the failure states analyzed. The fault tree does not include descriptions of the causes for these failures, since a given component failure mode may be initiated through a wide variety of cause sequences. Similarly, the fault tree does not include manual recoverability operations which can lead to either repair or circumvention of these failures. These causes and recoverability factors are quantified in the context of the specific fault tree constructed for each failure state as they impact upon the specific hardware configurations relevant to that state.

C.3 SYSTEM FAILURE STATE SYNTHESIS

For each boundary condition imposed upon the electric power system, there exists a unique fault tree corresponding to each system operability state. There are thus a total of 32 different top events for which system failure must be analyzed. In order to identify the component failure combinations contributing to each of these 32 cases, portions of the system fault tree shown in Figure 3 are combined to form a fault tree which uniquely describes the system hardware configuration applicable to each case under consideration.

In order for the application of the results of this electric power system analysis to be logically complete, each of the quantified system operability states must be mutually exclusive. Thus, for example, the calculated unavailability of power at bus 5A applied in the analysis of the event sequences must represent the condition that power is lost at only bus 5A (i.e., that buses 2A, 3A, and 6A remain energized). In principle, a complete mathematical expression may be developed from the system logic model which allows direct calculation of each of the mutually exclusive unavailabilities. However, in practice, the complexities of the system hardware configurations and the need to carefully compute several levels of conditional probabilities preclude the direct calculation of these mutually exclusive states. The computation methodology employed in this analysis, therefore, utilizes the system logic model to develop a complete mathematical expression of the failure modes necessary and sufficient to achieve each desired failure state without regard to the possible impacts of the failures upon other system states. The desired set of mutually exclusive failure

states is then quantified by applying a simple logic expression to these nonmutually exclusive analysis results. The general process is completely analogous to the determination of the mutually exclusive contributions to the problem represented by the Venn diagram shown below.



We desire the area of the shaded portion of circle B (i.e., the mutually exclusive condition represented by "B and only B"). If it is a relatively straightforward problem to compute the area of each of the three large circles and of each of the intersections, then the answer to the problem is determined through the logical expression:

$$\text{Shaded Area} = B - (A \wedge B) - (B \wedge C) + (A \wedge B \wedge C).$$

By following this approach, the electric power system analysis task is made both mathematically simpler and logically complete. All possible failure contributors are explicitly included in each of the nonmutually exclusive unavailability expressions, thereby minimizing the chances for omission or miscalculation of conditional events. The simple application of basic logic principles then assures that the mutually exclusive failure state representations are complete.

As an example of the methodology employed in the development of the nonmutually exclusive failure state fault trees, consider the case for which the top event definition is "Failure of Power at Buses 2A and 6A Given Offsite Power Available." The fault trees for failure of power at bus 2A and failure of power at bus 6A are thus combined with the following "house events" specified to define the applicable boundary conditions under which the system is analyzed.

- Offsite power is available to the station auxiliary transformer.

- The diesel generator operating mode selector switches are specified as being in the correct positions for automatic starting.

- Circuit breakers requiring manual operator action to close, such as the gas turbine feed breakers GT-35 and GT-36, and the 480V bus cross tie-breakers 2AT5A and 3AT6A, are specified to remain in the open position since the tree is developed only for hardware failure contributions to unavailability.

The resulting failure state fault tree is then analyzed to determine the minimal combinations of hardware failures which result in the failure of power at both buses 2A and FA. These minimal component failure combinations are then utilized in the development of an unavailability expression for the quantification of the hardware failure contributions to this scenario.

C.4 FAULT TREE CODING

Table 8 presents a list of the basic events in the electric power system fault tree, the corresponding component failure modes, and the applicable failure rates.

D. QUANTIFICATION

The unavailability of the Indian Point Unit 3 electric power system is quantified for each of the 16 system operability states listed in Table 1 under each of the general boundary conditions discussed in Section B.6. In order to illustrate the relative contributions to system failure from active component failures (i.e., failures on demand) and from component failures during operation, a nominal reference operating period of 6 hours following event initiation is applied to each of the cases analyzed. Detailed time-dependent conditional failure probabilities are not developed; rather, an upper bound for system failure is determined by applying a uniform failure rate for each component over the entire study period (i.e., components "X" and "Y" are allowed to fail at any time during the 6 hour period, even though component "Y" may not be called upon to operate until component "X" has failed).

D.1 HARDWARE FAILURES

The component hardware failure contribution to system unavailability is quantified under the following analysis criteria:

- An initiating event has occurred.
- Power is unavailable from the main generator.
- The electric power system was in its normal configuration per plant operating procedures immediately prior to event initiation.
- No operator intervention is considered during the study period.

The effects upon component operation of the boundary conditions imposed upon the system are described in the applicable analyses presented in Section D.5. Recovery actions requiring operator intervention are not included in the quantification of the hardware failure contributions because these actions are strongly dependent upon the available time frame for response, upon the specific event scenario in which they are applied (due to varying degrees of urgency and operator distraction imposed), and because any operator action will alter the system hardware configuration and component operating characteristics from those observed in an analysis of hardware failures alone.

The calculated system unavailability contribution from hardware failures thus represents a conservative upper bound which may be reduced through operator intervention within the context of the specific boundary conditions and event scenarios to which these analyses are applied. A general discussion of these time-dependent recoverability factors is presented in Section D.9.

D.2 TESTING CONTRIBUTION

Of the tests summarized in Section B.4, only actions performed during the diesel generator operability tests contribute to electric power system unavailability during noncold shutdown unit operating periods. During the monthly periodic functional tests (3PT-M22), the three diesel generators are started in succession and are operated under load for between 1 and 2 hours. These tests are performed from the local control panels in the diesel generator building.

Because each diesel generator is running and is attended during these operability tests, the diesel generators remain available for emergency service throughout the testing periods. However, the performance of these tests requires the diesel generator engine control switches to be removed from the "Auto" position. (The switch is placed in "Manual" for local starting of the diesel engine and is turned to "Off" for shutdown of the diesel at the conclusion of the test.) If left in any position other than "Auto," the switch inhibits an automatic starting signal from reaching the diesel engine control system and thus makes the unit unavailable for automatic emergency service. Removal of the switch from the "Auto" position is annunciated in the Unit 3 control room. All test procedures contain a step requiring the switch to be replaced in the "Auto" position following engine shutdown.

The section on Human Error Rates presented in the Methodology chapter of the main study report provides the following lognormal distribution for the frequency of an operator omitting a step while using a procedure with check-off provisions:

Mean: $\phi_{WP} = 2.2 \times 10^{-3}$ failures/test

Variance: 1.9×10^{-5}.

If the control switch is left in the wrong position at the end of the test, the control room annunciator will remain lit to alert the control room personnel to this condition. (The annunciator alarms when the switch is initially removed from "Auto" at the start of the test and remains lit throughout the test until the switch is returned to "Auto.") If the control room operator fails to respond to this annunciator, the switch will remain mispositioned, and the diesel generator will be unavailable for automatic operation. Neither the methodology chapter of this study nor the Human Reliability Handbook (NUREG/CR-1278) specifically addresses the issue of an operator failing to respond to an annunciator which remains lit for some time following its expected receipt. We have, therefore, assigned the following distribution as a conservative estimate of the total time required for the control room operator to respond to the lingering annunciator and for a local operator to return the control switch to the correct position.

Time to Restoration of Switch	Frequency
< 1 Hour	.750
1 - 12 Hours	.225
12 Hours - 7 Days	.024
7 Days - 30 Days	.001

If a switch is left in the wrong position, the majority of these recovery actions will take place within an hour following completion of the test. Although this action may be taken within a very few minutes, factors such as other tasks being performed by the control room operators, time delays in communicating with the local operator, the local operator's response time to the diesel generator building, and the perceived urgency of clearing these alarms may all contribute to extending the period over several minutes. We feel that a 75% recovery rate within one hour is very conservative and is applicable to this bounding system analysis. If the operators on shift at the time of testing fail to respond to the alarm, then it is very likely that the next shift of personnel will investigate the situation if they recognize it as an abnormal condition. (If the preceding shift did not respond to the annunciator, they would very probably not relate the alarm to the incoming shift as an abnormal condition.) The new operators are likely to notice the annunciator during their review of the control boards, but may delay their response or instruct the local operators to investigate the problem at their convenience due to factors such as sensitivity to spurious alarms, perceived urgency, additional tasks, etc. We believe that a 97.5% frequency of recovery within 12 hours is also very conservative for this analysis. If the alarm persists for several days, successive new shifts of operators will be exposed to the condition. However, it is possible that, due to unforeseen circumstances (which could include annunciator signal failure), the control switch could remain mispositioned for the entire 30-day period between tests. Of course, the mispositioned switch would be discovered during any diesel generator tests performed during this intervening period, but we take credit only for the regularly scheduled monthly operability tests as defining the maximum period during which this condition could persist.

It should be noted that the diesel generators are visually inspected at least once each week (3PT-W1). However, this inspection does not specifically require the verification of alignment for automatic operation. Since the mispositioned switches are not annunciated locally, detection of any of the switches being in the wrong position during these weekly checks is improbable. (The local operators will rely on the control room annunciator to alert the control room personnel to this condition.) The distribution presented above assigns a 99.9% frequency to the discovery of a mispositioned switch within 7 days due to the control room annunciator. The weekly inspection could reduce the recovery failure frequency during the period of 7 to 30 days, but the effects are minor and, in the interest of conservatism, are not specifically quantified in this analysis.

The unavailability of a diesel generator due to its control switch being left in the wrong position at the completion of a monthly test is obtained by multiplying the distribution for failure frequency ($\phi_{WP}/720$) by the distribution developed above for the time to discovery. The resulting lognormal distribution for the unavailability of a diesel generator due to these testing errors is:

Mean: $Q_{TE1} = 2.51 \times 10^{-5}$

Variance: 7.20×10^{-9}.

We believe this distribution to be very conservative for the reasons outlined above in the development of the recovery distribution.

During each monthly test, all three diesel generators are tested in succession. If the local test personnel leave one control switch mispositioned at the end of a test, it is possible that they could leave two or all three switches mispositioned. Since the same people perform all three tests and use the same test procedure, we feel that there exists at least a moderate dependence among these failures. Thus, if one switch is mispositioned, the second and third switches will be left in the wrong positions at a higher frequency than if each of the diesel generator tests was completely independent. There is also some dependence for the control room operator failing to respond to the annunciated conditions. Even though several alarms are lit, the control room operator may decide to have them all cleared at the end of the test, may be distracted by other operations, etc. We feel that the overall effect of the combined actions of the local test personnel and the control room operators is a low dependence between the unavailability of one diesel generator due to a mispositioned control switch and the unavailability of two or three diesel generators. The quantification of this dependence is extremely difficult.

The section on Human Error Rates in the Methodology chapter of the main report provides an analytical expression which models this low dependence between errors made during task N and the error rate for the preceding task N-1:

$$\gamma_N = \frac{1 + 19\gamma_{N-1}}{20}.$$

The development and application of this relation are discussed in the Methodology chapter. It is used in this analysis to quantify the coupling between the medians of the unavailability distributions resulting from these dependent testing errors. As discussed in the development of this expression, an error factor of 5 is assigned to the resulting distribution for γ_N to express our uncertainty about this relation. The median of the lognormal distribution presented above for the unavailability of a single diesel generator is $\gamma_{N-1} = 9.72 \times 10^{-6}$. Use of this value in the low dependence coupling expression and application of the error factor results in the following distribution for the conditional unavailability of a second

diesel generator, given an error has been committed following testing of the first unit:

Median: 5.00×10^{-2} error/second event, given an initial error

Mean: 8.07×10^{-2} error/second event, given an initial error

Variance: 1.05×10^{-2}.

The unavailability of both diesel generators due to these weakly coupled errors is determined by multiplying the conditional unavailability distribution for the second diesel generator by the distribution for error-produced unavailability of the first unit. The resulting distribution for the unavailability of two diesel generators due to mispositioned control switches is:

Mean: $Q_{TE2} = 2.03 \times 10^{-6}$

Variance: 2.34×10^{-11}.

Application of the weak coupling expression to determine the conditional unavailability of a third diesel generator, given the condition that errors have occurred during the testing of two diesel generators, results in the following distribution for the unavailability of three diesel generators due to mispositioned switches:

Mean: $Q_{TE3} = 1.63 \times 10^{-7}$

Variance: 2.02×10^{-13}.

We believe the coupling factor developed above to be a very conservative estimate of the dependence among these specific testing and annunciator response errors. The resulting unavailabilities for two and three diesel generators due to these errors are, therefore, considered to be bounding values.

D.3 MAINTENANCE CONTRIBUTION

The only maintenance which contributes to the unavailability of the electric power system during noncold shutdown unit operating periods is that performed on the diesel generators. The Indian Point Unit 3 technical specifications allow a single diesel generator to be removed from service for maintenance for a maximum period of 7 days, provided the remaining two diesel generators are operable and are started daily and provided both the 138 kV and 13.8 kV sources of offsite power remain available throughout this period. The unit must be shut down if more than one diesel generator becomes inoperable. Maintenance Data Table B.3-15 and Figure B.3-16 provide the following information with respect to diesel generator maintenance:

- The frequency of diesel generator maintenance is given by the lognormal distribution:

  Mean: 2.92×10^{-4} maintenance events/hour/diesel generator

  Variance: 3.97×10^{-9}.

- The mean unavailability of each diesel generator due to maintenance is 1.09×10^{-2}. In order to directly apply the unavailability information presented in Figure B.3-16 to this analysis, the smooth curve was discretized to produce the following histogram:

Generator Unavailability	Probability Density
.004	.039
.006	.113
.008	.188
.010	.242
.012	.150
.014	.108
.016	.075
.018	.053
.020	.032

D.4 DIESEL FUEL OIL SUPPLY FAILURE

The quantity of fuel normally contained in each of the diesel generator fuel oil day tanks is sufficient for the operation of a diesel generator for approximately 1 hour under full load conditions. For extended operating periods beyond this limit, fuel oil must be transferred from the underground storage tanks to the day tanks via the fuel oil transfer pumps. If a low level is detected in the day tank for diesel generator 31, transfer pump 31 will automatically start to refill the tank to approximately 158 gallons. In a similar manner, transfer pump 32 starts on a low level in the day tank for diesel generator 32, and transfer pump 33 starts for diesel generator 33. A low-low fuel oil level alarm is activated at the diesel generator panels if a day tank level drops to 52 gallons (approximately 24 minutes diesel generator operating reserve time). This alarm is also received in the Unit 3 control room at the common annunciator window for diesel generator trouble.

If the primary fuel oil transfer pump for a given diesel genertor fails, no automatic signals are available from the affected day tank to start either of the remaining two pumps. However, if more than one diesel generator is running, two or three fuel oil transfer pumps will receive starting signals as their associated day tank levels reach the low level setpoint. With all three diesel generators operating at full load, the total fuel consumption rate is approximately 7 gallons per minute. A single transfer pump can provide this capacity and can supply all three diesel engines simultaneously through the common fuel oil supply piping.

The fuel oil transfer pumps are each supplied from a different essential power motor control center (MCCs 36A, 36B, and 36C), none of which is affected by the automatic 480V switchgear bus load shedding operations described in Section B.2.2.4. Power will be lost at any of these MCCs if either the MCC supply breaker from the 480V switchgear bus fails or if the MCC, itself, fails during the 6-hour period following the initiating event. (Power failure at the 480V bus is a direct contributor to the electric power system failure state quantification. The contribution due to the unavailability of power at these MCCs must, therefore, be calculated conditionally upon the fact that power has not been lost at the 480V bus due to other causes.) Data Table B.2-2 provides the following lognormal distributions for the failure rates of circuit breakers and buswork:

- Circuit breaker transfers open:

  Mean: 2.67×10^{-6} failure/hour

  Variance: 3.21×10^{-12}.

- Bus open circuit:

  Mean: 3.25×10^{-8} failure/hour

  Variance: 1.27×10^{-14}.

The resulting unavailability of power at any one of the fuel oil transfer pump MCCs over the 6-hour period following event initiation, given that power is available at the associated 480V switchgear bus, is:

Mean: $P_{NP} = 1.62 \times 10^{-5}$

Variance: 7.98×10^{-11}.

No specific data is available in this study for failures of the diesel fuel oil transfer pumps. A review of the component failure data summaries for a wide variety of motor-driven pumps receiving automatic starting signals indicates that a median value of 2×10^{-3} is representative of the combined rate for these pumps failing to start on demand and remain in operation for at least 6 hours. Assigning an error factor of 5 to represent our uncertainty in this value results in the following lognormal distribution for fuel oil transfer pump failures given that power is available at the pump MCC:

Mean: $P_{PF} = 3.23 \times 10^{-3}$ pump failures/event

Variance: 1.67×10^{-5}.

Analysis of the Indian Point Unit 3 diesel generators has provided the following distributions for the unavailability of the diesel genertors, given the conditions that they are demanded to supply power to their respective buses:

- Unavailability of one diesel generator:

  Mean: $Q_{1DG} = 3.4 \times 10^{-2}$

  Variance: 7.1×10^{-5}.

- Unavailability of two diesel generators:

  Mean: $Q_{2DG} = 1.2 \times 10^{-3}$

  Variance: 1.7×10^{-7}.

- Unavailability of all three diesel generators:

  Mean: $Q_{3DG} = 4.7 \times 10^{-5}$

  Variance: 3.1×10^{-10}.

These distributions include contributions from diesel generator starting failures, output breaker failures, diesel generator failures during operation over a 6-hour period following start, unavailability due to maintenance, testing errors, and fires in the diesel generator rooms. They are conditional upon the availability of fuel to the diesel engines.

D.4.1 FUEL SUPPLY WITH OFFSITE POWER NOT AVAILABLE

All three diesel generators will receive starting signals when voltage is initially lost at their associated switchgear buses. After approximately 30 minutes of diesel generator operation, all three fuel oil transfer pumps should receive staring signals from the low levels in thier respective day tanks. Any single transfer pump can supply sufficient fuel to maintain all three diesel generators operating at full load. The fuel supply failure contribution to the unavailability of any combination of diesel generators under these conditions thus, depends not only upon the status of the respective diesel generators' transfer pumps, but also upon the status of the other diesel generators and their transfer pumps.

D.4.1.1 Fuel Contribution to Unavailability of One Diesel Generator

If the diesel generator in question fails due to causes other than fuel supply failure, the need for a continuous supply of fuel oil to the diesel engine is eliminated. Therefore, the evaluation of the fuel supply contribution to the unavailability of a single diesel generator must be performed under conditions in which that diesel generator is operating. The following discussion is presented using diesel generator 31 as an example; the analysis is identical for either of the other two diesel generators. Failure of fuel to diesel generator 31 requires any one of the following events to occur:

- If all three diesel generators are operating, failure of the fuel supply to diesel generator 31 requires failure of all three transfer pumps. The probability that all three diesel generators are

operating is approximated for this analysis by the factor $[1-(3Q_{1DG} + 3Q_{2DG} + Q_{3DG})]$. A transfer pump will not supply fuel if either its MCC is deenergized (P_{NP}) or if the pump itself fails (P_{PF}). The contribution to fuel supply failure from this diesel generator operability state is thus $[1-(3Q_{1DG} + 3Q_{2DG} + Q_{3DG})][(P_{NP} + P_{PF})^3]$.

- If diesel generator 32 (33) is unavailable, transfer pump 32 (33) will be deenergized and incapable of supplying fuel. However, transfer pumps 31 and 33 (31 and 32) should receive starting signals as their day tanks are drained. The unavailability of fuel to diesel generator 31 under this condition is given by $[Q_{1DG}][(P_{NP} + P_{PF})^2]$.

- If both diesel generators 32 and 33 are unavailable, transfer pumps 32 and 33 will be deenergized. Transfer pump 31 is the only pump available to supply fuel to diesel generator 31 under this condition, and the failure of that supply is quantified by $[Q_{2DG}][(P_{NP} + P_{PF})]$.

Any other failure states involve failure of diesel generator 31 and are, therefore, not relevant to this analysis. The total expression for the unavailability of fuel to diesel generator 31 is the sum of the individual contributions derived above:

$$Q_{F1} = [1-(3Q_{1DG} + 3Q_{2DG} + Q_{3DG})][(P_{NP} + P_{PF})^3] + 2[Q_{1DG}][(P_{NP} + P_{PF})^2]$$

$$+ [Q_{2DG}][(P_{NP} + P_{PF})].$$

The resulting unavailability of fuel oil to a single diesel generator under the boundary condition of offsite power not available is evaluated using discrete probability distribution arithmetic.

Mean: $Q_{F1} = 5.49 \times 10^{-6}$

Variance: 5.10×10^{-11}.

The dominant contributor to fuel supply failure is the failure of two diesel generators and failure of the fuel oil transfer pump for the diesel generator being analyzed.

D.4.1.2 Fuel Contribution to Unavailability of Two Diesel Generators

Fuel failure to diesel generators 31 and 32 is developed as a specific example in this discussion; the analysis is identical for any combination of two diesel generators. If both diesel generators have failed, their continued fuel supply is unnecessary. However, because each fuel oil transfer pump can supply both diesel engines, the contributions of individual failures of each of these diesel generators must be included in the quantification of the fuel supply unavailability to both. Failure of the fuel supply to diesel generators 31 and 32 will occur if:

- All three diesel generators are operating and all three transfer pumps fail: $[1-(3Q_{1DG} + 3Q_{2DG} + Q_{3DG})][(P_{NP} + P_{PF})^3]$

- Any one of the diesel generators is unavailable, and the remaining two transfer pumps fail: $[Q_{1DG}][(P_{NP} + P_{PF})^2]$

- Diesel generators 31 and 33 (32 and 33) are unavailable, and transfer pump 32 (31) fails: $[Q_{2DG}][(P_{NP} + P_{PF})]$.

All other possible states include the failure of both diesel generators 31 and 32 and are, therefore, not relevant to this analysis. The total unavailability expression for the failure of fuel to these two diesel generators is:

$$Q_{F2} = [1-(3Q_{1DG} + 3Q_{2DG} + Q_{3DG})][(P_{NP} + P_{PF})^3] + 3[Q_{1DG}][(P_{NP} + P_{PF})^2] + 2[Q_{2DG}][(P_{NP} + P_{PF})].$$

This equation is evaluated using discrete probability distribution arithmetic:

Mean: $Q_{F2} = 1.01 \times 10^{-5}$

Variance: 1.58×10^{-10}.

The dominant contributors to fuel supply are unavailability of two diesel generators and failure of the third fuel oil transfer pump.

D.4.1.3 Fuel Contribution to Unavailability of All three Diesel Generators

Fuel will be unavailable to all three diesel generators if any of the following conditions occur:

- All three diesel generators are operating and all three fuel transfer pumps fail

- Any single diesel generator is unavailable and the remaining two transfer pumps fail

- Any combination of two diesel generators are unavailable and the remaining single transfer pump fails.

Of course, if all three diesel generators have failed, all three transfer pumps will be deenergized, but there will also be no need to transfer any fuel. The fuel supply unavailability equation for this case is:

$$Q_{F3} = [1-(3Q_{1DG} + 3Q_{2DG} + Q_{3DG})][(P_{NP} + P_{PF})^3] + 3[Q_{1DG}] \times [(P_{NP} + P_{PF})^2] + 3[Q_{2DG}][(P_{NP} + P_{PF})].$$

The resulting unavailability of fuel is:

Mean: $Q_{F3} = 1.40 \times 10^{-5}$

Variance: 2.79×10^{-10}.

The dominant contributors are failure of any two diesel generators and failure of the third fuel oil transfer pump.

D.4.2 FUEL SUPPLY WITH OFFSITE POWER AVAILABLE

If offsite power is available to the station auxiliary transformer, the number of diesel generators required to operate depends entirely upon the electric power system failure state being analyzed. If only one diesel generator is called upon to supply power, only its associated fuel oil transfer pump will be available for automatic makeup to the diesel engine day tank. If two diesel generators are running, either fuel oil transfer pump can supply both day tanks and each pump should receive a starting signal as its respective tank reaches the low level setpoint. Of course, if all three diesel generators are called upon to supply power, all three transfer pumps receive starting signals.

D.4.2.1 Fuel Contribution to Unavailability of One Diesel Generator

If only one diesel generator is running, only its associated fuel oil transfer pump will receive an automatic starting signal from a low level in the day tank. If this pump fails to operate, the diesel generator will run out of fuel. Plant operating personnel may locally start one of the remaining two pumps to maintain a supply of fuel to the affected diesel, but these manual actions are not considered in this bounding analysis. Therefore, if only one diesel generator is operating, the fuel unavailability expression for that diesel generator is:

$$Q_{F1} = P_{NP} + P_{PF}$$

This expression is evaluated using discrete probability distribution arithmetic to compute the unavailability of fuel to a single diesel generator under a boundary condition that offsite power is available and only that single diesel generator is operating.

Mean: $Q_{F1} = 3.25 \times 10^{-3}$

Variance: 1.24×10^{-5}

The dominant contributor is failure of the transfer pump.

D.4.2.2 Fuel Contribution to Unavailability of Two Diesel Generators

If two diesel generators are running, both of their associated fuel oil transfer pumps should receive automatic starting signals. Either pump can supply sufficient fuel to maintain both diesel generators operating at full load. Failure of the fuel supply under these conditions will thus occur if:

- Both diesel generators are operating and both fuel oil transfer pumps fail. The probability that both diesel generators are operating, given signals to start, is approximated for this analysis by the factor $[1-(2Q_{1DG} + Q_{2DG})]$, and the total contribution to fuel unavailability is $[1-(2Q_{1DG} + Q_{2DG})][(P_{NP} + P_{PF})^2]$.

- One of the two diesel generators is unavailable and the remaining transfer pump fails. This contribution is quantified by the term $[Q_{1DG}][(P_{NP} + P_{PF})]$.

Of course, if both diesel generators have failed, there is no need for a continuous supply of fuel. The expression for the unavailability of fuel to a pair of diesel generators is, therefore:

$$Q_{F2} = [1-(2Q_{1DG} + Q_{2DG})][(P_{NP} + P_{PF})^2] + 2[Q_{1DG}][(P_{NP} + P_{PF})].$$

This expression is evaluated to provide the following distribution for the unavailability of fuel to two diesel generators with offsite power available.

Mean: $Q_{F2} = 2.40 \times 10^{-4}$

Variance: 6.93×10^{-8}.

The dominant contributor to fuel supply unavailability is failure of one of the diesel generators and failure of the remaining transfer pump.

D.4.2.3 Fuel Contribution to Unavailability of All Three Diesel Generators

If all three diesel generators are called upon to supply power, the fuel supply failure analysis is identical to that presented in Section D.4.1.3 above. From the standpoint of diesel generator and transfer pump operation, this condition has the same characteristics as that in which all three diesel generators are called upon to supply power in response to the failure of the offsite power supply. The results of the analysis presented in Section D.4.1.3 are repeated here for the unavailability of fuel to all three diesel generators under the boundary condition of offsite power available to the station auxiliary transformer:

Mean: $Q_{F3} = 1.40 \times 10^{-5}$

Variance: 2.79×10^{-10}.

Fuel failure is dominated by the unavailability of two diesel generators and failure of the third transfer pump.

D.5 SYSTEM FAILURE STATE QUANTIFICATION

The quantification of the nonmutually exclusive electric power system failure states is summarized in Tables 9.1 and 9.2. The basis for each table is an unavailability expression developed from the system failure

state logic model which includes all component failure modes necessary and sufficient to achieve the given failure state. The distributions characterizing the individual component failure rates are combined through this equation using discrete probability distribution arithmetic to develop the hardware contribution to failure. Specifying unity failure rates for each diesel generator allows the calculation of the conditional failure of power for various states of diesel generator unavailability. These conditional failure distributions are then combined with the probabilities of the diesel generators being in each of these unavailability states to determine the contributions to each system failure state from diesel generator maintenance and fuel oil supply failure. The conditional failure distributions also provide input to the quantification of common cause failures discussed in Section D.6.

A detailed description of the methodology employed in the calculation of the failure state summarized in Table 9.1-1 is presented below. The development of each of the other failure states is similar, and only a brief discussion of the applicable unavailability expression is included. The following variables are used in the development of the unavailability expressions:

Variable	Component Failure Mode
A	Bus failure (per hour)
B	Circuit breaker transfers open (per hour)
C	Transformer failure (per hour)
H	Diesel generator failure to start and load (per demand)
J	Circuit breaker failure to close (per demand)
K	Circuit breaker failure to open (per demand)
L	DC control power failure (per hour)
M	Diesel generator failure during operation (per hour)

D.5.1 BOUNDARY CONDITION 1 (OFFSITE POWER NOT AVAILABLE, NO RECOVERY FROM FAILURES DURING 6-HOUR STUDY PERIOD)

Under this boundary condition, the only source of power to the 480V switchgear buses is from the diesel generators. All three diesel generators start automatically and their output breakers receive automatic closing signals due to the inital loss of voltage at all of the buses. The normal supply breakers to all of the 480V buses are also automatically opened by these undervoltage signals. All motor control centers except MCCs 36A, 36B, and 36C are shed from the 480V buses.

Case 1: Failure of Power at Bus 2A (Table 9.1-1)

Since diesel generator 31 provides the only source of power to bus 2A under these boundary conditions, failure of the diesel generator to start (H) or failure of its output breaker EG1 to close (J) will prevent bus 2A from being reenergized following the loss of offsite power. Since breaker EG1 will not close unless the normal supply breaker to the bus is open, failure of breaker 2A to open (K) following the initial

loss of bus voltage will prevent the diesel generator from automatically reenergizing the bus. If the diesel generator starts and the breaker closes, then the diesel generator must maintain its power supply to the bus for a period of 6 hours. Failures of the diesel generator (M), the breaker (B), or failures of bus 2A itself (A) during this period will also result in a loss of bus voltage. A linear model for failures during the 6-hour period provides essentially the same results as does an exponential model, and the uniform hourly failure rates are simply multiplied by the duration of the period. The unavailability expression for this failure state thus takes the form:

$$Q_{2A} = H + J(1 - K) + K + [M(1 - H) + B(1 - J) + A]t.$$

Although recovery from many of these failures is certainly possible within the 6-hour study period, it must be remembered that this analysis has been developed as a conservatively bounding input to the quantification of the dominant event sequence contributors to risk. The inclusion of these recovery actions and the assignment of their associated time-dependent failure probability distributions will be undertaken within the context of specific dominant event sequences. These sequences define both the necessary actions to be taken and the time frame within which these actions must be accomplished to achieve overall plant recovery.

It should be noted that DC power failures are not included in the unavailability expression presented above. Since the entire electric power system is assumed to be in its normal operating state immediately prior to event initiation, DC control power will be available to this division. The probability of losing DC power as a result of the event is negligible when compared with the other component failure rates. Once the diesel generator has started and its output breaker has closed, loss of DC power during the subsequent 6-hour period will not affect electric power system operation and, therefore, is not quantified.

Since recovery of neither offsite power nor the diesel generator is allowed in this analysis, if diesel generator 31 is inoperable or otherwise unavailable for service when offsite power is lost, bus 2A will remain deenergized for the duration of the 6-hour study period. Therefore, the conditional unavailability of power at bus 2A is 1.0 if diesel generator 31 is inoperable under the established boundary conditions.

In order to develop the maintenance contribution to the failure of power at bus 2A, the unavailability of diesel generator 31 due to maintenance is simply combined with the conditional failure of power at bus 2A given that diesel generator 31 is unavailable. Since no recovery is included in the analysis, this latter value is unity, and the resulting distribution for the failure of power at bus 2A due to diesel generator maintenance is identical to the diesel generator unavailability distribution presented in Section D.3.

Since the fuel oil transfer system will be called upon to maintain operation of the diesel generator during the 6-hour period, the contribution to power failure at bus 2A from diesel fuel oil supply failures is identical to the fuel supply contribution to diesel generator unavailability developed in Section D.4.1.1.

Case 2: Failure of Power at Bus 3A (Table 9.1-2)

Tie-breaker 2AT3A is normally open during unit operation. This breaker receives an automatic closing signal following a loss of voltage at bus 3A. However, interlocks prevent the breaker from closing unless the normal feed breaker to bus 3A is open and the output breaker from diesel generator 31 (breaker EG1) is closed. Breaker EG1 is, in turn, interlocked to prevent automatic closure unless the normal feed breaker to bus 2A is open. Failure of either of the normal feed breakers to buses 2A and 3A to open, or failure of either breaker EG1 or 2AT3A to close will result in bus 3A remaining deenergized. Of course, failure of diesel generator 31 to start or remain in operation fo the entire 6-hour study period will also cause power failure at bus 3A.

It should be noted that several of the failures outlined above will cause power to be lost at both buses 2A and 3A. As discussed in Section C.2, these nonmutually exclusive failure states are quantified by evaluating all contributors which are both necessary and sufficient to achieve the given failure condition. The application of Boolean logic to the entire set of nonmutually exclusive states will eliminate higher order failure influences from each of the mutually exclusive states.

The unavailability expression for the failure of power at bus 3A is:

$$Q_{3A} = H + 2J(1 - K) + 2K + [M(1 - H) + 2B(1 - J) + 2A]t.$$

The diesel generator maintenance and fuel supply failure contributions to this failure state are identical to those described for Case 1 above.

Case 3: Failure of Power at Bus 5A (Table 9.1-3)

This case is similar to Case 1.

Case 4: Failure of Power at Bus 6A (Table 9.1-4)

This case is symmetric to Case 3.

Case 5: Failure of Power at Buses 2A and 3A (Table 9.1-5)

Any failure affecting the supply of power from diesel generator 31 to bus 2A will cause both buses 2A and 3A to be deenergized under these boundary conditions. The unavailability expression developed above for Case 1 thus quantifies the failures which are both necessary and sufficient for the achievement of this failure state:

$$Q_{2A+3A} = H + J(1 - K) + K + [M(1 - H) + B(1 - J) + A]t.$$

Of course, if diesel generator 31 is unavailable for service when offsite power is lost, both buses will remain deenergized. The conditional unavailability of power at these buses, given diesel generator 31 inoperable, is therefore, unity. The maintenance and fuel oil supply contributions to this failure state are identical to those discussed above for Case 1.

Case 6: Failure of Power at Buses 2A and 5A (Table 9.1-6)

With offsite power lost, the failure of power at both buses 2A and 5A requires component failures in the power supply trains from both diesel generators 31 and 33, respectively. Since these diesel generators operate independently from each other, the unavailability expressions for each of the two single bus power failure cases can be multiplied together to produce the equation applicable to this combined failure state. This expression is:

$$Q_{2A + 5A} = \{H + J(1 - K) + K + [M(1 - H) + B(1 - J) + A]t\}^2.$$

The system analysis guidelines preclude efforts to recover power to either bus after a failure has occurred. Therefore, failures need not be simultaneous in order to achieve this combined failure state. Any combination of failures of both diesel generator power supply trains with no recovery during the 6-hour study period is sufficient to produce power failure at both buses.

If diesel generator 33 is unavailable for service, the conditional failure of power at both buses 2A and 5A is determined by the failure of power at bus 2A alone. The failure distribution for this conditional state is thus identical to the distribution developed for the single state of failure of power at bus 2A. Similarly, if diesel generator 31 is unavailable, the conditional failure of power at buses 2A and 5A is determined by the failure of power at bus 5A. Of course, if both diesel generators are inoperable, both buses will remain deenergized when offsite power is lost.

Determination of the maintenance contribution to the failure of power at buses 2A and 5A is accomplished by multiplying the unavailablility of each diesel generator due to maintenance with the corresponding conditional distribution for failure of power with that diesel generator unavailable, and summing the resulting distributions. Since both diesel generators cannot be removed from service for maintenance at the same time during unit operation, there is no contribution to the unavailability of power at buses 2A and 5A from simultaneous diesel generator maintenance.

The fuel oil transfer system is common to both diesel generators. Because this analysis is extended for 6 hours following event initiation, failure of this system will cause failure of both diesel generators and will result in power being lost at both of these buses. The fuel supply contribution to this failure state is thus obtained by multiplying the conditional unavailability of power at both buses, given

that both diesel generators are inoperable (unity), with the distribution developed in Section D.4.1.2 for the unavailability of two diesel generators due to fuel supply failures.

Case 7: Failure of Power at Buses 2A and 6A (Table 9.1-7)

This case is symmetric to Case 6.

Case 8: Failure of Power at Buses 3A and 5A (Table 9.1-8)

The unavailability expression for this failure state is obtained by multiplying together the expression for the failure of power at each of the buses individually:

$$Q_{3A + 5A} = \{H + 2J(1 - K) + 2K + [M(1 - H) + 2B(1 - J) + 2A]t\}$$
$$\times \{H + J(1 - K) + K + [M(1 - H) + B(1 - J) + A]t\}.$$

Because diesel generators 31 and 33 provide the only sources of power to these buses under these boundary conditions, the contributions to this failure state from diesel generator maintenance and fuel supply failures are quantified in the same manner as those discussed above for Case 6.

Case 9: Failure of Power at Buses 3A and 6A (Table 9.1-9)

This case is symmetric to Case 8.

Case 10: Failure of Power at Buses 5A and 6A (Table 9.1-10)

This case is similar to Case 6.

Case 11: Failure of Power at Buses 2A, 3A, and 5A (Table 9.1-11)

This failure state will be achieved if failures occur in the power supply trains from diesel generators 31 and 33 at any time during the 6 hour period following the loss of offsite power. The unavailability expression for this case is thus identical to that developed above for Case 6:

$$Q_{2A,\ 3A + 5A} = \{H + J(1 - K) + K + [M(1 - H) + B(1 - J) + A]t\}^2.$$

The maintenance and fuel supply contributions to power failure at these three buses are treated in the same manner as described above for the cases of power failure at two buses.

Case 12: Failure of Power at Buses 2A, 3A, and 6A (Table 9.1-12)

This case is symmetric to Case 11.

Case 13: Failure of Power at Buses 2A, 5A, and 6A (Table 9.1-13)

The achievement of this failure state requires failures in the power supply trains from all three diesel generators. The unavailability expression for this state is:

$$Q_{2A,\ 5A\ +\ 6A} = \{H + J(1 - K) + K + [M(1 - H) + B(1 - J) + A]t\}^3.$$

Although failure of diesel generator 31 will cause power to be lost at both buses 2A and 3A, this expression defines the failure combinations which are both necessary and sufficient to achieve the given nonmutually exclusive failure state. The application of Boolean logic to the entire set of nonmutually exclusive states will eliminate higher order failure influences from each mutually exclusive state. (Refer to Section C.2 for a discussion of mutually exclusive and nonmutually exclusive failure states.)

Because no recovery actions are included in this analysis, it should be emphasized that this failure state is achieved if each of the three diesel generator divisions experiences a failure at any time during the 6-hour analysis period (i.e., once power has been lost to a specific bus, it remains deenergized for the entire period). The conditional unavailability of power at these buses with each combination of diesel generators inoperable is obtained directly from the reduced system failure state caused by that condition. (For example, with diesel generators 31 and 33 inoperable, power will be failed at buses 2A and 5A. The conditional unavailability of power at all three buses with these two diesel generators inoperable is thus identical to the distribution for failure of power at bus 6A, alone.)

The maintenance contribution to power unavailability is obtained by summing the effects from each of the three diesel generators. This value is calculated for each diesel generator from the product of diesel generator unavailability due to maintenance (from Section D.3) and the conditional power unavailability with that diesel generator inoperable.

Fuel transfer system failures cause all three diesel generators to fail. The contribution to power unavailability from this cause is obtained from the product of the unavailability of all three diesel generators due to fuel supply failures (from Section D.4.1.3) and the unavailability of power at these buses with all three diesel generators failed (unity).

Case 14: Failure of Power at Buses 3A, 5A, and 6A (Table 9.1-14)

The unavailability expression for this failure state is similar to that shown above for Case 13, except that the additional failures of breakers 2AT3A and 3A are included.

$$Q_{3A,\ 5A\ +\ 6A} = \{H + 2J(1 - K) + 2K + [M(1 - H) + 2B(1 - J) + 2A]t\}$$
$$\times \{H + J(1 - K) + K + [M(1 - H) + B(1 - J) + A]t\}^2.$$

The conditional unavailability of power at these buses with each combination of diesel generators inoperable is determined in the same manner as described for Case 13. The calculations of the maintenance and fuel supply failure contributions to power unavailability are identical to those in Case 13.

Case 15: Failure of Power at all 480V Switchgear Buses (Table 9.1-15)

Since failure of the power supply from diesel generator 31 to bus 2A is necessary and sufficient to cause both buses 2A and 3A to be deenergized, the contributions to this electric power failure state can be quantified through the same unavailability expression as that developed for Case 13.

$$Q_{2A,\ 3A,\ 5A\ +\ 6A} = \{H + J(1 - K) + K + [M(1 - H) + B(1 - J) + A]t\}^3.$$

The maintenance and fuel supply contribution to this failure state are quantified in the same manner as described for Case 13.

D.5.2 BOUNDARY CONDITION 2 (OFFSITE POWER AVAILABLE, NO RECOVERY FROM FAILURES DURING 6-HOUR STUDY PERIOD)

Under this boundary condition, the 480V switchgear buses should remain energized from the offsite power source. When the unit trip occurs, the supplies to 480V switchgear buses 2A and 3A (via 6.9 kV buses 2 and 3) are automatically transferred to the station auxiliary transformer; buses 5A and 6A remain energized through their normal supply paths. No motor control centers are automatically shed from the buses.

If an undervoltage condition is detected at any of the 480V switchgear buses (with the exception of bus 3A), an automatic signal is generated to start the associated diesel generator, open the normal bus feed breaker, and close the diesel generator output breaker to the bus. This bus undervoltage signal also sheds all loads from the affected bus (except MCCs 36A, 36B, and 36C, as applicable).

If the initiating event results in a safety injection signal being generated in additon to the unit trip, all three diesel generators are automatically started but run unloaded until power is lost at one of their associated buses. The safety injection signal also automatically sheds all nonessential loads from each of the 480V buses.

Since diesel generator 31 starts automatically on loss of power at bus 2A only, if an undervoltage condition exists at only bus 3A, this bus will remain deenergized until the operator takes manual action to provide an alternate power supply path to the bus. As discussed previously, the quantification presented in this section does not include operator recovery considerations for these events because of their strong dependence upon the allowable recovery time frame for the specific scenario analyzed and because the operator's actions will drastically modify the operating characteristics of the system

hardware. The unavailabilty calculated for each of these failure states is thus a conservative upper bound which may be reduced through operator intervention. (These recoverability factors are discussed further in Section D.9.)

Case 1: Failure of Power at Bus 2A (Table 9.2-1)

Tie-breaker 2AT3A is normally open and does not receive an automatic closing signal from an undervoltage condition at bus 2A. Since no manual operator actions are included in this bounding analysis, failure of the power supply to bus 2A from the offsite grid requires failure of any of the following components (refer to Figure 2 for component designation):

- Failure of the station auxiliary transformer.
- Breaker ST5 transfers open.
- Failure of 6.9 kV bus 5.
- Failure of breaker UT2/ST5 to close.
- Breaker UT2/ST5 transfers open after closure.
- Failure of 6.9 kV bus 2.
- Breaker SS2 or 2A transfers open.
- Failure of station service transformer 2.

The factor in the unavailability expression presented below which accounts for these component failures is:

$$J + [2A + 3B + B(1 - J) + 2C]t.$$

Since diesel generator 31 will automatically start and load onto bus 2A whenever an undervoltage condition is detected at the bus, failure of power at the bus requires failure of the normal power source and failure of the diesel generator supply. Failure of diesel generator 31 to start, load, or to remain in operation for the duration of the analysis period will cause subsequent power loss at bus 2A. Failure of the diesel generator output breaker EG1 to close or failure of the normal bus supply breaker 2A to open (due to the interlock between breakers 2A and EG1) will also prohibit diesel generator 31 from energizing the bus. The bus will also remain deenergized if DC control power has failed at either the diesel generator or the 480V switchgear during the intervening period between event initiation and loss of bus voltage. The factor in the unavailability expression which quantifies these diesel generator power train failures is:

$$H + J(1 - K) + K + [M(1 - H) + B(1 - J) + L]t.$$

Although specific sequential failures are required in this scenario (i.e., the diesel generator is required to operate only after power has initially been lost at bus 2A), the modeling of these failures is simplified by including component failures over the full duration of the 6-hour period. This introduces additional conservatism into the analysis results to the extent that the diesel generator may not be required to operate for 6 hours. However, these effects are minor and are conservative.

In addition to the failures discussed above, bus 2A, itself, may fail at any time during the 6-hour study period. This contribution to power failure is represented by the term "At". The complete unavailability expression for the failure of power at bus 2A under this boundary condition is:

$$Q_{2A} = At + \{J + [2A + 3B + B(1 - J) + 2C]t\}$$
$$\times \{H + J(1 - K) + K + [M(1 - H) + B(1 - J) + L]t\}.$$

If diesel generator 31 is unavailable for service, bus 2A will remain deenergized following any failure of the normal power supply to the bus. The conditional unavailability expression for the loss of power at bus 2A, given diesel generator 31 inoperable, is:

$$Q_{2A,\ \overline{DG}} = At + \{J + [2A + 3B + B(1 - J) + 2C]t\} .$$

Case 2: <u>Failure of Power at Bus 3A (Table 9.2-2)</u>

Tie-breaker 2AT3A will close automatically only if the normal feed breaker to bus 3A is open and the output breaker from diesel generator 31 is closed. Since manual operator actions are excluded from this bounding analysis, failure of the normal source of power to bus 3A through 6.9 kV breaker ST6 (excluding failures of the station auxiliary transformer) will cause bus 3A to remain deenergized. These component failures are quantified by the terms:

$$J + [2A + 3B + B(1 - J) + C]t.$$

If the station auxiliary transformer fails or if both of the normal power supply paths to buses 2A and 3A fail, bus 3A may be automatically reenergized from diesel generator 31. Under these conditions, both of the normal feed breakers to buses 2A and 3A should receive trip signals from the associated bus undervoltage relays. Diesel generator 31 starts automatically on undervoltage at bus 2A, and its output breaker closes automatically if the normal bus 2A feed breaker is open. Breaker 2AT3A closes automatically following closure of the diesel generator output breaker, if the normal bus 3A feed breaker is open. The contribution to this failure state from the failure of the station auxiliary transformer or both buses' normal power supply paths, is expressed by the factor:

$$\{J + [2A + 3B + B(1 - J) + C]t\}^2 + Ct$$

Failure of the power supply to bus 3A from diesel generator 31 will occur if the diesel generator itself fails, if either its output breaker to bus 2A or tie-breaker 2AT3A fails, or if either of the normal feed breakers to buses 2A and 3A fail to open. The failure of DC control power will also prevent bus 3A from being reenergized, since it will prevent diesel generator 31 from automatically starting and closing onto bus 2A. Failure of bus 2A itself will open the path from diesel generator 31 to bus 3A. The contribution of diesel generator 31 power supply failures is quantified through the factor:

$$\{H + 2J(1 - K) + 2K + [M(1 - H) + 2B(1 - J) + L + A]t\}.$$

Of course, failure of bus 3A, itself, at any time during the analysis period will also lead to power failure. The total unavailability expression for this failure state is thus:

$$Q_{3A} = At + \{J + [2A + 3B + B(1 - J) + C]t\}$$
$$+ [\{J + [2A + 3B + B(1 - J) + C]t\}^2 + (Ct)]$$
$$\times \{H + 2J(1 - K) + 2K + [M(1 - H) + 2B(1 - J) + L + A]t\}.$$

The conditional unavailability of power at bus 3A with diesel generator 31 inoperable is obtained by removing the effects of the diesel generator supply from the unavailability expression:

$$Q_{3A,\ \overline{DG}} = At + Ct + \{J + [2A + 3B + B(1 - J) + C]t\}.$$

The diesel generator maintenance and fuel supply failure contributions to power failure are quantified by combining this conditional unavailability with the unavailability of diesel generator 31 due to these factors as developed in Sections D.3 and D.4.2.1.

Case 3: Failure of Power at Bus 5A (Table 9.2-3)

Failure of power at bus 5A requires failure of any of the following components in the normal power supply path to the bus and subsequent failure of the power supply from diesel generator 33.

- Failure of the station auxiliary transformer or station service transformer 5.
- Breaker ST5, SS5 or 5A transfers open.
- Failure of 6.9 kV bus 5.

The unavailability expression for this failure state is:

$$Q_{5A} = At + [(A + 3B + 2C)t] \{H + J(1 - K) + K + [M(1 - H)$$
$$+ B(1 - J) + L]t\}.$$

If the diesel generator is unavailable for service, bus 5A will remain deenergized following any of the normal power supply path failures discussed above. The expression for the conditional unavailability of power at bus 5A with diesel generator 33 inoperable is thus:

$$Q_{5A,\ \overline{DG}} = At + (A + 3B + 2C)t.$$

As described previously, the maintenance and fuel supply failure contributions to this case are obtained by multiplying this conditional power failure distribution by the distributions from Sections D.3 and D.4.2.1 for diesel generator 33 unavailability due to these causes.

Case 4: Failure of Power at Bus 6A (Table 9.2-4)

This case is symmetric to Case 3.

Case 5: Failure of Power at Buses 2A and 3A (Table 9.2-5)

The combinations of failures which are sufficient for the achievement of this failure state are:

- Failure of buses 2A and 3A.
- Failure of bus 2A and failure of the normal power supply to bus 3A.
- Failure of bus 3A, failure of the normal power supply to bus 2A, and failure of the supply from diesel generator 31.
- Failure of the normal power supply paths to both buses and failure of the supply from diesel generator 31.
- Failure of the station auxiliary transformer and failure of the supply from diesel generator 31.

The factors which model each of these terms have been discussed in the preceding cases. The unavailability expression for this combined failure state is:

$$\begin{aligned} Q_{2A+3A} = {} & (At)^2 + (At)\{J + [2A + 3B + B(1 - J) + 2C]t\} \\ & \times [1 + \{H + J(1 - K) + K + [M(1 - H) + B(1 - J) + L]t\}] \\ & + [Ct + \{J + [2A + 3B + B(1 - J) + C]t\}^2] \\ & \times \{H + J(1 - K) + K + [M(1 - H) + B(1 - J) + L]t\}. \end{aligned}$$

If diesel generator 31 is inoperable, the conditional failure of power at buses 2A and 3A is quantified through the following expression:

$$\begin{aligned} Q_{2A+3A,\overline{DG}} = {} & (At)^2 + 2(At)\{J + [2A + 3B + B(1 - J) + C]t\} \\ & + \{J + [2A + 3B + B(1 - J) + C]t\}^2 + Ct. \end{aligned}$$

Calculation of the maintenance and fuel supply contributions to power failure uses this conditional failure distribution as discussed in the preceding cases.

Case 6: Failure of Power at Buses 2A and 5A (Table 9.2-6)

Failure of power at buses 2A and 5A will occur if any of the following conditions are satisfied:

- Buses 2A and 5A fail;

- Bus 2A fails, the normal power supply to bus 5A fails, and the power supply from diesel generator 33 fails.

- Bus 5A fails, the normal power supply to bus 2A fails, and the power supply from diesel generator 31 fails.

- The station auxiliary transformer, breaker ST5 or 6.9 kV bus 5 fails, and the supplies from diesel generators 31 and 33 fail.

- The supply path to bus 5A from 6.9 kV bus 5 fails, the supply path to bus 2A from 6.9 kV bus 5 fails, and the supplies from diesel generators 31 and 33 fail.

The unavailability expression derived from these five failure conditions is:

$$Q_{2A + 5A} = (At)^2 + (At)\{H + J(1 - K) + K + [M(1 - H) + B(1 - J) + L]t\}\{(A + 3B + 2C)t + J + [2A + 3B + B(1 - J) + 2C]t\} + \{H + J(1 - K) + K + [M(1 - H) + B(1 - J) + L]t\}^2 \times \{(A + B + C)t + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t]\}.$$

If diesel generator 31 is inoperable, the conditional failure of power at buses 2A and 5A is determined through evaluation of the expression:

$$Q_{2A + 5A, \overline{DG31}} = (At)^2 + (At)\{H + J(1 - K) + K + [M(1 - H) + B(1 - J) + L]t\}[(A + 3B + 2C)t] + (At) \times \{J + [2A + 3B + B(1 - J) + 2C]t\} + \{H + J(1 - K) + K + [M(1 - H) + B(1 - J) + L]t\}\{(A + B + C)t + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t]\}.$$

Similarly, if diesel generator 33 is inoperable:

$$Q_{2A + 5A, \overline{DG33}} = (At)^2 + (At)[(A + 3B + 2C)t] + (At)\{H + J(1 - K) + K + [M(1 - H) + B(1 - J) + L]t\} \times \{J + [2A + 3B + B(1 - J) + 2C]t\} + \{H + J(1 - K) + K + [M(1 - H) + B(1 - J) + L]t\}\{(A + B + C)t + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t]\}.$$

If both diesel generators are unavailable, the conditional failure of power at these buses is quantified through:

$$Q_{2A + 5A, \overline{DG31 + 33}} = (At)^2 + (A + B + C)t + [(A + 2B + C)t] \times [J + (2A + 2B + B(1 - J) + C)t].$$

The maintenance contribution to this failure state is calculated by combining the unavailability of each diesel generator due to maintenance with the corresponding conditional power failure distribution. Since either diesel generator may be out of service for maintenance when the initiating event occurs, these individual diesel generator effects are added to produce the total maintenance contribution.

Failure of the fuel oil transfer system will result in failure of both diesel generators. The contribution to this failure state from diesel fuel oil supply failures is obtained by multiplying the conditional power unavailability distribution developed above with both diesel generators inoperable by the distribution presented in Section D.4.2.2 for the unavailability of diesel generators 31 and 33 due to fuel supply failures.

Case 7: <u>Failure of Power at Buses 2A and 6A (Table 9.2-7)</u>

This case is very similar to Case 6. However, in the preceding case, the station auxiliary transformer, breaker ST5 and 6.9 kV bus 5 each provided a common failure point in the power supplies to both buses 2A and 5A. In this case, only the station auxiliary transformer is common to both buses. This configuration introduces a change to the final term in the unavailability expression. The unavailability expression for this failure state is:

$$\begin{aligned} Q_{2A + 6A} = {} & (At)^2 + (At)\{H + J(1 - K) + K + [M(1 - H) \\ & + B(1 - J) + L]t\}\{(A + 3B + 2C)t + J + [2A + 3B \\ & + B(1 - J) + 2C]t\} + \{H + J(1 - K) + K + [M(1 - H) \\ & + B(1 - J) + L]t\}^2 \{Ct + [(A + 3B + C)t] \\ & \times [J + (2A + 3B + B(1 - J) + C)t]\}. \end{aligned}$$

The conditional power failure expressions and the diesel generator maintenance and fuel supply failure contributions to power unavailability are developed in the same manner as in Case 6.

Case 8: <u>Failure of Power at Buses 3A and 5A (Table 9.2-8)</u>

Buses 3A and 5A will lose power if any of the following conditions are satisfied:

- Buses 3A and 5A fail.

- Bus 5A fails and the normal supply to bus 3A fails (excluding the station auxiliary transformer).

- Bus 5A fails, the normal supply to bus 3A through 6.9 kV bus 3 fails, the normal supply to bus 2A through 6.9 kV bus 2 fails, and the supply from diesel generator 31 fails.

- Bus 5A fails, the station auxiliary tranformer fails, and the supply from diesel generator 31 fails.

- Bus 3A fails, the normal supply to bus 5A fails, and the supply from diesel generator 33 fails.

- The normal supply to bus 5A from 6.9 kV bus 5 fails, the normal supply to bus 3A through 6.9 kV bus 3 fails, and the supply from diesel generator 33 fails.

- Either 6.9 kV bus 5 or breaker ST5 fails, the normal supply to bus 3A through 6.9 kV bus 3 fails, and the supplies from diesel generators 31 and 33 fail.

- The station auxiliary transformer fails, and the supplies from diesel generators 31 and 33 fail.

In order to simplify the presentation of the unavailability expression for this failure state, the following variables are defined:

$X \equiv H + J(1 - K) + K + [M(1 - H) + B(1 - J) + L]t$
(diesel generator 33 supply failure)

$Y \equiv J + [2A + 3B + B(1 - J) + C]t$
(failure of normal power supply to bus 2A through 6.9 kV bus 2 or bus 3A through 6.9 kV bus 3).

$Z \equiv H + 2J(1 - K) + 2K + [M(1 - H) + 2B(1 - J) + A + L]t$
(diesel generator 31 supply failure).

The unavailability expression derived from the failure conditions discussed above is thus:

$$Q_{3A + 5A} = (At)^2 + (At)(Y) + (At)(X)[(A + 3B + 2C)t] + (At)(Z)(Ct + Y^2) + (X)(Z)\{Ct + [(A + B)t](Y)\} + (X)(Y)[(2B + C)t].$$

If diesel generator 31 is inoperable, the conditional unavailability of power at buses 3A and 5A is calculated through the following reduced expression:

$$Q_{3A + 5A, \overline{DG31}} = (At)^2 + (At)(Y) + (At)(X)[(A + 3B + 2C)t] + (At)(Ct + Y^2) + (X)\{Ct + [(A + B)t](Y)\} + (X)(Y)[(2B + C)t].$$

Similarly, if diesel generator 33 is inoperable:

$$Q_{3A + 5A, \overline{DG33}} = (At)^2 + (At)(Y) + (At)[(A + 3B + 2C)t] + (At)(Z)(Ct + Y^2) + (Z)\{Ct + [(A + B)t](Y)\} + (Y)[(2B + C)t].$$

If both diesel generators are unavailable, the conditional failure of power at these buses is characterized by the following expression:

$$Q_{3A + 5A, \overline{DG31 + 33}} = Ct + [(2A + 3B + C)t](At + Y).$$

The maintenance and fuel supply failure contributions to this case are quantified in the same manner as described for Case 6.

Case 9: <u>Failure of Power at Buses 3A and 6A (Table 9.2-9)</u>

This case is very similar to Case 8. The principal difference between this and the preceding case is the treatment of the common supply to buses 3A and 6A through breaker ST6 and 6.9 kV bus 6. A rearrangement of failure terms is also necessary to account for the possibility of supplying power to bus 3A from diesel generator 31. Tie-breaker 2AT3A will automatically close only if the normal feed breaker to bus 3A is open and the output breaker from diesel generator 31 is closed. Diesel generator 31 automatically closes onto bus 2A only if an undervoltage condition is detected at that bus. Therefore, the diesel generator can automatically supply power to bus 3A only under those failure conditions which involve an initial loss of voltage at both buses 2A and 3A. Higher order failure states are removed from this nonmutually exclusive case through the application of Boolean logic, as described in Section C.2. The unavailability expression for this case, utilizing the definitions for variables X, Y, and Z presented above, is:

$$Q_{3A + 6A} = (At)^2 + (At)(Y) + (At)(X)[(A + 3B + 2C)t] + (At)(Z)(Ct + Y^2) + (X)[(A + B)t] + (X)(Z)(Ct) + (X)[(2B + C)t]\{J + [A + 2B + B(1 - J) + C]t\}[1 - (Y)(Z)].$$

The reductions of this complete unavailability expression to obtain the conditional power failure states with diesel generator 31, diesel generator 32, and both diesel generators inoperable are accomplished in the same manner as outlined in Case 8. The resulting maintenance and fuel supply failure contributions to power unavailability at these buses are also quantified as above.

Case 10: Failure of Power at Buses 5A and 6A (Table 9.2-10)

Since the normal and emergency power supplies to these buses are completely symmetric, achievement of this failure state requires:

- Failure of both buses.

- Failure of one bus and failure of both the normal and diesel generator supplies to the other bus.

- Failure of the normal supplies to both buses and failure of the supplies from diesel generators 32 and 33.

- Failure of the station auxiliary transformer and failure of the supplies from diesel generators 32 and 33.

The complete unavailability expression for these failure conditions is:

$$Q_{5A + 6A} = (At)^2 + 2(At)(X)[(A + 3B + 2C)t]$$
$$+ \{Ct + [(A + 3B + C)t]^2\}(X^2).$$

The variable X represents failure of the power supply from a diesel generator as defined in Case 8. If either diesel generator 32 or diesel generator 33 is inoperable, the conditional failure of power at buses 5A and 6A is determined by the expression:

$$Q_{5A + 6A, \overline{DG}} = (At)^2 + (At)[(A + 3B + 2C)t] + (At)[(A + 3B + 2C)t](X)$$
$$+ \{Ct + [(A + 3B + C)t]^2\}(X).$$

If both diesel generators are unavailable for service, the conditional failure state is characterized by:

$$Q_{5A + 6A, \overline{DG32 + 33}} = Ct + [(2A + 3B + C)t]^2.$$

Case 11: Failure of Power at Buses 2A, 3A, and 5A (Table 9.2-11)

The methodology employed in the analysis of this failure state is identical to that described for the preceding cases under this boundary condition. Failure of power at all three of these buses will occur if any of the following criteria are satisfied:

- Buses 2A, 3A, and 5A fail.

- Buses 2A and 5A fail and the normal power supply to bus 3A fails.

- Buses 2A and 3A fail, the normal power supply to bus 5A fails, and the supply from diesel generator 33 fails.

- Buses 3A and 5A fail, the normal power supply to bus 2A fails, and the supply from diesel generator 31 fails.

- Bus 2A fails, either the station auxiliary transformer or the normal supply paths to buses 3A and 5A fail, and the supply from diesel generator 33 fails.

- Bus 5A fails, either the station auxiliary transformer or the normal supply paths to buses 2A and 3A fail, and the supply from diesel generator 31 fails.

- Bus 3A fails, either the station auxiliary transformer, breaker ST5 or 6.9 kV bus 5 fails, and the supplies from diesel generators 31 and 33 fail.

- Bus 3A fails, the normal supply paths to buses 2A and 5A from 6.9 kV bus 5 fail, and the supplies from diesel generators 31 and 33 fail.

- Either the station auxiliary transformer or the normal power supply paths to all three buses fail, and the supplies from diesel generators 31 and 33 fail.

The variables X and Y are retained in this case with the same definitions as in Case 8 (failure of the supply from a diesel generator and failure of the normal supply to either bus 2A or bus 3A, respectively). The unavailability expression for this combined failure state is:

$$
\begin{aligned}
Q_{2A,\ 3A + 5A} = {} & (At)^3 + (At)^2 (Ct + Y) + (At)^2 (X)[(A + 3B \\
& + 2C)t + Ct + Y] + (At)(X) \{2Ct + Y^2 + [(A + 3B + C)t](Y)\} \\
& + (At)(X^2) \{(A + B + C)t + [(2B + C)t] \\
& \times [J + (A + 2B + B(1 - J) + C)t]\} + (X^2) \{Ct + (Y) \\
& \times [(A + B)t + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t]]\}.
\end{aligned}
$$

The derivations of the conditional power unavailability expressions with diesel generator 31 inoperable, diesel generator 33 inoperable, and with both diesel generators unavailable for service are analogous to those presented in each of the preceding cases. These conditional equations are:

$$
\begin{aligned}
Q_{2A,\ 3A + 5A,\ \overline{DG31}} = {} & (At)^3 + (At)^2 (X)[(A + 3B + 2C)t] + 2(At)^2 \\
& \times (Ct + Y) + (At)(X) \{(A + B + 2C)t + [(A + 3B \\
& + C)t](Y) + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t]\} \\
& + (At)(Ct + Y^2) + (X) \{Ct + (Y)[(A + B)t \\
& + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t]]\}.
\end{aligned}
$$

$$Q_{2A,\ 3A\ +\ 5A,\ \overline{DG33}} = (At)^3 + (At)^2 [(A + 3B + 2C)t + Ct + Y] + (At)^2 (X)(Ct + Y) + (At)(X) \{(A + B + 2C)t + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t] + Y^2\} + (At) \{Ct + [(A + 3B + C)t](Y)\} + (X) \{Ct + (Y) \times [(A + B)t + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t]]\}$$

$$Q_{2A,\ 3A\ +\ 5A,\ \overline{DG31\ +\ 33}} = (At)^3 + (At)^2 [(A + 3B + 2C)t + 2Ct + 2Y] + (At) \{(A + B + 3C)t + [(A + 3B + C)t](Y) + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t] + (Y^2)\} + (Y) \{(A + B)t + [(2B + C)t] \times [J + (A + 2B + B(1 - J) + C)t]\} + Ct.$$

Case 12: <u>Failure of Power at Buses 2A, 3A, and 6A (Table 9.2-12)</u>

This case is similar to Case 11. Component failure terms have been rearranged in the unavailability expression to account for the common supply path to buses 3A and 6A through 6.9 kV bus 6. The effects of these common failures are slightly asymmetric from those in Case 11 due to the single supply path from diesel generator 31 to bus 3A through the bus tie. The unavailability expression for this failure state is:

$$Q_{2A,\ 3A\ +\ 6A} = (At)^3 + (At)^2 (Ct + Y) + (At)^2 (X) \times [(A + 3B + 2C)t + Ct + Y] + (At)(X) \{(A + B + 2C)t + Y^2 + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t]\} + (At)(X^2) \{Ct + [(A + 3B + C)t](Y)\} + (X^2) \{Ct + (Y) \times [(A + B)t + [2B + C)t][J + (A + 2B + B(1 - J) + C)t]]\}.$$

The conditional unavailability expressions and the diesel generator maintenance and fuel supply failure contributions to power unavailability are developed in the same manner as described in the preceding cases.

Case 13: <u>Failure of Power at Buses 2A, 5A, and 6A (Table 9.2-13)</u>

The failure of power at buses 2A, 5A, and 6A will occur if:

- Buses 2A, 5A, and 6A fail.

- Buses 2A and 5A (2A and 6A) fail, the normal supply to bus 6A (5A) fails, and supply from diesel generator 32 (33) fails.

- Buses 5A and 6A fail, the normal supply to bus 2A fails, and the supply from diesel generator 31 fails.

- Bus 2A fails, the normal supply paths to buses 5A and 6A fail, and the supplies from diesel generators 32 and 33 fail.

- Bus 5A fails, the normal supply paths to buses 2A and 6A fail, and the supplies from diesel generators 31 and 32 fail.

- Bus 6A fails, either breaker ST5 or 6.9 kV bus 5 fails, and the supplies from diesel generators 31 and 33 fail.

- Bus 6A fails, the supply paths to buses 2A and 5A from 6.9 kV bus 5 fail, and the supplies from diesel generators 31 and 33 fail.

- Any one of the buses fails, the station auxiliary transformer fails, and the supplies from the diesel generators to the two remaining buses fail.

- Either the station auxiliary transformer fails or the normal power supply paths to all three buses fail, and the supplies from all three diesel generators fail.

The unavailability expression for this failure state is:

$$
\begin{aligned}
Q_{2A,\ 5A\ +\ 6A} = {} & (At)^3 + (At)^2 (X) \{ 2[(A + 3B + 2C)t] + Ct + Y \} \\
& + (At)(X^2) \{ (A + B + 3C)t + [(A + 3B + C)t]^2 \\
& + [(A + 3B + C)t](Y) + [(2B + C)t][J + (A + 2B + B(1 - J) \\
& + C)t] \} + (X^3)[Ct + [(A + 3B + C)t] \{ (A + B)t \\
& + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t] \}]
\end{aligned}
$$

The variables X and Y remain as defined in Case 8.

Some of the failures described above may also cause the failure of power at bus 3A. However, it must be remembered that the given unavailability expression has been derived for the set of failure conditions which are both necessary and sufficient for the achievement of this nonmutually exclusive failure state. Section C.2 discusses the application of Boolean logic to determine the mutually exclusive failure states from the complete set of nonmutually exclusive states.

The conditional failure of power at all three of these buses with each combination of diesel generators unavailable is computed by selectively removing the inoperable diesel generator(s) from the given

unavailability expression and evaluating the resulting reduced equation. The maintenance contribution to power failure is obtained by multiplying the distributions for individual diesel generator unavailability due to maintenance (from Section D.3) with the corresponding conditional power failure distributions. Since any of the diesel generators may be out of service for maintenance when the initiating event occurs, these three individual diesel generator maintenance inputs are added to produce the total contribution to power failure due to maintenance. Similarly, the distribution presented in Section D.4.2.3 for the unavailability of all three diesel generators due to fuel supply failures is multiplied by the conditional power failure distribution with all three diesel generators inoperable to produce the fuel supply failure contribution to this power failure state.

Case 14: Failure of Power at Buses 3A, 5A, and 6A (Table 9.2-14)

The component failures contributing to this power unavailability state are similar to those outlined above in Case ... However, diesel generator 31 can automatically supply power to bus 3A only under conditions in which power is initially lost at both buses 2A and 3A. If bus 2A remains energized, breaker 2AT3A will not close automatically, and bus 3A will remain deenergized when its normal source of power is lost. The definitions of the variables X (failure of the supply from diesel generator 32 to bus 6A or from diesel generator 33 to bus 5A), Y (failure of the normal supply path to bus 2A or bus 3A), and Z (failure of the supply from diesel generator 31 to bus 3A) are retained in this case as outlined in Case 8. The unavailability expression is:

$$
\begin{aligned}
Q_{3A,\ 5A\ +\ 6A} = {} & (At)^3 + 2(At)^2 (X)[(A + 3B + 2C)t] + (At)^2(Y) \\
& + (At)^2(Z)(Ct + Y^2) + (At)(X^2)\{Ct + [(A + 3B + C)t]^2\} \\
& + (At)(X)\{(A + B)t + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t] \\
& + [(2B + C)t](Y)\} + 2(At)(X)(Z)[Ct + (Y)\{(A + B)t \\
& + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t]\}] \\
& + (X^2)[(2B + C)t]\{(A + B)t + [(2B + C)t][J + (A + 2B \\
& + B(1 - J) + C)t]\} + (X^2)(Z)[Ct + \{(A + B)t + [(2B + C)t] \\
& \times [J + (A + 2B + B(1 - J) + C)t]\}^2].
\end{aligned}
$$

Treatment of the conditional power unavailability distributions is consistent with the methodology presented in the previous cases.

Case 15: Failure of Power at all 480V Switchgear Buses (Table 9.2-15)

The derivation of the unavailability expression for this failure state is an extension of the process outlined in the preceding cases. The unavailability expression for the failure of power at all four 480V switchgear buses with offsite power available is:

$$
\begin{aligned}
Q_{2A,\,3A,\,5A-6A} = {} & (At)^4 - (At)^3 (Ct + Y) - (At)^3 (X)[2(A + 3B \\
& + 2C)t + Ct + Y] + (At)^2 (X) \{ (A + B + 3C)t + Y^2 \\
& + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t] \\
& + [(A + 3B + C)t](Y) \} + (At)^2 (X^2) \{ (A + B + 3C)t \\
& + [(A + 3B + C)t]^2 + [(2B + C)t][J + (A + 2B \\
& + B(1 - J) + C)t] + [(A + 3B + C)t](Y) \} \\
& + (At)(X^2) [3Ct + [(A + 3B + C)t] \{ (A + B)t \\
& + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t] \} + 2(Y) \\
& \times \{ (A + B)t + [(2B + C)t][J + (A + 2B + B(1 - J) \\
& + C)t] \}] + (At)(X^3) [Ct + [(A + 3B + C)t] \{ (A + B)t \\
& + [(2B + C)t][J + (A + 2B + B(1 - J) + C)t] \} \\
& + (X^3) [Ct + \{ (A + B)t + [(2B + C)t] \\
& \times [J + (A + 2B + B(1 - J) + C)t] \}^2].
\end{aligned}
$$

The variable X represents failure of the power supply from a diesel generator; Y represents failure of the normal supply path to bus 2A or bus 3A. The expansions of these variables are defined in Case 8.

As in all of the cases analyzed under this boundary condition, failures of any of the components in the electric power system are conservatively allowed to occur at any time during the 6-hour period of this study. No attempt is made to model the time sequencing of the various combined failures required to achieve this failure state, and no recovery of failed components is considered.

The maintenance and fuel supply failure contributions to power unavailability are quantified in the same manner as described in the preceding cases.

D.5 COMMON CAUSE FAILURES

A number of common causes have been identified as potential contributors to failure of the electric power system at Indian Point Unit 3. The susceptibility of the system to failures induced by these causes is generally dependent upon: (1) the locations of the system components, (2) the physical properties of these components, (3) the operating characteristics of the components as they are integrated into the power system design, and (4) the manner in which the system is operated, maintained, and tested by plant personnel.

D.6.1 EXTERNAL EVENTS

Electrical power supply equipment is generally susceptible to failures induced by high temperature, moisture, vibration or impact, and grit or dirt. Switchgear and cable fires can affect the operation of many plant safeguards systems. Because of their pervasive nature, these fires are treated separately in this study as a generic failure cause applicable to all systems. For similar reasons, the generic category of plant system failures caused by seismic events is also treated as a unique subject in this study.

The diesel generators are housed in the diesel generator building located adjacent to the Unit 3 control building. The building is divided into three separate rooms, each of which contains a diesel generator, its associated starting air compressor and receiver, local control panel and fuel oil day tank. The area housing diesel generator 31 also contains a separate battery enclosure for station battery 33. Three 7,700 gallon fuel oil storage tanks are buried outside of and adjacent to the diesel generator building. Each diesel generator room is provided with an automatic water spray fire suppression system and a temperature sensitive fire detection system which alarms in the Unit 3 control room. The Indian Point Unit 3 fire hazards analysis study has assessed the diesel generator building as an area of low fire loading. The fire walls between each of the rooms will contain a fire involving the diesel fuel oil day tank, such that a maximum of only one diesel generator should be incapacitated by any fire in this building.

The fire walls for the battery enclosure will prevent a fire at diesel generator 31 from propagating to and involving battery 33.

Studies have indicated that a conservative lognormal distribution for the frequency of fires occurring in diesel generator rooms is:*

Median:	1.80×10^{-2}	fires/room/year
Mean:	1.90×10^{-2}	fires/room/year
Variance:	3.53×10^{-5}.	

The detectors located in each of the diesel generator rooms will quickly alert the plant operating personnel to a fire in any of these rooms. In this study we assign a 50% effectiveness to the combined efforts of the automatic suppression system and the plant fire brigade to extinguish any fire in one of these rooms before it reaches sufficient magnitude to cause damage to the diesel engine, the generator, or their controls. It

*Apostolakis, G. and M. Kazarians, "The Frequency of Fires in Light Water Reactor Compartments," presented at the ANS/ENS Topical Meeting on Thermal Reactor Safety, Knoxville, Tennessee, April 7-11, 1980.

should be noted that in order to be damaging, the fire need not be of very large magnitude; for example, a single relay or wire failure could necessitate repair, testing, or replacement of portions of the diesel generator control or protection systems. Applications of this conservative response factor to the distribution of fire frequency in the diesel generator rooms results in the following lognormal distribution for the frequency of fires which result in sufficient damage to cause a diesel generator to be removed from service for repair or inspection:

Mean: 1.08×10^{-6} disabling fires/diesel generator room/hour

Variance: 1.11×10^{-13}.

Each of these fires could result in a diesel generator being unavailable for a maximum period of 168 hours prior to unit shutdown (per the plant technical specifications). Many of the fires will cause such minor damage as to require a much shorter repair or inspection period. However, in order to develop a very conservative bounding estimate of diesel generator unavailability as a result of fires, it is assumed that any damaging fire will necessitate the removal from service of the associated diesel generator for the full 7-day period allowed by the plant technical specifications. Application of this maximum repair period to the frequency distribution developed above results in the following lognormal distribution for the unavailability of any diesel generator due to fires:

Mean: $Q_{DF} = 1.82 \times 10^{-4}$

Variance: 3.14×10^{-9}.

In order to assess the impact of these fires upon each of the electric power system failure states developed in Section D.5, this diesel generator unavailability distribution is simply combined with the distribution for the conditional failure of power in each state with each of the diesel generators unavailable for service. (The process is identical to the calculation of the maintenance and fuel oil supply contributions to power failure.) The results of these computations are presented in the system failure state summary, Tables 10.1 and 10.2, which are discussed more completely in Section D.7. It should be noted that no fires analyzed in this study result in more than one diesel generator being made inoperable.

The only portions of the electric power system subject to conditions in which significant moisture or flooding could be present are the electrical cable tunnel and the containment penetration area. In the cable tunnel, all cables are fully insulated and are routed in cable trays supported above floor level. A floor drain system is provided, and ventilation fans maintain sufficient air circulation to reduce the latent moisture to a level below which cable degradation could be expected. In order to disable any portion of the electric power system,

a flood in this area would have to be of sufficient magnitude and duration to submerge at least the lower cable trays. Under these extreme conditions, it is expected that many plant systems and components located at lower elevations would be affected more severely than the cabling. Even if submerged, water could affect the cables only through insulation faults, and such faults would have to result in a very selected set of consequences to produce any significant damage to the power system (e.g., since the power supply cables to the switchgear buses are not routed in the cable tunnel, the flooding-induced faults would have to be of such a nature as to defeat the normal overcurrent fault protection devices which would open the affected load circuits at their switchgear supply breakers). Moisture present in the containment cable penetration area (from pipe ruptures, minor leakage, condensation, etc.) could similarly affect single component power supply circuits through selected insulation faults, but is very unlikely to result in damage to the power supply switchgear due to the operation of the fault protection devices.

Diesel engine failures which result in the ejection of large missiles are extremely rare events. Even if such an event were to occur, the walls separating the diesel generator rooms would provide sufficient shielding to prevent more than just the failed diesel engine and its associated auxiliaries from being damaged. Such failures would be documented in the specific diesel generator failure data base and are thus included in the hardware failure contribution to electric power system unavailability. The only other location in which the electric power system exhibits a potential susceptibility to impact damage is the 480V switchgear room located in the control building. The instrument air compressor located in this room is a low pressure reciprocating unit which is not subject to failures resulting in the ejection of high energy missiles. Even if such a failure were to occur, the compressor is oriented such that the most probable trajectory for the resulting low energy missiles is away from the switchgear. The switchgear buswork is mounted in steel enclosures which provide additional protection of the energized sections from impact damage.

None of the electric power system equipment is located in areas of the plant subject to significant dust, dirt, or grit. Individual component failures resulting from such conditions as dirty contacts, relay plunger binding, control line clogging, etc., which are symptomatic of this general cause category, have been included in the quantification of the plant-specific hardware failure data presented in Appendix B to this report.

D.6.2 HUMAN ERROR

Personnel errors associated with the periodic testing of the diesel generators are included in the testing contribution to power failure for each operability state. In Section D.2 it is noted that the diesel generator operating mode selector switches are annunciated at the Unit 3 control panels if they are placed in any position other than "Auto." The inoperability of a diesel generator due to a mispositioned switch,

therefore, requires errors of both the testing personnel and the control room operators. These errors are discussed in greater detail and are quantified in Section D.2.

The diesel generators are the only major components of the electric power system which are subject to frequent maintenance during unit operation. Errors made by maintenance personnel during the disassembly, inspection, repair, and reassembly of the diesel engine, the generator, or of any portion of their control or support systems could result in subsequent failure of the diesel generator. The section on Human Error Rates presented in the Methodology chapter of the main study report provides the following lognormal distribution for the frequency of errors by maintenance personnel:

Mean: 9.0×10^{-3} error/maintenance event

Variance: 1.8×10^{-4}.

Not all of the errors committed during maintenance have the same potential for causing total failure of the diesel generator. In fact, it is expected that most of the errors will have relatively minor impacts upon the successful operation of the unit. However, it must also be recognized that any error results in a measurable level of degradation, even if it is as seemingly innocuous as failure to torque a single bolt to the manufacturer's recommended specifications. Because very little information is available regarding the long-term operational effects of minor errors, it is conservatively assumed in this analysis that any error, regardless of its precise nature, could lead to failure of the diesel generator.

Each diesel generator must be tested to verify its operability following any maintenance. Since the successful completion of this testing requires that the diesel generator start, accept the load, and operate under load for some period of time without exceeding established operating parameter limits, the majority of maintenance personnel errors affecting diesel generator operability will be detected before the diesel generators are returned to service. We use a conservative estimate of 95% for the effectiveness of the diesel generator testing program for detecting these errors. The resulting frequency of undetected maintenance errors is thus:

Mean: 4.50×10^{-4} undetected error/maintenance event

Variance: 4.50×10^{-7}.

Since normal diesel generator testing will not identify these errors, they would remain in effect for the entire period between successive maintenance events. Because the frequency of maintenance and the mean duration between maintenance events are reciprocal quantities, the distribution developed above for the error frequency per maintenance event is numerically equal to the distribution for the unavailability of each diesel generator due to these undetected errors:

Mean: $Q_{ME1} = 4.50 \times 10^{-4}$

Variance: 4.50×10^{-7}.

All of the diesel generators are serviced by the same plant maintenance staff and are subject to the same testing procedures. A review of the plant's maintenance records indicates that the actual work performed during individual maintenance events varies significantly in terms of both scope and specific components affected. With the exception of the major overhaul and inspection of each unit performed once during each refueling cycle, there is no significant evidence of maintenance trends in which the same work is performed on each of the diesel generators in succession. There is thus considered to be only a weak coupling between errors made during the repair of one diesel generator and those made during work on the other units. The section on Human Error Rates in the Methodolody chapter of the main report provides an analytical expression which models this low dependence between errors made during task N and the error rate for the preceding task N-1:

$$\gamma_N = \frac{1 + 19\,\gamma_{N-1}}{20}.$$

The development and application of this relation are discussed in Methodology chapter. It is used in this analysis to quantify the coupling between the medians of the error frequency distributions for maintenance events. As discussed in the development of this expression, an error factor of 5 is assigned to the resulting distribution for γ_N to express our uncertainty about this relation. The median of the lognormal distribution presented above for undetected errors on single diesel generators is $\gamma_{N-1} = 2.50 \times 10^{-4}$. Use of this value in the low dependence coupling expression and application of the error factor results in the following distribution for the frequency of undetected errors on a second diesel generator, given an error has been committed during maintenance of the first unit:

Median: 5.02×10^{-2} error/second event, given an initial error

Mean: 8.10×10^{-2} error/second event, given an initial error

Variance: 1.05×10^{-2}.

The unavailability of both diesel generators due to these weakly coupled errors is determined by multiplying the conditional unavailability distribution for the second diesel generator by the distribution for error-produced unavailability of the first unit. The resulting distribution for the unavailability of two diesel generators due to undetected maintenance errors is:

Mean: $Q_{ME2} = 3.65 \times 10^{-5}$

Variance: 4.73×10^{-9}.

Application of the weak coupling expression to determine the conditional error frequency for a third diesel generator, given the condition that errors have occurred during the maintenance of two diesel generators, results in the following distribution for the unavailability of three diesel generators due to undetected maintenance errors:

Mean: $Q_{ME3} = 2.95 \times 10^{-6}$

Variance: 4.92×10^{-11}.

The net effect of these maintenance errors is thus the possibility that one, two, or all three diesel generators may be unavailable for service due to some undetected flaw which will cause failure of the diesel generator during starting or subsequent operation. Each of the electric power system failure states developed in Section D.5 contains distributions for the conditional unavailability of power for various combinations of diesel generator unavailability. The contribution to power failure from undetected maintenance errors is thus obtained by combining the conditional power failure distributions with the corresponding diesel generator unavailability distributions presented above. The process is analogous to that described previously for quantifying the effects of fuel supply failures. Mathematically, the contribution to power failure from diesel generator maintenance errors (Q_{HE}) is obtained through evaluation of the following general expression:

Q_{HE} = [Q_{ME1} x $\sum$ (conditional unavailability of power with each single diesel generator inoperable)]

+ [Q_{ME2} x $\sum$ (conditional unavailability of power with each set of two diesel generators inoperable)]

+ [Q_{ME3} x $\sum$ (conditional unavailability of power with all three diesel generators inoperable)].

The results of this combination process are presented in the system failure state summary, Tables 10.1 and 10.2, which are discussed more fully in Section D.7.

The only other significant human error contribution to failure of the electric power system is due to operator errors associated with the recovery of portions of the system which are deenergized by other independent failures following event initiation. As discussed previously, in order to develop a conservative set of bounding failure probabilities for application in each of the event sequences considered in this study, the operator recovery error rate is taken to be unity over the 6-hour period following event initiation. For those event sequences in which the failure of electric power under these boundary conditions is a major contributor to overall plant nonrecoverability, the time-dependent operator interactions with the electric power system will be quantified within the specific context of the applicable accident scenario.

D.6.3 SYSTEM DESIGN

The most significant design-related contributor to electric power system failures is the fact that normally open tie-breaker 2AT3A will not close automatically unless the normal feed breaker to bus 3A is open and the diesel generator 31 output breaker to bus 2A (breaker EG1) is closed. Breaker EG1 is, in turn, interlocked to prevent automatic closure unless the normal feed breaker to bus 2A is open. Because of these breaker interlocks, power must be initially lost at both buses 2A and 3A before bus 3A can be automatically reenergized from diesel generator 31. This contribution is discussed in more detail and quantified in the system hardware failure analysis presented in Section D.5.

D.6.4 OTHER FAILURE CAUSE CONTRIBUTORS

It is possible that other factors not explicitly identified and quantified in the preceding sections could affect the operation of the electric power system. The contribution of these causes to the unavailability of power for each of the system failure states depends upon both the nature of the specific hardware failures required to achieve the loss of power and the anticipated impacts of these unidentified causes upon these components. It is important to emphasize that these causes are unidentified; they have not been observed during the operational history of Indian Point Unit 3 and are difficult to conceptualize through any specific failure scenario. Furthermore, since many unobserved causes have been specifically identified and quantified in the preceding sections, it is expected that the failure contribution from these other causes will be significantly lower than any of those presented thus far in the analysis.

The quantification of this contribution, although subjective in nature, is possible through a conservative assessment of the analysis developed in the preceding sections of this report. We are extremely confident that the total contribution to each system failure state from these unidentified causes is much less than that presented by the least contributing identified cause. For conservatism, however, we set the 95th percentile of the "other causes" distribution equal to the mean of this smallest identified contributor. (This process essentially assigns a 95% confidence to our ability to identify the significant contributors to failure for any possible failure state.) Of course, we are also highly uncertain of the precise contribution from these causes and, therefore, allow a range of three orders of magnitude between the 5th and 95th percentiles of the assumed lognormal distribution. The resulting distribution for the contribution of these other causes is thus dependent upon the magnitude of the smallest identifed cause for each electric power system failure state and is characterized by the following parameters:

95th Percentile = mean value of smallest identified cause distribution

5th Percentile = (95th Percentile) x 10^{-3}.

It is felt that this distribution provides a very conservative upper-bound estimate of the impacts of these other causes. The contribution of this cause category to each of the electric power system failure states is shown in the summary tables discussed in Section D.7.

D.7 SYSTEM FAILURE STATE SUMMARIES

Tables 10.1 and 10.2 summarize the contributions to each of the Indian Point Unit 3 electric power system failure states from each of the cause categories discussed in the preceding sections of this report. The hardware, testing error, maintenance, and fuel supply failure contributors are developed in Section D.5 and are shown explicitly in Tables 9.1 and 9.2. The diesel generator fire and human error contributors have been calculated by multiplying the diesel generator unavailability distributions resulting from these causes (presented in Sections D.6.1 and D.6.2, respectively) with the corresponding conditional power failure distributions for the various states of diesel generator inoperability shown in Tables 9.1 and 9.2. The quantification of the unidentified "other causes" contributor is discussed in detail in Section D.6.4.

Although each of these contributing causes has been developed separately in this analysis, they are not independent and, therefore, cannot be simply summed to produce the total unavailability of power for each system failure state. Examples illustrating the dependencies between causes are that fuel supply failure can lead to loss of power only if no other diesel generator failures occur; hardware failures can occur only if the affected components are not tagged out of service for maintenance. It is conservatively assumed that the unidentified "other causes" of system failure can occur independently of any of the identified causes. The following variables are used to define each of the given cause categories:

[illegible] = unavailability due to hardware failures.

Q_M = unavailability due to components out of service for maintenance.

Q_T = unavailabiltity due to human error following testing.

Q_{DF} = unavailability due to diesel generator fires.

Q_{FS} = unavailability due to fuel supply failures.

Q_{HE} = unavailability due to human errors during maintenance.

Q_O = unavailability due to other (unidentified) causes.

The distributions for these failure contributors are combined to produce the total unavailability distribution for each electric power system failure state through the following expression, which specifically identifies the significant dependencies among the various cause categories:

$$Q_{Total} = Q_H \times [(1 - Q_M)(1 - Q_T)(1 - Q_{DF})(1 - Q_{HE})(1 - Q_{FS})]$$
$$+ Q_M \times [(1 - Q_T)(1 - Q_{DF})] + Q_{FS} \times [(1 - Q_H)(1 - Q_M)$$
$$\times (1 - Q_T)(1 - Q_{DF})(1 - Q_{HE})] + Q_T \times [(1 - Q_M)(1 - Q_{DF})]$$
$$+ Q_{DF} \times [(1 - Q_M)(1 - Q_T)] + Q_{HE} \times [(1 - Q_M)(1 - Q_T)$$
$$\times (1 - Q_{DF})] + Q_O.$$

The "total" columns in Tables 10.1 and 10.2 thus characterize the distributions for the unavailability of power in each of the system failure states obtained from the combined contributions of all possible causes, including the dependencies among these cause categories.

It must be remembered that each of the failure state distributions presented in Tables 10.1 and 10.2 has been developed by considering all possible contributors to failure without regard to the impacts of these contributors upon other system failure states. These distributions are, therefore, the quantification of the nonmutually exclusive unavailabilities discussed in Section C.2. The application of the electric power system analysis to the quantification of the event trees requires that each of the electric power failure states is mutually exclusive (e.g., the "failure of power at buses 2A and 5A" must represent the system state of no power at bus 2A, no power at bus 5A, and power is available at buses 3A and 6A).

The discussion presented in Section C.2 provides the basis for determining the required mutually exclusive failure state unavailability distributions from the results summarized in Tables 10.1 and 10.2. For each of the desired mutually exclusive failure states, a logic expression can be constructed which accounts for the relative contributions from each of the nonmutually exclusive states (refer to the determination of the shaded area of the Venn diagram in Section C.2). The m tually exclusive failure distribution for the failure of power at only bus 2A is thus determined from the following combination of nonmutually exclusive failure distributions (the circled numbers correspond to the identification numbers of the failure states presented in Tables 10.1 and 10.2).

Unavailability of power at only bus 2A =

$$\textcircled{2} - (\textcircled{6} + \textcircled{7} + \textcircled{8}) + (\textcircled{12} + \textcircled{13} + \textcircled{14}) - \textcircled{16}.$$

Similarly,

Unavailability of power at only bus 3A =

$$\textcircled{3} - (\textcircled{6} + \textcircled{9} + \textcircled{10}) + (\textcircled{12} + \textcircled{13} + \textcircled{15}) - \textcircled{16}.$$

The quantification of the other two mutually exclusive single bus failure states follows the same logic. The expression for the mutually exclusive failure of power at only buses 2A and 3A is given by:

Unavailability of power at only buses 2A and 3A =

⑥ - (⑫ + ⑬) + ⑯

and

Unavailability of power at only buses 2A and 5A =

⑦ - (⑫ + ⑭) + ⑯.

The remaining mutually exclusive two-bus failure states are obtained in the same manner. Extending this logic to the mutually exclusive state of failure of power at buses 2A, 3A and 5A results in:

Unavailability of power at only buses 2A, 3A and 5A = ⑫ - ⑯.

The expressions for the other three-bus states are similar. Since the failure of power at all four buses is a unique event for this system, the mutually exclusive distribution for this failure state is identical to the nonmutually exclusive distribution.

Once the 15 mutually exclusive failure states have been determined, the remaining possible state of the electric power system (i.e., the state in which power is available at all four buses) is defined by the following expression:

Probability that power is available at all four buses
$= 1.0 - \sum$ (15 mutually exclusive failure states).

Tables 2.1 and 2.2 present the results of this process and are the logically complete mutually exclusive electric power system failure state distributions for each of the specified system analysis boundary conditions.

Diesel generator 31 can supply power to 480V switchgear bus 3A only through bus 2A and tie-breaker 2AT3A. Under the boundary condition of offsite power not available to Unit 3, any failure which causes bus 2A to be deenergized will also result in the failure of power at bus 3A. Therefore, the mutually exclusive system failure states presented in Table 2.1 which include failure of power at only bus 2A and not at bus 3A are indicated as being undefined for the given boundary conditions (i.e., states 2, 7, 8 and 14 cannot exist as mutually exclusive states under the given boundary conditions). Of course, if offsite power is available, power may be lost at bus 2A with bus 3A remaining energized. All of the mutually exclusive states are, therefore, defined under the boundary conditions for Table 2.2.

D.8 INTERFACE WITH EVENT TREE QUANTIFICATION

The Indian Point Unit 3 electric power system is analyzed for the unavailability of power for each of 16 possible system operability states under two different boundary conditions. In order to interface directly with the quantification of the event trees developed for this

study, these electric power system failure states must be carefully examined and combined to satisfy the appropriate initiating event analysis boundary conditions.

The "Loss of Offsite Power" initiating event requires failure of at least the 345 kV and 138 kV offsite power supplies to Unit 3. (These are the minimum failures required to cause a unit trip and failure of all offsite power, if no operator actions are considered.) The electric power system failure state quantifications directly applicable to this initiating event are those summarized in Table 2.1. For completeness, these results are repeated in Table 2.3a for the loss of offsite power initiating event.

It is assumed in this study that all initiating events ultimately result in a trip of the main generator. Since Indian Point Unit 3 is rated at 965 MW(e), the instantaneous loss of this input could have a significant effect upon the stability of the offsite power supply network due to reduced transmission voltages, frequency fluctuations, or power flow imbalances as the grid recovers from the transient. The Consolidated Edison transmission network has been designed to provide a stable power supply grid under conditions of multiple large generating unit and major transmission line outages. Detailed guidelines have been established for the entire Consolidated Edison power supply network which define the basis for system operation under a wide variety of steady-state and transient conditions. A prime consideration in the establishment of these guidelines is the requirement that no single loss of a generating unit or transmission facility should result in an unacceptable condition of degraded system operation. System operating contingencies are defined by these guidelines and specify the need to provide additional generating capacity from Consolidated Edison's own facilities or to provide power from network interties long before critical operating stability limits are approached. A detailed voltage reduction and selective load shedding program is also specified in order to maintain grid stability with adequate margins under the most severe conditions. Detailed system stability studies have been performed to verify the efficacy of these operating guidelines under a wide range of scenarios.

The assignment of a distribution for the probability of losing offsite power to Indian Point Unit 3 as a result of a trip of that unit is an extremely difficult task. Factors affecting this condition are total system load, available spinning reserve capacity, the fraction of the load being supplied from the Indian Point units, the status of neighboring utilities' networks, scheduled and unscheduled outages of specific generating units and transmission lines, etc. The analysis of this problem presented in WASH-1400 applies a median value of 10^{-3} for the conditional loss of offsite power as a result of a unit trip.*

Several factors limit the applicability of this value to the specific problem faced in this study. The WASH-1400 distribution was developed from a review of Federal Power Commission studies of power supply

*WASH-1400, Apendix II, page 34.

networks in a wide variety of locations east of the Rocky Mountains. While it may be applicable to the composite site studied in WASH-1400, it is certainly not directly applicable to the Indian Point site. It must also be recognized that the reference study is now several years outdated and that significant advances in the design, operation, and overall stability of virtually all transmission networks in the United States have been made during the intervening years.

A detailed study of the availability of offsite power to the Indian Point site was undertaken by the Consolidated Edison Electrical Planning Department in support of this project. This study provided a macroscopic analysis of the independent hardware failure contributors to the unavailability of offsite power at Buchanan Substation. Local grid failures and Consolidated Edison interconnected system failures were investigated. The analysis utilized Consolidated Edison historical component failure data, where available, and generic industry data where no specific failure data was found. The assumptions and boundary conditions applied to the analysis provided a pessimistic assessment of system-wide and localized grid stability within the established system operating and design criteria. The study results conclude that the unavailability of offsite power at Buchanan Substation due to independent hardware failures is approximately 3.88×10^{-8}, without regard to the status of either of the Indian Point units. The stated uncertainty in these results is one to two orders of magnitude, primarily due to uncertainties in the component failure data bases applied.

The Consolidated Edison study provides a firm basis for a lower limit estimation of the probability of failure of offsite power due to a trip of one of the Indian Point units. Power availability at Buchanan Substation should certainly be no better than that evaluated through the analysis of these independent failures. However, the study does not consider the effects of either common cause hardware failures or the effects of multiple component unavailabilities due to causes such as nonroutine maintenance, construction, system contingencies, etc. Furthermore, the analysis has not evaluated the contributions to power failure from local or system-wide transient instabilities which could be either initiated or aggravated by the trip of a large generating unit under rare severe operating contingency conditions.

For the reasons cited above, we feel that the conditional power unavailability at Buchanan Substation, given a trip of either Indian Point unit, could be higher than that evaluated in the Consolidated Edison study. In order to quantify the impact of this conditional power failure state upon the public risk from Indian Point Unit 3, the following approach was adopted for this study. An uncertainty of one order of magnitude was applied to the Consolidated Edison analysis results. The value of 3.88×10^{-7} was then assigned as the 5th percentile of an assumed lognormal distribution for this conditional loss of power. Since very little evidence is available for the quantification of the upper limits of this distribution, the value of 1.0×10^{-3} from the WASH-1400 study was conservatively assigned as the

95th percentile. The following parameters are, therefore, used in this study to characterize the distribution to be applied for the probability of losing offsite power to Indian Point Unit 3 as a result of any trip of that unit:

5th Percentile:	3.88×10^{-7}	Failure/unit trip
95th Percentile:	1.00×10^{-3}	Failure/unit trip
Median:	1.97×10^{-5}	Failure/unit trip
Mean:	3.41×10^{-4}	Failure/unit trip
Variance:	3.45×10^{-5}.	

A few observations must be made in order to place this distribution in a proper perspective. It is our best estimate of a conservative distribution to be applied to this analysis only. Although it is broadly based upon the results of the Consolidated Edison power unavailability study performed for the Indian Point site, that study provided substantial information for the estimation of the lower bound only. The Consolidated Edison analysis does, however, demonstrate the extreme stability of the power supply grid at Buchanan under severe operating conditions and reinforces our belief that the conditional power failure distribution for Indian Point lies below that applied in WASH-1400.

For these reasons, we feel that the median value of our distribution is a very conservative estimate for the frequency of this event. However, we also feel that the assigned broad distribution adequately accounts for our uncertainty in this value. The given distribution is thus considered to represent a conservatively bounding estimate for the conditional failure of offsite power, which is as specialized to the Indian Point site as is possible with the existing information base.

For all initiating events other than the loss of offsite power initiator, offsite power is considered to be available immediately prior to event initiation. Since each event results in the loss of the main generator, the electric power unavailability for each of the system operability states must be evaluated in light of the probability that offsite power could be lost as a result of the unit trip. The distributions presented in Tables 2.1 and 2.2 are based upon the existence of clearly defined boundary conditions. We also define the following general quantities:

$Q(X, O)$ = unavailability of power in state X, given that offsite power is available.

$Q(X, \overline{O})$ = unavailability of power in state X, given that offsite power is not available.

$P(\overline{O}, T)$ = probability of losing offsite power due to a unit trip.

$Q(X, T)$ = unavailability of power in state X, given that a unit trip has occurred.

For any initiator other than the loss of offsite power, we thus have:

$$Q(X, T) = Q(X, \overline{O}) \times P(\overline{O}, T) + Q(X, O) \times [1 - P(\overline{O}, T)].$$

Table 2.3b presents the mutually exclusive electric power system operability state distributions which are applicable to initiating events other than the loss of offsite power. They have been computed by combining the distributions from Tables 2.1 and 2.2 with the distribution for the conditional loss of offsite power discussed above.

D.9 RECOVERABILITY FACTORS

In order to develop consistent failure probabilities to be applied to all of the event sequences analyzed in this study, the electric power system failure states have been quantified under the limiting condition of an operator recovery failure rate of unity applicable to those situations in which power is lost due to equipment inoperability or failure. This is certainly a very pessimistic assessment of human response, but it is not meant to be applied as a model of real behavior. Rather, it represents a convenient method for temporarily removing a very complex and subjective influence from the treatment of a detailed system analysis which must be consistently applied to a wide variety of event scenarios. Human response to system failures cannot be neglected. However, the quantitative treatment of that response is made manageable by addressing the issue in detail only in those specific instances in which the lack of response is critical to overall plant recovery success or failure.

The actions which must be taken by the plant operators for recovery of any portion of the electric power system vary from simple manual operations of circuit breaker controls from the main control room panels to rather complex local manual switching, starting, and control of the emergency diesel generators, and provisions of emergency power supplies from onsite and near-site sources. The nature of the required actions depends upon the observed system failures; the required response time is determined by the magnitude of the failure and its effects upon the operation of those safeguards systems necessary to maintain the plant in a stable condition under the imposed initiating event scenario. The failure rate of the operator in responding to the emergency is influenced by its actual magnitude, the perceived urgency, the presence of conflicting or confusing indications, his training and written procedural guidance, and a vast array of additional technical, physical, and psychological factors too numerous to consider explicitly in a study such as this. The task of assigning a measure of our confidence in the operator's performance under these conditions is not as difficult as it might seem at first glance. However, in order to provide a meaningful assessment of his likely behavior, we must be very careful to provide a precise description of the situation with which he is faced. "Best estimate" quantifications of human performance under the worst case

conditions applied to a broad range of scenarios are thus no more meaningful than are very optimistic assessments of simple actions applied to complex and confusing situations requiring rapid (correct) assessment and response.

Having discussed the basis for our deferral of operator response to electric power system recovery, we provide in this section a summary of the actions available and the applicable time frames for successful performance of these actions in order to mitigate a wide variety of the failures quantified in Section D.5. Our general methodology for the assignment of human error rates under time-dependent situations of varying stress levels and with varying degrees of operator assistance is described in a separate section of this report. We defer the detailed application of this methodology to the summarized recovery actions until we have completely defined the scenarios in which it must be applied (i.e., until we have identified the precise event sequences in which these actions are required).

Tables 11.1 and 11.2 summarize the recovery actions which are most likely to reduce the consequences of or completely mitigate each of the electric power system failures states presented in Section D.5. Also included are estimates of the time required for the performance of each of these actions. Of course, this summary is not an exhaustive documentation of all possible recovery actions; it is simply our assessment of the most direct methods available for coping with each of the analyzed failure states as based upon such information as automatic system response and dominant contributors to failure. Since the loss of offsite power is of particular significance in its effects upon the availability of the electric power system, several recovery actions available for the restoration of this vital source of power are summarized in Table 12.

E. CONCLUSIONS

The Indian Point Unit 3 electric power system has been analyzed for the failure of power at the 480V switchgear buses during the 6-hour period immediately following an initiating event. This analysis provides a very conservative upper bound for the unavailability of power in each of the system failure states examined. Operator actions for the recovery of failed components have not been included in this analysis because it has been developed for a broad range of initiating event scenarios. It is unrealistically pessimistic to assume that nothing can be done to restore power during a period as long as 6 hours. However, the impacts of that power recovery and the probability of successful operator response are highly dependent upon the precise event scenario during which the failures occur. The bounding analysis presented in this report will be used in the identification of those event sequences in which electric power failure results in a significant impact upon public risk. Once these dominant sequences have been identified, the boundary conditions will be established for the inclusion and quantification of specific power recovery actions.

A total of 16 electric power system operability states have been quantified for each of two analysis boundary conditions. The more restrictive of these boundary conditions is that in which all offsite power remains unavailable for the entire 6-hour study period. It must be remembered that "offsite power" is defined in this analysis as including, at a minimum, the 345 kV and 138 kV offsite power supplies to Unit 3. Because manual operator recovery actions are excluded from this analysis, the unavailability of offsite power does not define the status of either the 13.8 kV offsite supply from Buchanan Substation or the status of any of the gas turbine units available to the site. The availability of these reserve offsite supplies will significantly affect the time required to recover a source of power from other than the diesel generators, but it has had no impact upon this conservatively bounding failure analysis. The quantification of offsite power recovery, including the effects of the gas turbine units, will be included in the overall plant recoverability analysis for those event sequences in which offsite power failure proves to be a dominant contributor to public risk.

If the diesel generators provide the only possible source of power to the 480V switchgear buses, diesel generator failures and diesel generator unavailability due to maintenance are the dominant contributors to all of the electric power system failure states.

With offsite power available, failures must occur in the normal power supply trains to the 480V buses in order to interrupt voltage at any of the buses. The failure of power at bus 2A is dominated by the failure of breaker UT2/ST5 to close following a unit trip, with subsequent failure or unavailability of diesel generator 31. Since tie-breaker 2AT3A will not automatically close if bus 2A is energized from its normal power source, the single failure to close of breaker UT3/ST6 represents the dominant contributor to the loss of power at only

bus 3A. Failure of the common supplies to buses 2A and 5A, and buses 3A and 6A from 6.9 kV buses 5 and 6, respectively, are the dominant contributors to the loss of normal power to these specific pairs of buses. The dominant contributors to the buses remaining deenergized following the initial loss of voltage are subsequent failures in the diesel generator supply trains and diesel generator unavailability due to maintenance when the initial failure occurs. Failure of the station auxiliary transformer is the single most important contributor to the loss of power at more than two buses.

Following any transient other than the loss of offsite power initiating event, the probability of losing the offsite power supply as a result of the unit trip is extremely low. Even though this analysis is conservatively bounding and includes no power recovery considerations, the availability of the Indian Point Unit 3 electric power system is extremely high under these conditions.

The loss of offsite power transient produces the most severe impacts upon the electric power system. The results reported in this analysis do not take credit for any operator actions to effect recovery of either onsite components or offsite power at any time during the 6-hour period following event initiation. It must be especially emphasized that absolutely no consideration has been given in this bounding analysis to the operation or availability of the gas turbine units at the Indian Point site or Buchanan Substation. Even under extremely severe conditions affecting the offsite power supply grid, these units should provide a reserve source of power available to station personnel well within the 6-hour period covered by this analysis. It is, therefore, felt that the inclusion of recovery actions will significantly improve the availabilty of power in all of these electric power operability states. The quantification of these effects is, however, deferred to the detailed evaluation of specific event sequences in which electric power failure contributes significantly to public risk. The time frames available for plant recovery and the response characteristics of plant operating personnel are defined through these specific event sequences. This information provides a necessary input to the final quantification of not only electric power recovery actions, but also to the specific efforts made to minimize the consequences of the given event scenario.

The intricacies and operational complexities of the Indian Point Unit 3 electric power system have necessitated the bounding analysis approach adopted in this study. It cannot be emphasized too strongly that the results presented in this section do not provide the full quantification of the contribution to risk from electric power failures. The conservative boundary conditions and restrictive guidelines imposed upon this analysis insure that the results reported herein provide bounding values for any of the event sequences studied. However, vital interactions between the operators and the electric power system have been omitted from this analysis and cannot be effectively evaluated until specific event sequences are clearly defined. It is, therefore, extremely restrictive and improper to remove this system analysis from the context of the main study report. The full effects of electric

TABLE 1

INDIAN POINT UNIT 3 ELECTRIC POWER SYSTEM OPERABILITY STATES

State	No Power at Bus(es)	Power Available at Bus(es)
1	-	All Buses
2	2A	3A, 5A, and 6A
3	3A	2A, 5A, and 6A
4	5A	2A, 3A, and 6A
5	6A	2A, 3A, and 5A
6	2A and 3A	5A and 6A
7	2A and 5A	3A and 6A
8	2A and 6A	3A and 5A
9	3A and 5A	2A and 6A
10	3A and 6A	2A and 5A
11	5A and 6A	2A and 3A
12	2A, 3A, and 5A	6A
13	2A, 3A, and 6A	5A
14	2A, 5A, and 6A	3A
15	3A, 5A, and 6A	2A
16	All buses	-

power system failures are important only as they impact upon ultimate public risk. Therefore, these effects, including operator recovery actions, are quantified in detail only at the specific event sequence level.

TABLE 2.1

INDIAN POINT UNIT 3 ELECTRIC POWER SYSTEM MUTUALLY EXCLUSIVE FAILURE STATES

Boundary Conditions: Offsite Power Not Available
No Recovery From Failures
Study Period Of 6 Hours

State	Failure of Power At Bus(es)	Frequency of Given Electric Power State				
		Mean	Median	Variance	5th Percentile	95th Percentile
1	-	8.99×10^{-1}	8.98×10^{-1}	3.33×10^{-4}	8.67×10^{-1}	9.25×10^{-1}
2	2A	*				
3	3A	2.60×10^{-3}	5.52×10^{-4}	1.43×10^{-4}	3.05×10^{-5}	9.99×10^{-3}
4	5A	3.16×10^{-2}	3.01×10^{-2}	6.71×10^{-5}	1.90×10^{-2}	4.41×10^{-2}
5	6A	3.16×10^{-2}	3.01×10^{-2}	6.71×10^{-5}	1.90×10^{-2}	4.41×10^{-2}
6	2A & 3A	3.17×10^{-2}	3.02×10^{-2}	6.70×10^{-5}	1.91×10^{-2}	4.42×10^{-2}
7	2A & 5A	*				
8	2A & 6A	*				
9	3A & 5A	9.65×10^{-5}	1.56×10^{-5}	3.45×10^{-7}	6.79×10^{-7}	3.61×10^{-4}
10	3A & 6A	9.65×10^{-5}	1.56×10^{-5}	3.45×10^{-7}	6.79×10^{-7}	3.61×10^{-4}
11	5A & 6A	1.11×10^{-3}	1.00×10^{-3}	1.62×10^{-7}	5.02×10^{-4}	1.70×10^{-3}
12	2A, 3A & 5A	1.11×10^{-3}	1.01×10^{-3}	1.62×10^{-7}	5.07×10^{-4}	1.70×10^{-3}
13	2A, 3A & 6A	1.11×10^{-3}	1.01×10^{-3}	1.62×10^{-7}	5.07×10^{-4}	1.70×10^{-3}
14	2A, 5A & 6A	*				
15	3A, 5A & 6A	3.50×10^{-6}	4.08×10^{-7}	8.88×10^{-10}	1.35×10^{-8}	1.24×10^{-5}
16	All buses	5.81×10^{-5}	5.65×10^{-5}	4.48×10^{-10}	2.86×10^{-5}	9.18×10^{-5}

*State is undefined for these boundary conditions.

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TABLE 2.2

INDIAN POINT UNIT 3 ELECTRIC POWER SYSTEM MUTUALLY EXCLUSIVE FAILURE STATES

Boundary Conditions: Offsite Power Available
No Recovery From Failures
Study Period Of 6 Hours

State	Failure of Power At Bus(es)	Frequency of Given Electric Power State				
		Mean	Median	Variance	5th Percentile	95th Percentile
1	-	9.99×10^{-1}	9.99×10^{-1}	9.23×10^{-7}	9.96×10^{-1}	9.99×10^{-1}
2	2A	5.24×10^{-5}	4.37×10^{-5}	7.33×10^{-10}	1.80×10^{-5}	9.25×10^{-5}
3	3A	1.42×10^{-3}	1.08×10^{-3}	9.25×10^{-7}	3.45×10^{-4}	2.81×10^{-3}
4	5A	2.34×10^{-6}	2.13×10^{-6}	6.27×10^{-13}	1.18×10^{-6}	3.69×10^{-6}
5	6A	1.80×10^{-6}	1.71×10^{-6}	6.72×10^{-13}	5.72×10^{-7}	3.14×10^{-6}
6	2A & 3A	3.21×10^{-7}	2.74×10^{-7}	2.56×10^{-14}	1.15×10^{-7}	5.68×10^{-7}
7	2A & 5A	2.26×10^{-8}	2.05×10^{-8}	1.21×10^{-16}	6.72×10^{-9}	4.15×10^{-8}
8	2A & 6A	$<1.00 \times 10^{-10}$*				
9	3A & 5A	2.21×10^{-9}	9.07×10^{-10}	2.41×10^{-17}	1.01×10^{-10}	8.15×10^{-9}
10	3A & 6A	5.66×10^{-7}	5.01×10^{-7}	4.95×10^{-14}	2.42×10^{-7}	8.92×10^{-7}
11	5A & 6A	6.73×10^{-9}	5.78×10^{-9}	1.02×10^{-17}	2.37×10^{-9}	1.14×10^{-8}
12	2A, 3A & 5A	6.74×10^{-9}	5.80×10^{-9}	1.01×10^{-17}	2.38×10^{-9}	1.14×10^{-8}
13	2A, 3A & 6A	6.74×10^{-9}	5.80×10^{-9}	1.01×10^{-17}	2.38×10^{-9}	1.14×10^{-8}
14	2A, 5A & 6A	$<5.00 \times 10^{-13}$*				
15	3A, 5A & 6A	$<5.00 \times 10^{-13}$*				
16	All buses	2.87×10^{-10}	2.81×10^{-10}	1.59×10^{-20}	1.17×10^{-10}	4.99×10^{-10}

*Bounded by more limiting failure state

TABLE 2.3a

INDIAN POINT UNIT 3 ELECTRIC POWER SYSTEM MUTUALLY EXCLUSIVE FAILURE STATES

Applicability: Loss Of Offsite Power Initiating Event

Boundary Conditions: No Recovery From Failures
Study Period Of 6 Hours

State	Failure of Power At Bus(es)	Frequency of Given Electric Power State				
		Mean	Median	Variance	5th Percentile	95th Percentile
1	-	8.99×10^{-1}	8.98×10^{-1}	3.33×10^{-4}	8.67×10^{-1}	9.25×10^{-1}
2	2A	*				
3	3A	2.60×10^{-3}	5.52×10^{-4}	1.43×10^{-4}	3.05×10^{-5}	9.99×10^{-3}
4	5A	3.16×10^{-2}	3.01×10^{-2}	6.71×10^{-5}	1.90×10^{-2}	4.41×10^{-2}
5	6A	3.16×10^{-2}	3.01×10^{-2}	6.71×10^{-5}	1.90×10^{-2}	4.41×10^{-2}
6	2A & 3A	3.17×10^{-2}	3.02×10^{-2}	6.70×10^{-5}	1.91×10^{-2}	4.42×10^{-2}
7	2A & 5A	*				
8	2A & 6A	*				
9	3A & 5A	9.65×10^{-5}	1.56×10^{-5}	3.45×10^{-7}	6.79×10^{-7}	3.61×10^{-4}
10	3A & 6A	9.65×10^{-5}	1.56×10^{-5}	3.45×10^{-7}	6.79×10^{-7}	3.61×10^{-4}
11	5A & 6A	1.11×10^{-3}	1.09×10^{-3}	1.62×10^{-7}	5.02×10^{-4}	1.70×10^{-3}
12	2A, 3A & 5A	1.11×10^{-3}	1.01×10^{-3}	1.62×10^{-7}	5.07×10^{-4}	1.70×10^{-3}
13	2A, 3A & 6A	1.11×10^{-3}	1.01×10^{-3}	1.62×10^{-7}	5.07×10^{-4}	1.70×10^{-3}
14	2A, 5A & 6A	*				
15	3A, 5A & 6A	3.50×10^{-6}	4.08×10^{-7}	8.88×10^{-10}	1.35×10^{-8}	1.24×10^{-5}
16	All buses	5.81×10^{-5}	5.65×10^{-5}	4.48×10^{-10}	2.86×10^{-5}	9.18×10^{-5}

*State is undefined for this initiating event.

TABLE 2.3b

INDIAN POINT UNIT 3 ELECTRIC POWER SYSTEM MUTUALLY EXCLUSIVE FAILURE STATES

Applicability: Initiating Events Other Than Loss Of Offsite Power

Boundary Conditions: No Recovery From Failures
Study Period Of 6 Hou

State	Failure of Power At Bus(es)	Frequency of Given Electric Power State				
		Mean	Median	Variance	5th Percentile	95th Percentile
1	-	9.99×10^{-1}	9.99×10^{-1}	1.61×10^{-6}	9.97×10^{-1}	1.00
2	2A	5.24×10^{-5}	4.37×10^{-5}	7.33×10^{-10}	1.80×10^{-5}	9.25×10^{-5}
3	3A	1.42×10^{-3}	1.11×10^{-3}	8.11×10^{-7}	3.76×10^{-4}	3.41×10^{-3}
4	5A	1.31×10^{-5}	4.38×10^{-6}	1.14×10^{-9}	1.53×10^{-6}	2.82×10^{-5}
5	6A	1.26×10^{-5}	3.85×10^{-6}	1.14×10^{-9}	1.01×10^{-6}	2.76×10^{-5}
6	2A & 3A	1.11×10^{-5}	2.31×10^{-6}	1.14×10^{-9}	2.15×10^{-7}	2.62×10^{-5}
7	2A & 5A	2.26×10^{-8}	2.05×10^{-8}	1.21×10^{-16}	6.72×10^{-9}	4.15×10^{-8}
8	2A & 6A	$<1.00 \times 10^{-10}$*				
9	3A & 5A	3.51×10^{-8}	3.38×10^{-9}	1.57×10^{-14}	2.48×10^{-10}	4.12×10^{-8}
10	3A & 6A	5.99×10^{-7}	5.09×10^{-7}	6.25×10^{-14}	2.76×10^{-7}	1.06×10^{-6}
11	5A & 6A	3.85×10^{-7}	7.52×10^{-8}	1.41×10^{-12}	4.81×10^{-9}	7.74×10^{-7}
12	2A, 3A & 5A	3.85×10^{-7}	7.52×10^{-8}	1.41×10^{-12}	4.83×10^{-9}	7.74×10^{-7}
13	2A, 3A & 6A	3.85×10^{-7}	7.52×10^{-8}	1.41×10^{-12}	4.83×10^{-9}	7.74×10^{-7}
14	2A, 5A & 6A	$<5.00 \times 10^{-13}$*				
15	3A, 5A & 6A	1.19×10^{-9}	1.97×10^{-11}	2.13×10^{-17}	3.07×10^{-13}	1.07×10^{-9}
16	All buses	2.01×10^{-8}	3.83×10^{-9}	3.87×10^{-15}	2.27×10^{-10}	4.04×10^{-8}

*Bounded by more limiting failure state

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TABLE 3

INDIAN POINT UNIT 3 480V BUS LOADS

Bus 2A	Pressurizer Heaters Backup Group 32
	Component Cooling Pump 32
	Service Water Pump 32
	Safety Injection Pump 32
	Fan Cooler Unit 32
	De-Icing Pump 31
	Rod Power Supply M-G Set 31
	MCC 31
	MCC 33
	MCC 34
	MCC 36C
	MCC 310
	Lighting Tran_former 31 (normal supply)
Bus 3A	Pressurizer Heaters Backup Group 31
	Service Water Pump 38
	Service Water Pump 35
	Residual Heat Removal Pump 31
	Auxiliary Feedwater Pump 31
	Fan Cooler Unit 34
	Charging Pump 32
	De-Icing Pump 32
	MCC 32
	MCC 35
	Lighting Transformer 32
Bus 5A	Pressurizer Heaters Backup Group 33
	Safety Injection Pump 31
	Containment Spray Pump 31
	Recirculation Pump 31
	Component Cooling Pump 31
	Service Water Pump 31
	Service Water Pump 34
	Service Water Pump 37
	Fan Cooler Unit 31
	Fan Cooler Unit 33
	Charging Pump 31
	Service Air Compressor
	MCC 36A
	MCC 38
	MCC 39
	Lighting Transformer 33

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TABLE 3 (continued)

INDIAN POINT UNIT 3 480V BUS LOADS

Bus 6A	Pressurizer Heaters Control Group
	Safety Injection Pump 33
	Component Cooling Pump 33
	Containment Spray Pump 32
	Recirculation Pump 32
	Residual Heat Removal Pump 32
	Service Water Pump 33
	Service Water Pump 36
	Service Water Pump 39
	Auxiliary Feedwater Pump 33
	Fan Cooler Unit 35
	Charging Pump 33
	Rod Power Supply M-G Set 32
	Main Turbine Auxiliary Lube Oil Pump
	MCC 36B
	MCC 37
	Lighting Transformer 31 (emergency supply)

TABLE 4

INDIAN POINT UNIT 3 DIESEL GENERATOR AUXILIARIES POWER SUPPLIES

Diesel Generator 31	
Crankcase Exhauster	MCC 36C
Starting Air Compressor	MCC 34
Fuel Oil Transfer Pump 31	MCC 36C
Diesel Generator Control Power	DC Power Panel 33
Output Breaker Control Power	DC Power Panel 33
Diesel Generator 32	
Crankcase Exhauster	MCC 36B
Starting Air Compressor	MCC 37
Fuel Oil Transfer Pump 32	MCC 36B
Diesel Generator Control Power	DC Power Panel 32
Output Breaker Control Power	DC Power Panel 32
Diesel Generator 33	
Crankcase Exhauster	MCC 36A
Starting Air Compressor	MCC 39
Fuel Oil Transfer Pump 33	MCC 36A
Diesel Generator Control Power	DC Power Panel 31
Output Breaker Control Power	DC Power Panel 31

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TABLE 5

INDIAN POINT UNIT 3 MAJOR DC POWER SYSTEM LOADS

Power Panel 31	Main Turbine Emergency Oil Pump Instrument Bus 31 Static Inverter 480V Bus 5A Control Power Control Rod Position Indication Inverter Conventional Plant Emergency Lighting Control Room Emergency Lighting Diesel Generator Building Emergency Lighting Distribution Panel 31 Distribution Panel 33
Distribution Panel 31	Safety Injection System Valves Control Power Diesel Generator 33 Control Power Main Steam Dump Control Main Generator Trip Relays Main Turbine Trip Relays Station Auxiliary Transformer Trip Relays Safeguards Actuation Train B Relays Reactor Protection Train B Relays
Distribution Panel 33	13.8 kV/Gas Turbine Substation Control Power Main Steam Isolation Valves Control Power
Power Panel 32	Main Feedwater Pumps Emergency Oil Pump Air Side Seal Oil Backup Pump Instrument Bus 32 Static Inverter 480V Bus 6A Control Power Nuclear Plant Emergency Lighting Electrical Tunnel Emergency Lighting Distribution Panel 32 Distribution Panel 34
Distribution Panel 32	Safety Injection System Valves Control Power Diesel Generator 32 Control Power Main Generator Backup Trip Relays Main Turbine Backup Trip Relays Station Auxiliary Transformer Backup Trip Relays Safeguards Actuation Train A Relays Reactor Protection Train A Relays
Distribution Panel 34	Main Steam Isolation Valves Control Power Miscellaneous Plant Fire Protection System Controls
Power Panel 33	Instrument Bus 33 Static Inverter Diesel Generator 31 Control Power 480V Buses 2A and 3A Control Power
Power Panel 34	Instrument Bus 34 Static Inverter

TABLE 6

INDIAN POINT UNIT 3 118 VAC INSTRUMENT BUS
POWER SUPPLIES

Instrument Bus	Normal Power Supply	Reserve Power Supply
31	DC Power Panel 31 through Static Inverter 31	120 VAC Lighting Bus 32*
32	DC Power Panel 32 through Static Inverter 32	120 VAC Lighting Bus 32*
33	DC Power Panel 33 through Static Inverter 33	120 VAC Lighting Bus 32*
34	DC Power Panel 34 through Static Inverter 34	120 VAC Lighting Bus 32*

*Sized to supply only one istrument bus at a time. Supply to 120 VAC Lighting Bus 32 is from 480V Bus 3A through 480/120V Lighting Transformer 32.

TABLE 7

INDIAN POINT UNIT 3 ELECTRIC POWER FAILURE INITIATING EVENTS

System Failure	Initiating Event Category
Loss of offsite power supply from Station Auxiliarly Transformer	Loss of Offsite Power
Loss of power to 6.9 kV bus 1, 2, 3 or 4	Loss of Primary Flow
Loss of power at DC Power Panel 31 or 32	Reactor Trip
Loss of power to any two instrument power buses	Reactor Trip or Safety Injection (depends upon which buses are deenergized)

TABLE 8

INDIAN POINT UNIT 3 ELECTRIC POWER FAULT TREE BASIC EVENT DESCRIPTION, COMPONENT FAILURE MODE CODING, AND FAILURE RATES

Component	Failure Mode	Coding	Failure Rate(1)	Reference(2)
6.9 kV Bus 2	Open Circuit	JBS6932K	3.25×10^{-8}	42
6.9 kV Bus 3	Open Circuit	JBS6933K	3.25×10^{-8}	42
6.9 kV Bus 5	Open Circuit	JBS6935K	3.25×10^{-8}	42
6.9 kV Bus 6	Open Circuit	JBS6936K	3.25×10^{-8}	42
480V Bus 2A	Open Circuit	JBS 32AK	3.25×10^{-8}	42
480V Bus 3A	Open Circuit	JBS 33AK	3.25×10^{-8}	42
480V Bus 5A	Open Circuit	JBS 35AK	3.25×10^{-8}	42
480V Bus 6A	Open Circuit	JBS 36AK	3.25×10^{-8}	42
DC Power Panel 31	Open Circuit	4BS 331K	3.25×10^{-8}	42
DC Power Panel 32	Open Circuit	4BS 332K	3.25×10^{-8}	42
DC Power Panel 33	Open Circuit	4BS 333K	3.25×10^{-8}	42
DC Power Panel 34	Open Circuit	4BS 334K	3.25×10^{-8}	42
Motor Control Center 32	Open Circuit	JBSMC32K	3.25×10^{-8}	42
Motor Control Center 36A	Open Circuit	JBSM36AK	3.25×10^{-8}	42
Motor Control Center 36B	Open Circuit	JBSM36BK	3.25×10^{-8}	42
Motor Control Center 36C	Open Circuit	JBSM36CK	3.25×10^{-8}	42
Motor Control Center 37	Open Circuit	JBSMC37K	3.25×10^{-8}	42
Motor Control Center 39	Open Circuit	JBSMC39K	3.25×10^{-8}	42
Instrument Bus 31	Open Circuit	JBSIB31K	3.25×10^{-8}	42
Instrument Bus 32	Open Circuit	JBSIB32K	3.25×10^{-8}	42
Instrument Bus 33	Open Circuit	JBSIB33K	3.25×10^{-8}	42
Instrument Bus 34	Open Circuit	JBSIB34K	3.25×10^{-8}	42
480V Lighting Bus 32	Open Circuit	JBS4B32K	3.25×10^{-8}	42

(1)All failure rates shown are failure rates per hour, except those marked with an asterisk (*), which are failure rates per demand.

(2)All failure data obtained from Table B.2-2 in Appendix B to this report. The number listed corresponds to the specific item number presented in Table B.2-2.

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TABLE 8 (continued)

INDIAN POINT UNIT 3 ELECTRIC POWER FAULT TREE BASIC EVENT DESCRIPTION, COMPONENT FAILURE MODE CODING, AND FAILURE RATES

Component	Failure Mode	Coding	Failure Rate	Reference
120V Lighting Bus 31	Open Circuit	JBS1231K	3.25×10^{-8}	42
120V Lighting Bus 32	Open Circuit	JBS1232K	3.25×10^{-8}	42
120V Lighting Bus 33	Open Circuit	JBS1233K	3.25×10^{-8}	42
120 VAC Distribution Panel 31	Open Circuit	JBSDP31K	3.25×10^{-8}	42
120 VAC Distribution Panel 32	Open Circuit	JBSDP32K	3.25×10^{-8}	42
Station Auxiliary Transformer	Open circuit, loss of function	JPTSTAXK	8.39×10^{-7}	32
Station Service Transformer 2	Open circuit, loss of function	JPTSST2K	8.39×10^{-7}	32
Station Service Transformer 3	Open circuit, loss of function	JPTSST3K	8.39×10^{-7}	32
Station Service Transformer 5	Open circuit, loss of function	JPTSST5K	8.39×10^{-7}	32
Station Service Transformer 6	Open circuit, loss of function	JPTSST6K	8.39×10^{-7}	32
Lighting Transformer 31	Open circuit, loss of function	JPTLT31K	8.39×10^{-7}	32
Lighting Transformer 32	Open circuit, loss of function	JPTLT32K	8.39×10^{-7}	32
Lighting Transformer 33	Open circuit, loss of function	JPTLT33K	8.39×10^{-7}	32
Circuit Breaker ST5	Transfers open	JCB ST5B	2.67×10^{-6}	31
Circuit Breaker ST6	Transfers open	JCB ST6B	2.67×10^{-6}	31
Circuit Breaker SS2	Transfers open	JCB SS2B	2.67×10^{-6}	31
Circuit Breaker SS3	Transfers open	JCB SS3B	2.67×10^{-6}	31
Circuit Breaker SS5	Transfers open	JCB SS5B	2.67×10^{-6}	31
Circuit Breaker SS6	Transfers Open	JCB SS6B	2.67×10^{-6}	31
Circuit Breaker 2A	Transfers Open	JCB 32AB	2.67×10^{-6}	31
Circuit Breaker 3A	Transfers Open	JCB 33AB	2.67×10^{-6}	31
Circuit Breaker 5A	Transfers Open	JCB 35AB	2.67×10^{-6}	31
Circuit Breaker 6A	Transfers Open	JCB 36AB	2.67×10^{-6}	31
Battery Charger 31 Supply Breaker	Transfers Open	JCB3931B	2.67×10^{-6}	31
Battery Charger 32 Supply Breaker	Transfers Open	JCB3732B	2.67×10^{-6}	31
Battery Charger 33 Supply Breaker	Transfers Open	JCB3633B	2.67×10^{-6}	31
Battery Charger 34 Supply Breaker	Transfers Open	JCB3234B	2.67×10^{-6}	31

TABLE 8 (continued)

INDIAN POINT UNIT 3 ELECTRIC POWER FAULT TREE BASIC EVENT DESCRIPTION, COMPONENT FAILURE MODE CODING, AND FAILURE RATES

Component	Failure Mode	Coding	Failure Rate	Reference
Supply Breaker to MCC 32	Transfers Open	JCBMCC2B	2.67×10^{-6}	31
Supply Breaker to MCC 36A	Transfers Open	JCBMC6AB	2.67×10^{-6}	31
Supply Breaker to MCC 36B	Transfers Open	JCBMC6BB	2.67×10^{-6}	31
Supply Breaker to MCC 37	Transfers Open	JCBMCC7B	2.67×10^{-6}	31
Supply Breaker to MCC 39	Transfers Open	JCBMCC9B	2.67×10^{-6}	31
Supply Breaker to Sola Transformer 34	Transfers open	JCBSO34B	2.67×10^{-6}	31
Supply Breaker to Lighting Transformer 32	Transfers open	JCB LT2B	2.67×10^{-6}	31
Supply Breaker to Lighting Transformer 33	Transfers open	JCB LT3B	2.67×10^{-6}	31
Supply Breaker to 120 VAC Lighting Bus 31	Transfers open	JCBLB31B	2.67×10^{-6}	31
Supply Breaker to 120 VAC Lighting Bus 32	Transfers open	JCBLB32B	2.67×10^{-6}	31
Supply Breaker to 120 VAC Lighting Bus 33	Transfers open	JCBLB33B	2.67×10^{-6}	31
Supply Breaker to 120 VAC Distribution Panel 31	Transfers open	JCBDP31B	2.67×10^{-6}	31
Supply Breaker to 120 VAC Distribution Panel 32	Transfers open	JCBDP32B	2.67×10^{-6}	31
480V Lighting Bus 32 Normal Supply Breaker	Transfers open	JCBLTINB	2.67×10^{-6}	31
480V Lighting Bus 32 Emergency Supply Breaker	Transfers open	JCBLTIEB	2.67×10^{-6}	31
DC Supply Breaker to Inverter 31	Transfers Open	4CBNV31B	2.67×10^{-6}	31
DC Supply Breaker to Inverter 32	Transfers Open	4CBNV32B	2.67×10^{-6}	31
DC Supply Breaker to Inverter 33	Transfers Open	4CBNV33B	2.67×10^{-6}	31
DC Supply Breaker to Inverter 34	Transfers Open	4CBNV34B	2.67×10^{-6}	31

TABLE 8 (continued)

INDIAN POINT UNIT 3 ELECTRIC POWER FAULT TREE BASIC EVENT DESCRIPTION, COMPONENT FAILURE MODE CODING, AND FAILURE RATES

Component	Failure Mode	Coding	Failure Rate	Reference
Supply Breaker from 120 VAC Lighting Bus 32 to Instrument Bus Supply	Transfers Open	JCBIBASB	2.67×10^{-6}	31
Circuit Breaker U2S5	Fails to close on demand	JCBU2S5X	1.33×10^{-3}*	29
Circuit Breaker U3S6	Fails to close on demand	JCBU2S6X	1.33×10^{-3}*	29
Circuit Breaker EG1	Fails to close on demand	JCB EG1X	1.33×10^{-3}*	29
Circuit Breaker EG2	Fails to close on demand	JCBEG2BX	1.33×10^{-3}*	29
Circuit Breaker EG3	Fails to close on demand	JCB EG3X	1.33×10^{-3}*	29
Circuit Breaker 2AT3A	Fails to close on demand	JCB2A3AX	1.33×10^{-3}*	29
Circuit Breaker 2A	Fails to open on demand	JCB 32AQ	1.45×10^{-3}*	30
Circuit Breaker 3A	Fails to open on demand	JCB 33AQ	1.45×10^{-3}*	30
Circuit Breaker 5A	Fails to open on demand	JCB 35AQ	1.45×10^{-3}*	30
Circuit Breaker 6A	Fails to open on demand	JCB 36AQ	1.45×10^{-3}*	30
Circuit Breaker GT-35	Fails to close	JCB GT5X	1.00*	(3)
Circuit Breaker GT-36	Fails to close	JCB GT6X	1.00*	(3)
Circuit Breaker 2AT5A	Fails to close	JCB2A5AX	1.00*	(3)
Circuit Breaker 3AT6A	Fails to close	JCB3A6AX	1.00*	(3)
DC Power Panels 31 and 32 Crosstie	Fails to close	JCB3132X	1.00*	(3)
Supply Breaker to MCC 32	Fails to close (if open)	JCBMCC2X	1.00*	(3)
Supply Breaker to MCC 37	Fails to close (if open)	JCBMCC7X	1.00*	(3)
Supply Breaker to MCC 39	Fails to close (if open)	JCBMCC9X	1.00*	(3)
120 VAC Lighting Buses 32 and 33 Crosstie	Fails to close	JCBLBXTX	1.00*	(3)
Gas Turbine Unit #1	Fails to supply power	JGEGASTS	1.00*	(4)
Diesel Generator 31	Fails to start and load	XDLDG31N	1.44×10^{-2}*	27
Diesel Generator 32	Fails to start and load	XDLDG32N	1.44×10^{-2}*	27
Diesel Generator 33	Fails to start and load	XDLDG33N	1.44×10^{-2}*	27

(3) Circuit breaker requires manual operator action to close and is considered to remain open for hardware failure quantification.

(4) Operator must manually start and load gas turbine unit.

* Failure on demand

TABLE 8 (continued)

INDIAN POINT UNIT 3 ELECTRIC POWER FAULT TREE BASIC EVENT DESCRIPTION, COMPONENT FAILURE MODE CODING, AND FAILURE RATES

Component	Failure Mode	Coding	Failure Rate	Reference
Diesel Generator 31 Starting Air	Insufficient air supply pressure	XCRDG31S	Included in diesel generator failure rate	
Diesel Generator 32 Starting Air	Insufficient air supply pressure	XCRDG32S	Included in diesel generator failure rate	
Diesel Generator 33 Starting Air	Insufficient air supply pressure	XCRDG33S	Included in diesel generator failure rate	
Battery 31 Output Fuse	Opens below rating	4FUBY31K	8.32×10^{-7}	36
Battery 32 Output Fuse	Opens below rating	4FUBY32K	8.32×10^{-7}	36
Battery 33 Output Fuse	Opens below rating	4FUBY33K	8.32×10^{-7}	36
Battery 34 Output Fuse	Opens below rating	4FUBY34K	8.32×10^{-7}	36
Battery 31	Failure (no output)	4BY 331D	8.35×10^{-8}	34
Battery 32	Failure (no output)	4BY 332D	8.35×10^{-8}	34
Battery 33	Failure (no output)	4BY 333D	8.35×10^{-8}	34
Battery 34	Failure (no output)	4BY 334D	8.35×10^{-8}	34
Battery Charger 31	Failure (no output)	4BC 331S	1.35×10^{-5}	35
Battery Charger 32	Failure (no output)	4BC 332S	1.35×10^{-5}	35
Battery Charger 33	Failure (no output)	4BC 333S	1.35×10^{-5}	35
Battery Charger 34	Failure (no output)	4BC 334S	1.35×10^{-5}	35
Static Inverter 31	Failure (no output)	JIVSI31S	3.77×10^{-6}	33
Static Inverter 32	Failure (no output)	JIVSI32S	3.77×10^{-6}	33
Static Inverter 33	Failure (no output)	JIVSI33S	3.77×10^{-6}	33
Static Inverter 34	Failure (no output)	JIVSI34S	3.77×10^{-6}	33

TABLE 8 (continued)

INDIAN POINT UNIT 3 ELECTRIC POWER FAULT TREE BASIC EVENT DESCRIPTION, COMPONENT FAILURE MODE CODING, AND FAILURE RATES

Component	Failure Mode	Coding	Failure Rate	Reference
Instrument Bus 31 Supply Transfer Switch	Transfers open (open circuit)	JSSMT31B	ϵ	43
Instrument Bus 32 Supply Transfer Switch	Transfers open (open circuit)	JSSMT32B	ϵ	43
Instrument Bus 33 Supply Transfer Switch	Transfers open (open circuit)	JSSMT33B	ϵ	43
Instrument Bus 34 Supply Transfer Switch	Transfers open (open circuit)	JSSMT34B	ϵ	43
Instrument Bus 31 Supply Transfer Switch	Failure to Transfer	JSSMT31X	1.00*	(5)
Instrument Bus 32 Supply Transfer Switch	Failure to Transfer	JSSMT32X	1.00*	(5)
Instrument Bus 33 Supply Transfer Switch	Failure to Transfer	JSSMT33X	1.00*	(5)
Instrument Bus 34 Supply Transfer Switch	Failure to Transfer	JSSMT34X	1.00*	(5)
480V Lighting Bus 32 Transfer Switch	Failure to Transfer	JSSTS32S	1.33×10^{-3}*	29
480V Lighting Bus 32 Transfer Switch	Transfers open (open circuit)	JSSTS32B	ϵ	43
Circuit Breaker U2S5	Failure of closing signal	JREU2S5S	Included in breaker failure rate	
Circuit Breaker U2S6	Failure of closing signal	JREU3S6S	Included in breaker failure rate	
Circuit Breaker EG1	Failure of closing signal	JRE EG1S	Included in breaker failure rate	
Circuit Breaker EG2	Failure of closing signal	JRE EG2S	Included in breaker failure rate	
Circuit Breaker EG3	Failure of closing signal	JRE EG3S	Included in breaker failure rate	

(5) Transfer switch requires manual operator action and is considered to remain in normal position for hardware failure quantification.

*Failure on demand

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INDIAN POINT UNIT 3 ELECTRIC POWER FAULT TREE BASIC EVENT DESCRIPTION, COMPONENT FAILURE MODE CODING, AND FAILURE RATES

Component	Failure Mode	Coding	Failure Rate	Reference
Circuit Breaker EG3	Failure of closing signal	JRE EG3S	Included in breaker failure rate	
Offsite Power Supply	Failure (no offsite power)	JSHOSPSD	Determined by boundary conditions	
Diesel Generator 31	Failure of Safety Injection signal	MRESIS1S	Included in diesel generator failure	
Diesel Generator 32	Failure of Safety Injection signal	MRESIS2S	Included in diesel generator failure	
Diesel Generator 33	Failure of Safety Injection signal	MRESIS3S	Included in diesel generator failure	
Diesel Generator 31	Failure of undervoltage signal	JBSUV31S	Included in diesel generator failure	
Diesel Generator 32	Failure of undervoltage signal	JBSUV32S	Included in diesel generator failure	
Diesel Generator 33	Failure of undervoltage signal	JBSUV32S	Included in diesel generator failure	
Diesel Generator 31	Starting selector switch in "Auto"	XSSSEL1K	0.00	(6)
Diesel Generator 32	Starting selector switch in "Auto"	XSSSEL2K	0.00	(6)
Diesel Generator 33	Starting selector switch in "Auto"	XSSSEL3K	0.00	(6)
Supply Breaker to MCC 32	Receives signal to open	JREMCC2D	Determined by boundary conditions	
Supply Breaker to MCC 37	Receives signal to open	JREMCC7D	Determined by boundary conditions	
Supply Breaker to MCC 39	Receives signal to open	JREMCC9D	Determined by boundary conditions	
Diesel Generator 31	Fails during operation	XDLDG31N(7)	9.37×10^{-4}	28
Diesel Generator 32	Fails during operation	XDLDG32N(7)	9.37×10^{-4}	28
Diesel Generator 33	Fails during operation	XDLDG33N(7)	9.37×10^{-4}	28

(6) This failure rate is determined by human interactions during testing and maintenance and is considered to be in the unfailed state for hardware failure quantifications.

(7) Failure to start on demand and failure during operations combined in a single code to reduce number of cutsets generated.

TABLE 9.1-1

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Bus 2A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Unavailability on demand (at event initiation):
  mean: 1.72×10^{-2}
  variance: 4.27×10^{-5}

- Dominant failure contributors:

  Diesel Generator 31 failure to start on demand
  mean: 1.44×10^{-2}
  variance: 5.12×10^{-5}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: 1.00

- Diesel Generator 32: No effect

- Diesel Generator 33: No effect

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Bus 2A with Diesel Generator 31 inoperable yields:

  Testing contribution to unavailability (Q_T):
  mean: 2.51×10^{-5}
  variance: 7.20×10^{-9}

TABLE 9.1-1 (continued)

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Bus 2A

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Bus 2A with Diesel Generator 31 inoperable yields:

  Maintenance contribution to unavailability (Q_M):
  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.1, unavailability of Diesel Generator 31 due to fuel oil supply failure:

  mean: 5.49×10^{-6}
  variance: 5.10×10^{-11}

  Applying this to the conditional unavailability of power at Bus 2A with Diesel Generator 31 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
  mean: 5.49×10^{-6}
  variance: 5.10×10^{-11}

TABLE 9.1-2

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Bus 3A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 2.55×10^{-2}
  variance: 9.28×10^{-5}

- Unavailability on demand (at event initiation):
  mean: 2.00×10^{-2}
  variance: 5.70×10^{-5}

- Dominant failure contributors:

  Diesel Generator 31 failure to start on demand
  mean: 1.44×10^{-2}
  variance: 5.12×10^{-5}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: 1.00

- Diesel Generator 32: No effect

- Diesel Generator 33: No effect

Testing Contribution to Unavailability

- From Section D.2, unavailability of one die[illegible]enerator due to testing errors:
  mean: Q_{TE1} = 2.51 [illegible]
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Bus 3A with Diesel Generator 31 inoperable yields:

  Testing contribution to unavailability (Q_T):
  mean: 2.51×10^{-5}
  variance: 7.20×10^{-9}

TABLE 9.1-2 (continued)

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Bus 3A

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Bus 3A with Diesel Generator 31 inoperable yields:

  Maintenance contribution to unavailability (Q_M):
  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.1, unavailability of Diesel Generator 31 due to fuel oil supply failure:

  mean: 5.49×10^{-6}
  variance: 5.10×10^{-11}

  Applying this to the conditional unavailability of power at Bus 3A with Diesel Generator 31 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
  mean: 5.49×10^{-6}
  variance: 5.10×10^{-11}

TABLE 9.1-3

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Bus 5A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Unavailability on demand (at event initiation):
  mean: 1.72×10^{-2}
  variance: 4.27×10^{-5}

- Dominant failure contributors:

  Diesel Generator 33 failure to start on demand
  mean: 1.44×10^{-2}
  variance: 5.12×10^{-5}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: No effect

- Diesel Generator 32: No effect

- Diesel Generator 33: 1.00

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Bus 5A with Diesel Generator 33 inoperable yields:

  Testing contribution to unavailability (Q_T):
  mean: 2.51×10^{-5}
  variance: 7.20×10^{-9}

TABLE 9.1-3 (continued)

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Bus 5A

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Bus 5A with Diesel Generator 33 inoperable yields:

  Maintenance contribution to unavailability (Q_M):
  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.1, unavailability of Diesel Generator 33 due to fuel oil supply failure:

  mean: 5.49×10^{-6}
  variance: 5.10×10^{-11}

  Applying this to the conditional unavailability of power at Bus 5A with Diesel Generator 33 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
  mean: 5.49×10^{-6}
  variance: 5.10×10^{-11}

TABLE 9.1-4

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Bus 6A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Unavailability on demand (at event initiation):
  mean: 1.72×10^{-2}
  variance: 4.27×10^{-5}

- Dominant failure contributors:

  Diesel Generator 32 failure to start on demand
  mean: 1.44×10^{-2}
  variance: 5.12×10^{-5}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: No effect

- Diesel Generator 32: 1.00

- Diesel Generator 33: No effect

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Bus 6A with Diesel Generator 32 inoperable yields:

  Testing contribution to unavailability (Q_T):
  mean: 2.51×10^{-5}
  variance: 7.20×10^{-9}

TABLE 9.1-4 (continued)

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Bus 6A

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Bus 6A with Diesel Generator 32 inoperable yields:

  Maintenance contribution to unavailability (Q_M):
  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.1, unavailability of Diesel Generator 32 due to fuel oil supply failure:

  mean: 5.49×10^{-6}
  variance: 5.10×10^{-11}

  Applying this to the conditional unavailability of power at Bus 6A with Diesel Generator 32 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
  mean: 5.49×10^{-6}
  variance: 5.10×10^{-11}

TABLE 9.1-5

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A and 3A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Unavailability on demand (at event initiation):
  mean: 1.72×10^{-2}
  variance: 4.27×10^{-5}

- Dominant failure contributors:

  Diesel Generator 31 failure to start on demand
  mean: 1.44×10^{-2}
  variance: 5.12×10^{-5}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: 1.00

- Diesel Generator 32: No effect

- Diesel Generator 33: No effect

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

Applying this to the conditional unavailability of power at Buses 2A and 3A with Diesel Generator 31 inoperable yields:

Testing contribution to unavailability (Q_T):
mean: 2.51×10^{-5}
variance: 7.20×10^{-9}

TABLE 9.1-5 (continued)

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A and 3A

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Buses 2A and 3A with Diesel Generator 31 inoperable yields:

  Maintenance contribution to unavailability (Q_M):
  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.1, unavailability of Diesel Generator 31 due to fuel oil supply failure:

  mean: 5.49×10^{-6}
  variance: 5.10×10^{-11}

  Applying this to the conditional unavailability of power at Buses 2A and 3A with Diesel Generator 31 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
  mean: 5.49×10^{-6}
  variance: 5.10×10^{-11}

TABLE 9.1-6

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A and 5A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 5.97×10^{-4}
  variance: 2.06×10^{-7}

- Unavailability on demand (at event initiation):
  mean: 3.38×10^{-4}
  variance: 6.22×10^{-8}

- Dominant failure contributors:

  Diesel Generators 31 and 33 fail to start on demand:
  mean: 2.46×10^{-4}
  variance: 4.13×10^{-8}

  Diesel Generators 21 and 22 fail during operation for 6 hours:
  mean: 6.75×10^{-5}
  variance: 1.20×10^{-8}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generator 32: No effect

- Diesel Generator 33:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generators 31 and 33
  1.00

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Buses 2A and 5A with Diesel Generator 31 or Diesel Generator 33 inoperable yields:

  mean: 1.14×10^{-6}
  variance: 5.39×10^{-12}

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A and 5A

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at Buses 2A and 5A with Diesel Generator 31 and Diesel Generator 33 inoperable yields:

  mean: 2.03×10^{-6}
  variance: 2.34×10^{-11}

- Testing contribution to unavailability (Q_T):

  mean: 3.17×10^{-6}
  variance: 1.76×10^{-11}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Buses 2A and 5A with Diesel Generator 31 or Diesel Generator 33 inoperable yields:

  Maintenance contribution to unavailability (Q_M):

  mean: 4.93×10^{-4}
  variance: 4.89×10^{-8}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.1, unavailability of Diesel Generators 31 and 33 due to fuel oil supply failure:

  mean: 1.01×10^{-5}
  variance: 1.58×10^{-10}

  Applying this to the conditional unavailability of power at Buses 2A and 5A with Diesel Generators 31 and 33 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):

  mean: 1.01×10^{-5}
  variance: 1.58×10^{-10}

TABLE 9.1-7

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A and 6A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 5.97×10^{-4}
  variance: 2.06×10^{-7}

- Unavailability on demand (at event initiation):
  mean: 3.38×10^{-4}
  variance: 6.22×10^{-8}

- Dominant failure contributors:

  Generators 31 and 32 fail to start on demand:
  mean: 2.46×10^{-4}
  variance: 4.13×10^{-8}

  Diesel Generators 31 and 32 fail during operation for 6 hours:
  mean: 6.75×10^{-5}
  variance: 1.20×10^{-8}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generator 32:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generator 33: No effect

- Diesel Generators 31 and 32:
  1.00

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

Applying this to the conditional unavailability of power at Buses 2A and 6A with Diesel Generator 31 or Diesel Generator 32 inoperable yields:

mean: 1.14×10^{-6}
variance: 5.39×10^{-12}.

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A and 6A

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at Buses 2A and 6A with Diesel Generator 31 and Diesel Generator 32 inoperable yields:

  mean: 2.03×10^{-6}
  variance: 2.34×10^{-11}

- Testing contribution to unavailability (Q_T):

  mean: 3.17×10^{-6}
  variance: 1.76×10^{-11}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Buses 2A and 6A with Diesel Generator 31 or Diesel Generator 32 inoperable yields:

  Maintenance contribution to unavailability (Q_M):

  mean: 4.93×10^{-4}
  variance: 4.89×10^{-8}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.1, unavailability of Diesel Generators 31 and 32 due to fuel oil supply failure:

  mean: 1.01×10^{-5}
  variance: 1.58×10^{-10}

  Applying this to the conditional unavailability of power at Buses 2A and 6A with Diesel Generators 31 and 32 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):

  mean: 1.01×10^{-5}
  variance: 1.58×10^{-10}

TABLE 9.1-8

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 3A and 5A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 6.65×10^{-4}
  variance: 2.43×10^{-7}

- Unavailability on demand (at event initiation):
  mean: 3.91×10^{-4}
  variance: 8.04×10^{-8}

- Dominant failure contributors:

  Diesel Generators 31 and 33 fail to start on demand:
  mean: 2.46×10^{-4}
  variance: 4.13×10^{-8}

  Diesel Generators 31 and 33 fail during operation for 6 hours:
  mean: 6.75×10^{-5}
  variance: 1.20×10^{-8}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generator 32: No effect

- Diesel Generator 33:
  mean: 2.55×10^{-2}
  variance: 9.28×10^{-5}

- Diesel Generators 31 and 33
  1.00

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Buses 3A and 5A with Diesel Generator 31 or Diesel Generator 33 inoperable yields:

  mean: 1.21×10^{-6}
  variance: 6.07×10^{-12}

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 3A and 5A

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at Buses 3A and 5A with Diesel Generator 31 and Diesel Generator 33 inoperable yields:

  mean: 2.03×10^{-6}
  variance: 2.34×10^{-11}

- Testing contribution to unavailability (Q_T):

  mean: 3.24×10^{-6}
  variance: 1.84×10^{-11}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Buses 3A and 5A with Diesel Generator 31 or Diesel Generator 33 inoperable yields:

  Maintenance contribution to unavailability (Q_M):

  mean: 5.24×10^{-4}
  variance: 5.44×10^{-8}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.1, unavailability of Diesel Generators 31 and 33 due to fuel oil supply failure:

  mean: 1.01×10^{-5}
  variance: 1.58×10^{-10}

  Applying this to the conditional unavailability of power at Buses 3A and 5A with Diesel Generators 31 and 33 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):

  mean: 1.01×10^{-5}
  variance: 1.58×10^{-10}

TABLE 9.1-9

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 3A and 6A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 6.65×10^{-4}
  variance: 2.43×10^{-7}

- Unavailability on demand (at event initiation):
  mean: 3.91×10^{-4}
  variance: 8.04×10^{-8}

- Dominant failure contributors:

  Diesel Generators 31 and 32 fail to start on demand:
  mean: 2.46×10^{-4}
  variance: 4.13×10^{-8}

  Diesel Generators 31 and 32 fail during operation for 6 hours:
  mean: 6.75×10^{-5}
  variance: 1.20×10^{-8}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generator 32:
  mean: 2.55×10^{-2}
  variance: 9.28×10^{-5}

- Diesel Generator 33: No effect

- Diesel Generators 31 and 32:
  1.00

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Buses 3A and 6A with Diesel Generator 31 or Diesel Generator 32 inoperable yields:

  mean: 1.21×10^{-6}
  variance: 6.07×10^{-12}

TABLE 9.1-9 (continued)

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 3A and 6A

- From Section D.2, unavailability of two diesel generators due to testing errors:

mean: $Q_{TE2} = 2.03 \times 10^{-6}$
variance: 2.34×10^{-11}

Applying this to the conditional unavailability of power at Buses 3A and 6A with Diesel Generator 31 and Diesel Generator 32 inoperable yields:

mean: 2.03×10^{-6}
variance: 2.34×10^{-11}

- Testing contribution to unavailability (Q_T):

mean: 3.24×10^{-6}
variance: 1.84×10^{-11}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

mean: 1.09×10^{-2}
variance: 1.48×10^{-5}

Applying this to the conditional unavailability of power at Buses 3A and 6A with Diesel Generator 31 or Diesel Generator 32 inoperable yields:

Maintenance contribution to unavailability (Q_M):

mean: 5.24×10^{-4}
variance: 5.44×10^{-8}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.1, unavailability of Diesel Generators 31 and 32 due to fuel oil supply failure:

mean: 1.01×10^{-5}
variance: 1.58×10^{-10}

Applying this to the conditional unavailability of power at Buses 3A and 6A with Diesel Generators 31 and 32 inoperable yields:

Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):

mean: 1.01×10^{-5}
variance: 1.58×10^{-10}

TABLE 9.1-10

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 5A and 6A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 5.97×10^{-4}
  variance: 2.06×10^{-7}

- Unavailability on demand (at event initiation):
  mean: 3.38×10^{-4}
  variance: 6.22×10^{-8}

- Dominant failure contributors:

  Failure of Diesel Generators 31 and 33 to start on demand:
  mean: 2.46×10^{-4}
  variance: 4.13×10^{-8}

  Failue of Diesel Generators 32 and 33 during operation for 6 hours:
  mean: 6.75×10^{-5}
  variance: 1.20×10^{-8}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: No effect

- Diesel Generator 32:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generator 33:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generators 32 and 33:
  1.00

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Buses 5A and 6A with Diesel Generator 32 or Diesel Generator 33 inoperable yields:

  mean: 1.14×10^{-6}
  variance: 5.39×10^{-12}

TABLE 9.1-10 (continued)

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 5A and 6A

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at Buses 5A and 6A with Diesel Generator 32 and Diesel Generator 33 inoperable yields:
  mean: 2.03×10^{-6}
  variance: 2.34×10^{-11}

- Testing contribution to unavailability (Q_T):
  mean: 3.17×10^{-6}
  variance: 1.76×10^{-11}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:
  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Buses 5A and 6A with Diesel Generator 32 or Diesel Generator 33 inoperable yields:

  Maintenance contribution to unavailability (Q_M):
  mean: 4.93×10^{-4}
  variance: 4.89×10^{-8}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.1, unavailability of Diesel Generators 32 and 33 due to fuel oil supply failure:
  mean: 1.01×10^{-5}
  variance: 1.58×10^{-10}

  Applying this to the conditional unavailability of power at Buses 5A and 6A with Diesel Generators 32 and 33 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
  mean: 1.01×10^{-5}
  variance: 1.58×10^{-10}

TABLE 9.1-11

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 3A and 5A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 5.97×10^{-4}
  variance: 2.06×10^{-7}

- Unavailability on demand (at event initiation):
  mean: 3.38×10^{-4}
  variance: 6.22×10^{-8}

- Dominant failure contributors:

  Failure of Diesel Generators 31 and 33 to start on demand:
  mean: 2.46×10^{-4}
  variance: 4.13×10^{-8}

  Failure of Diesel Generators 31 and 33 during operation for 6 hours:
  mean: 6.75×10^{-5}
  variance: 1.20×10^{-8}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generator 32: No effect

- Diesel Generator 33:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generators 31 and 33:
  1.00

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Buses 2A, 3A and 5A with Diesel Generator 31 or Diesel Generator 33 inoperable yields:

  mean: 1.14×10^{-6}
  variance: 5.39×10^{-12}

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 3A and 5A

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at Buses 2A, 3A and 5A with Diesel Generator 31 and Diesel Generator 33 inoperable yields:

  mean: 2.03×10^{-6}
  variance: 2.34×10^{-11}

- Testing contribution to unavailability (Q_T):

  mean: 3.17×10^{-6}
  variance: 1.76×10^{-11}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Buses 2A, 3A and 5A with Diesel Generator 31 or Diesel Generator 33 inoperable yields:

  Maintenance contribution to unavailability (Q_M):

  mean: 4.93×10^{-4}
  variance: 4.89×10^{-8}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.1, unavailability of Diesel Generators 31 and 33 due to fuel oil supply failure:

  mean: 1.01×10^{-5}
  variance: 1.58×10^{-10}

  Applying this to the conditional unavailability of power at Buses 2A, 3A, and 5A with Diesel Generators 31 and 33 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):

  mean: 1.01×10^{-5}
  variance: 1.58×10^{-10}

TABLE 9.1-12

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 3A, and 6A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 5.97×10^{-4}
  variance: 2.06×10^{-7}

- Unavailability on demand (at event initiation):
  mean: 3.38×10^{-4}
  variance: 6.22×10^{-8}

- Dominant failure contributors:

  Failure of Diesel Generators 31 and 32 to start on demand:
  mean: 2.46×10^{-4}
  variance: 4.13×10^{-8}

  Failure of Diesel Generators 31 and 32 during operation for 6 hours:
  mean: 6.75×10^{-5}
  variance: 1.20×10^{-8}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generator 32:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generator 33: No effect

- Diesel Generators 31 and 32:
  1.00

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

Applying this to the conditional unavailability of power at Buses 2A, 3A, and 6A with Diesel Generator 31 or Diesel Generator 32 inoperable yields:

mean: 1.14×10^{-6}
variance: 5.39×10^{-12}

TABLE 9.1-12 (continued)

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 3A, and 6A

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at Buses 2A, 3A and 6A with Diesel Generator 31 and Diesel Generator 32 inoperable yields:
  mean: 2.03×10^{-6}
  variance: 2.34×10^{-11}

- Testing contribution to unavailability (Q_T):
  mean: 3.17×10^{-6}
  variance: 1.76×10^{-11}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:
  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Buses 2A, 3A and 6A with Diesel Generator 31 or Diesel Generator 32 inoperable yields:

  Maintenance contribution to unavailability (Q_M):
  mean: 4.93×10^{-4}
  variance: 4.89×10^{-8}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.1, unavailability of Diesel Generators 31 and 32 due to fuel oil supply failure:
  mean: 1.01×10^{-5}
  variance: 1.58×10^{-10}

  Applying this to the conditional unavailability of power at Buses 2A, 3A, and 6A with Diesel Generators 31 and 32 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
  mean: 1.01×10^{-5}
  variance: 1.58×10^{-10}

TABLE 9.1-13

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 5A and 6A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 1.76×10^{-5}
  variance: 3.91×10^{-10}

- Unavailability on demand (at event initiation):
  mean: 7.44×10^{-6}
  variance: 6.22×10^{-11}

- Dominant failure contributors:

  Failure of Diesel Generators 31, 32 and 33 to start on demand:
  mean: 4.78×10^{-6}
  variance: 3.06×10^{-11}

  Failure of Diesel Generators 31, 32 and 33 during operation for 6 hours:
  mean: 1.03×10^{-6}
  variance: 3.30×10^{-12}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31:
  mean: 5.97×10^{-4}
  variance: 2.06×10^{-7}

- Diesel Generator 32:
  mean: 5.97×10^{-4}
  variance: 2.06×10^{-7}

- Diesel Generator 33:
  mean: 5.97×10^{-4}
  variance: 2.06×10^{-7}

- Diesel Generators 31 and 32:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generators 31 and 33:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generators 32 and 33:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- All three diesel generators: 1.00

TABLE 9.1-13 (continued)

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 5A, and 6A

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:

  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Buses 2A, 5A and 6A with Diesel Generator 31, 32, or 33 inoperable yields:

  mean: 4.50×10^{-8}
  variance: 8.79×10^{-15}

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at Buses 2A, 5A and 6A with each combination of two diesel generators inoperable yields:

  mean: 1.38×10^{-7}
  variance: 5.59×10^{-14}

- From Secton D.2, unavailability of three diesel generators due to testing errors:

  mean: $Q_{TE3} = 1.63 \times 10^{-7}$
  variance: 2.02×10^{-13}

  Applying this to the conditional unavailability of power at Buses 2A, 5A, and 6A with al three diesel generators inoperable yields:

  mean: 1.63×10^{-7}
  variance: 2.02×10^{-13}

- Testing contribution to unavailability (Q_T):

  mean: 3.46×10^{-7}
  variance: 1.59×10^{-13}

TABLE 9.1-13 (continued)

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 5A, and 6A

Maintenance Contribution to Unavaila .lity

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Buses 2A, 5A, and 6A with Diesel Generator 31, 32, or 33 inoperable yields:

  Maintenance contribution to unavailability (Q_M):
  mean: 1.95×10^{-5}
  variance: 1.16×10^{-10}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.1, unavailability of Diesel Generators 31, 32 and 33 due to fuel oil supply failure:

  mean: 1.40×10^{-5}
  variance: 2.79×10^{-10}

  Applying this to the conditional unavailability of power at Buses 2A, 5A and 6A with all three diesel generators inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
  mean: 1.40×10^{-5}
  variance: 2.79×10^{-10}

TABLE 9.1-14

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 3A, 5A, and 6A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  - mean: 1.95×10^{-5}
  - variance: 4.62×10^{-10}
- Unavailability on demand (at event initiation):
  - mean: 8.56×10^{-6}
  - variance: 8.09×10^{-11}
- Dominant failure contributors:
  - Failure of Diesel Generators 31, 32, and 33 to start on demand:
    - mean: 4.78×10^{-6}
    - variance: 3.06×10^{-11}
  - Failure of Diesel Generators 31, 32, and 33 during operation for 6 hours:
    - mean: 1.03×10^{-6}
    - variance: 3.30×10^{-12}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31:
  - mean: 5.97×10^{-4}
  - variance: 2.06×10^{-7}
- Diesel Generator 32:
  - mean: 6.65×10^{-4}
  - variance: 2.43×10^{-7}
- Diesel Generator 33:
  - mean: 6.65×10^{-4}
  - variance: 2.43×10^{-7}
- Diesel Generators 31 and 32:
  - mean: 2.27×10^{-2}
  - variance: 7.89×10^{-5}
- Diesel Generators 31 and 33:
  - mean: 2.27×10^{-2}
  - variance: 7.89×10^{-5}
- Diesel Generators 32 and 33:
  - mean: 2.55×10^{-2}
  - variance: 9.28×10^{-5}
- All three diesel generators: 1.00

TABLE 9.1-14 (continued)

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 3A, 5A, and 6A

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:

  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Buses 3A, 5A, and 6A with Diesel Generator 31, 32, or 33 inoperable yields:

  mean: 4.84×10^{-8}
  variance: 1.01×10^{-14}

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at Buses 3A, 5A, and 6A with each combination of two diesel generators inoperable yields:

  mean: 1.44×10^{-7}
  variance: 6.05×10^{-14}

- From Section D.2, unavailability of three diesel generators due to testing errors:

  mean: $Q_{ET3} = 1.63 \times 10^{-7}$
  variance: 2.02×10^{-13}

  Applying this to the conditional unavailability of power at Buses 3A, 5A, and 6A with all three diesel generators inoperable yields:

  mean: 1.63×10^{-7}
  variance: 2.02×10^{-13}

- Testing contribution to unavailability (Q_T):

  mean: 3.55×10^{-7}
  variance: 1.67×10^{-13}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

TABLE 9.1-14 (continued)

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 3A, 5A, and 6A

Applying this to the conditional unavailability of power at Buses 3A, 5A, and 6A with Diesel Generator 31, 32, or 33 inoperable yields:

Maintenance contribution to unavailability (Q_M):
mean: 2.09×10^{-5}
variance: 1.32×10^{-10}

Diesel Fuel Oil Supply Contribution to Unavailability

From Section D.4.1, unavailability of Diesel Generators 31, 32, and 33 due to fuel oil supply failure:
mean: 1.40×10^{-5}
variance: 2.79×10^{-10}

Applying this to the conditional unavailability of power at Buses 3A, 5A, and 6A with all three diesel generators inoperable yields:

Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
mean: 1.40×10^{-5}
variance: 2.79×10^{-10}

TABLE 9.1-15

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at all 480V Switchgear Buses

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 1.76×10^{-5}
  variance: 3.91×10^{-10}

- Unavailability on demand (at event initiation):
  mean: 7.44×10^{-6}
  variance: 6.22×10^{-11}

- Dominant failure contributors:

  Failure of all three diesel generators to start on demand:
  mean: 4.78×10^{-6}
  variance: 3.06×10^{-11}

  Failure of all three diesel generators during operation for 6 hours:
  mean: 1.03×10^{-6}
  variance: 3.30×10^{-12}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31:
  mean: 5.97×10^{-4}
  variance: 2.06×10^{-7}

- Diesel Generator 32:
  mean: 5.97×10^{-4}
  variance: 2.06×10^{-7}

- Diesel Generator 33:
  mean: 5.97×10^{-4}
  variance: 2.06×10^{-7}

- Diesel Generators 31 and 32:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generators 31 and 33:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- Diesel Generators 32 and 33:
  mean: 2.27×10^{-2}
  variance: 7.89×10^{-5}

- All three diesel generators: 1.00

TABLE 9.1-15 (continued)

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at all 480V Switchgear Buses

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:

  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at all four buses with each of the diesel generators inoperable yields:

  mean: 4.50×10^{-8}
  variance: 8.79×10^{-15}

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at all four buses with each combination of two diesel generators inoperable yields:
  mean: 1.38×10^{-7}
  variance: 5.59×10^{-14}

- From Section D.2, unavailability of three diesel generators due to testing errors:

  mean: $Q_{ET3} = 1.63 \times 10^{-7}$
  variance: 2.02×10^{-13}

  Applying this to the conditional unavailability of power at all four buses with all three diesel generators inoperable yields:
  mean: 1.63×10^{-7}
  variance: 2.02×10^{-13}

- Testing contribution to unavailability (Q_T):
  mean: 3.46×10^{-7}
  variance: 1.59×10^{-13}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

TABLE 9.1-15 (continued)

Boundary Condition: Offsite Power Not Available
No Recovery from Failures
Study Period of 6 Hours

Failure State: Failure of Power at all 480V Switchgear Buses

Applying this to the conditional unavailability of power at all four buses with each of the diesel generators inoperable yields:

- Maintenance contribution to unavailability (Q_M):
  mean: 1.95×10^{-5}
  variance: 1.16×10^{-10}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.1, unavailability of Diesel Generators 31, 32, and 33 due to fuel oil supply failure:
  mean: 1.40×10^{-5}
  variance: 2.79×10^{-10}

Applying this to the conditional unavailability of power at all four buses with all three diesel generators inoperable yields:

- Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
  mean: 1.40×10^{-5}
  variance: 2.79×10^{-10}

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TABLE 9.2-1

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Bus 2A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 3.21×10^{-5}
  variance: 1.27×10^{-9}

- Unavailability on demand (at event initiation):
  mean: 2.48×10^{-5}
  variance: 9.25×10^{-10}

- Dominant failure contributors:

  Breaker UT2/ST5 fails to close on demand and diesel generator 31 fails to start on demand:
  mean: 1.92×10^{-5}
  variance: 5.46×10^{-10}

  Breaker UT2/ST5 fails to close on demand and diesel generator 31 fails during operation:
  mean: 7.37×10^{-6}
  variance: 1.95×10^{-10}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31:
  mean: 1.40×10^{-3}
  variance: 1.90×10^{-6}

- Diesel Generator 32: No effect

- Diesel Generator 33: No effect

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Bus 2A with Diesel Generator 31 inoperable yields:

  Testing contribution to unavailability (Q_T):
  mean: 3.51×10^{-8}
  variance: 6.83×10^{-15}

TABLE 9.2-1 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Bus 2A

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Bus 2A with Diesel Generator 31 inoperable yields:

  Maintenance contribution to unavailability (Q_M):
  mean: 1.52×10^{-5}
  variance: 2.25×10^{-10}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.2, unavailability of Diesel Generator 31 due to fuel oil supply failure:

  mean: 3.25×10^{-3}
  variance: 1.24×10^{-5}

  Applying this to the conditional unavailability of power at Bus 2A with Diesel Generator 31 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
  mean: 4.55×10^{-6}
  variance: 4.16×10^{-11}

TABLE 9.2-1

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Bus 3A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 1.40×10^{-3}
  variance: 1.90×10^{-6}

- Unavailability on demand (at event initiation):
  mean: 1.33×10^{-3}
  variance: 1.90×10^{-6}

- Dominant failure contributors:

  Breaker UT3/ST6 failure to close on demand
  mean: 1.33×10^{-3}
  variance: 5.57×10^{-6}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31:
  mean: 1.41×10^{-3}
  variance: 1.92×10^{-6}

- Diesel Generator 32: No effect

- Diesel Generator 33: No effect

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Bus 3A with Diesel Generator 31 inoperable yields:

  Testing contribution to unavailability (Q_T):
  mean: 3.54×10^{-8}
  variance: 6.92×10^{-15}

TABLE 9.2-2 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours

Failure State: Failure of Power at Bus 3A

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Bus 3A with Diesel Generator 31 inoperable yields:

  Maintenance contribution to unavailability (Q_M):
  mean: 1.53×10^{-5}
  variance: 2.27×10^{-10}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.2, unavailability of Diesel Generator 31 due to fuel oil supply failure:

  mean: 3.25×10^{-3}
  variance: 1.24×10^{-5}

  Applying this to the conditional unavailability of power at Bus 3A with Diesel Generator 31 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
  mean: 4.58×10^{-6}
  variance: 4.21×10^{-11}

TABLE 9.2-3

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Bus 5A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 1.52×10^{-6}
  variance: 7.69×10^{-13}

- Unavailability on demand (at event initiation): Bus 5A remains energized at event initiation.

- Dominant failure contributors:

  Failure of Bus 5A over 6 hours:
  mean: 1.95×10^{-7}
  variance: 6.56×10^{-14}

  Failure of one transformer over 6 hours and failure of Diesel Generator 33 to start on demand:
  mean: 7.25×10^{-8}
  variance: 6.76×10^{-15}

  One circuit breaker transfers open over 6 hours and Diesel Generator 33 fails to start on demand:
  mean: 2.31×10^{-7}
  variance: 2.95×10^{-14}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: No effect

- Diesel Generator 32: No effect

- Diesel Generator 33:
  mean: 5.85×10^{-5}
  variance: 8.02×10^{-10}

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

TABLE 9.2-3 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Bus 5A

Applying this to the conditional unavailability of power at Bus 5A with Diesel Generator 33 inoperable yields:

Testing contribution to unavailability (Q_T):
mean: 1.47×10^{-9}
variance: 9.71×10^{-18}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:
mean: 1.09×10^{-2}
variance: 1.48×10^{-5}

Applying this to the conditional unavailability of power at Bus 5A with Diesel Generator 33 inoperable yields:

Maintenance contribution to unavailability (Q_M):
mean: 6.36×10^{-7}
variance: 1.44×10^{-13}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.2, unavailability of Diesel Generator 33 due to fuel oil supply failure:
mean: 3.25×10^{-3}
variance: 1.24×10^{-5}

Applying this to the conditional unavailability of power at Bus 5A with Diesel Generator 33 inoperable yields:

Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
mean: 1.90×10^{-7}
variance: 4.53×10^{-14}

TABLE 9.2-4

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Bus 6A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 1.52×10^{-6}
  variance: 7.69×10^{-13}

- Unavailability on demand (at event initiation): Bus 6A remains energized at event initiation.

- Dominant failure contributors:

  Failure of Bus 6A over 6 hours:
  mean: 1.95×10^{-7}
  variance: 6.56×10^{-14}

  Failure of one transformer over 6 hours and failure of Diesel Generator 32 to start on demand:
  mean: 7.25×10^{-8}
  variance: 6.76×10^{-15}

  One circuit breaker transfers open over 6 hours and Diesel Generator 32 fails to start on demand:
  mean: 2.31×10^{-7}
  variance: 2.95×10^{-14}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: No effect

- Diesel Generator 32:
  mean: 5.85×10^{-5}
  variance: 8.02×10^{-10}

- Diesel Generator 33: No effect

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

TABLE 9.2-4 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Bus 6A

Applying this to the conditional unavailability of power at Bus 6A with Diesel Generator 32 inoperable yields:

Testing contribution to unavailability (Q_T):
mean: 1.47×10^{-9}
variance: 9.71×10^{-18}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:
  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

Applying this to the conditional unavailability of power at Bus 6A with Diesel Generator 32 inoperable yields:

Maintenance contribution to unavailability (Q_M):
mean: 6.36×10^{-7}
variance: 1.44×10^{-13}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.2, unavailability of Diesel Generator 32 due to fuel oil supply failure:
  mean: 3.25×10^{-3}
  variance: 1.24×10^{-5}

Applying this to the conditional unavailability of power at Bus 6A with Diesel Generator 32 inoperable yields:

Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
mean: 1.90×10^{-7}
variance: 4.53×10^{-14}

TABLE 9.2-5

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A and 3A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 2.03×10^{-7}
  variance: 4.02×10^{-14}

- Unavailability on demand (at event initiation):
  mean: 7.19×10^{-8}
  variance: 1.54×10^{-14}

- Dominant failure contributors:

  Failure of the station auxiliary transformer over 6 hours and failure of Diesel Generator 31 to start on demand:
  mean: 7.25×10^{-8}
  variance: 6.76×10^{-15}

  Breakers UT2/ST5 and UT3/ST6 fail to close and Diesel Generator 31 fails to start on demand:
  mean: 5.35×10^{-8}
  variance: 9.12×10^{-15}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31:
  mean: 8.94×10^{-6}
  variance: 6.01×10^{-11}

- Diesel Generator 32: No effect

- Diesel Generator 33: No effect

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

TABLE 9.2-5 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A and 3A

Applying this to the conditional unavailability of power at buses 2A and 3A with Diesel Generator 31 inoperable yields:

Testing contribution to unavailability (Q_T):
mean: 2.24×10^{-10}
variance: 2.66×10^{-19}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:
  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

Applying this to the conditional unavailability of power at Buses 2A and 3A with Diesel Generator 31 inoperable yields:

Maintenance contribution to unavailability (Q_M):
mean: 9.71×10^{-8}
variance: 7.60×10^{-15}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.2, unavailability of Diesel Generator 31 due to fuel oil supply failure:
  mean: 3.25×10^{-3}
  variance: 1.24×10^{-5}

Applying this to the conditional unavailability of power at Buses 2A and 3A with Diesel Generator 31 inoperable yields:

Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
mean: 2.91×10^{-8}
variance: 1.53×10^{-15}

TABLE 9.2-6

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A and 5A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 1.25×10^{-8}
  variance: 1.24×10^{-16}

- Unavailability on demand (at event initiation): Bus 5A remains energized at event initiation.

- Dominant failure contributors:

  Breaker ST5 transfers open and failure of Diesel Generators 31 and 33 to start on demand:
  mean: 3.94×10^{-9}
  variance: 1.87×10^{-17}

  Failure of the station auxiliary transformer over 6 hours and failure of Diesel Generators 31 and 33 to start on demand:
  mean: 1.24×10^{-9}
  variance: 3.44×10^{-18}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31:
  mean: 4.85×10^{-7}
  variance: 9.06×10^{-14}

- Diesel Generator 32: No effect

- Diesel Generator 33:
  mean: 4.85×10^{-7}
  variance: 9.06×10^{-14}

- Diesel Generators 31 and 33:
  mean: 2.13×10^{-5}
  variance: 1.03×10^{-10}

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:

  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Buses 2A and 5A with Diesel Generator 31 or Diesel Generator 33 inoperable yields:

  mean: 2.43×10^{-11}
  variance: 2.57×10^{-21}

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A and 5A

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at Buses 2A and 5A with Diesel Generator 31 and Diesel Generator 33 inoperable yields:

  mean: 4.32×10^{-11}
  variance: 6.03×10^{-21}

- Testing contribution to unavailability (Q_T):

  mean: 6.76×10^{-11}
  variance: 8.33×10^{-21}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Buses 2A and 5A with Diesel Generator 31 or Diesel Generator 33 inoperable yields:

  Maintenance contribution to unavailability (Q_M):

  mean: 1.05×10^{-8}
  variance: 3.46×10^{-17}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.2, unavailability of Diesel Generators 31 and 33 due to fuel oil supply failure:

  mean: 2.40×10^{-4}
  variance: 6.93×10^{-8}

  Applying this to the conditional unavailability of power at Buses 2A and 5A with Diesel Generators 31 and 33 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):

  mean: 5.11×10^{-9}
  variance: 3.30×10^{-17}

TABLE 9.2-7

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A and 6A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 3.01×10^{-9}
  variance: 1.62×10^{-17}

- Unavailability on demand (at event initiation): Bus 6A remains energized at event initiation.

- Dominant failure contributors:

  Failure of the station auxiliary transformer over 6 hours and failure of Diesel Generators 31 and 32 to start on demand:
  mean: 1.24×10^{-9}
  variance: 3.44×10^{-18}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: mean: 1.16×10^{-7}
  variance: 1.55×10^{-14}

- Diesel Generator 32: mean: 1.16×10^{-7}
  variance: 1.55×10^{-14}

- Diesel Generator 33: No effect

- Diesel Generators 31 and 32:
  mean: 5.11×10^{-6}
  variance: 2.30×10^{-11}

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Buses 2A and 6A with Diesel Generator 31 or Diesel Generator 32 inoperable yields:

  mean: 5.82×10^{-12}
  variance: 1.65×10^{-22}

TABLE 9.2-7 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A and 6A

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at Buses 2A and 6A with Diesel Generator 31 and Diesel Generator 32 inoperable yields:

  mean: 1.04×10^{-11}
  variance: 4.36×10^{-22}

- Testing contribution to unavailability (Q_T):

  mean: 1.62×10^{-11}
  variance: 5.81×10^{-22}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Buses 2A and 6A with Diesel Generator 31 or Diesel Generator 32 inoperable yields:

  Maintenance contribution to unavailability (Q_M):
  mean: 2.50×10^{-9}
  variance: 3.96×10^{-18}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.2, unavailability of Diesel Generators 31 and 32 due to fuel oil supply failure:

  mean: 2.40×10^{-4}
  variance: 6.93×10^{-8}

  Applying this to the conditional unavailability of power at Buses 2A and 6A with Diesel Generators 31 and 32 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
  mean: 1.23×10^{-9}
  variance: 2.95×10^{-18}

TABLE 9.2-8

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 3A and 5A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 4.39×10^{-9}
  variance: 1.70×10^{-17}

- Unavailability on demand (at event initiation): Bus 5A remains energized at event initiation.

- Dominant failure contributors:

  Failure of the station auxiliary transformer over 6 hours and failure of Diesel Generators 31 and 33 to start on demand:
  mean: 1.24×10^{-9}
  variance: 3.44×10^{-18}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: mean: 1.16×10^{-7}
  variance: 1.55×10^{-14}

- Diesel Generator 32: No effect

- Diesel Generator 33: mean: 1.81×10^{-7}
  variance: 2.43×10^{-14}

- Diesel Generators 31 and 33:
  mean: 5.11×10^{-6}
  variance: 2.31×10^{-11}

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Buses 3A and 5A with Diesel Generator 31 or Diesel Generator 33 inoperable yields:

  mean: 7.45×10^{-12}
  variance: 2.60×10^{-22}

TABLE 9.2-8 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 3A and 5A

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at Buses 3A and 5A with Diesel Generator 31 and Diesel Generator 33 inoperable yields:

  mean: 1.04×10^{-11}
  variance: 4.36×10^{-22}

- Testing contribution to unavailability (Q_T):

  mean: 1.78×10^{-11}
  variance: 6.59×10^{-22}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Buses 3A and 5A with Diesel Generator 31 or Diesel Generator 33 inoperable yields:

  Maintenance contribution to unavailability (Q_M):

  mean: 3.22×10^{-9}
  variance: 5.55×10^{-18}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.2, unavailability of Diesel Generators 31 and 33 due to fuel oil supply failure:

  mean: 2.40×10^{-4}
  variance: 6.93×10^{-8}

  Applying this to the conditional unavailability of power at Buses 3A and 5A with Diesel Generators 31 and 33 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):

  mean: 1.23×10^{-9}
  variance: 2.95×10^{-18}

TABLE 9.2-9

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 3A and 6A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 3.73×10^{-7}
  variance: 6.52×10^{-14}

- Unavailability on demand (at event initiation): Bus 6A remains energized at event initiation.

- Dominant failure contributors:

  Failure of breaker ST6 over 6 hours and failure of Diesel Generator 32 to start on demand:
  mean: 2.31×10^{-7}
  variance: 2.95×10^{-14}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: mean: 4.85×10^{-7}
  variance: 9.06×10^{-14}

- Diesel Generator 32: mean: 1.64×10^{-5}
  variance: 7.86×10^{-11}

- Diesel Generator 33: No effect

- Diesel Generators 31 and 32:
  mean: 2.13×10^{-5}
  variance: 1.03×10^{-10}

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Buses 3A and 6A with Diesel Generator 31 or Diesel Generator 32 inoperable yields:

  mean: 4.24×10^{-10}
  variance: 8.02×10^{-19}

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 3A and 6A

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at Buses 3A and 6A with Diesel Generator 31 and Diesel Generator 32 inoperable yields:

  mean: 4.32×10^{-11}
  variance: 6.03×10^{-21}

- Testing contribution to unavailability (Q_T):

  mean: 4.67×10^{-10}
  variance: 8.06×10^{-19}

<u>Maintenance Contribution to Unavailability</u>

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Buses 3A and 6A with Diesel Generator 31 or Diesel Generator 32 inoperable yields:

- Maintenance contribution to unavailability (Q_M):

  mean: 1.83×10^{-7}
  variance: 1.32×10^{-14}

<u>Diesel Fuel Oil Supply Contribution to Unavailability</u>

- From Section D.4.2, unavailability of Diesel Generators 31 and 32 due to fuel oil supply failure:

  mean: 2.40×10^{-4}
  variance: 6.93×10^{-8}

  Applying this to the conditional unavailability of power at Buses 3A and 6A with Diesel Generators 31 and 32 inoperable yields:

- Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):

  mean: 5.11×10^{-9}
  variance: 3.30×10^{-17}

TABLE 9.2-10

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 5A and 6A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 2.96×10^{-9}
  variance: 1.61×10^{-17}

- Unavailability on demand (at event initiation): Buses 5A and 6A remain energized at event initiation.

- Dominant failure contributors:

  Failure of the station auxiliary transformer over 6 hours and failure of Diesel Generators 32 and 33 to start on demand:
  mean: 1.24×10^{-9}
  variance: 3.44×10^{-18}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: No effect

- Diesel Generator 32: mean: 1.15×10^{-7}
  variance: 1.54×10^{-14}

- Diesel Generator 33: mean: 1.15×10^{-7}
  variance: 1.54×10^{-14}

- Diesel Generators 31 and 33:
  mean: 5.04×10^{-6}
  variance: 2.30×10^{-11}

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Buses 5A and 6A with Diesel Generator 32 or Diesel Generator 33 inoperable yields:
  mean: 5.82×10^{-12}
  variance: 1.65×10^{-22}

TABLE 9.2-10 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 5A and 6A

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at buses 5A and 6A with Diesel Generator 32 and Diesel Generator 33 inoperable yields:

  mean: 1.02×10^{-11}
  variance: 4.27×10^{-22}

- Testing contribution to unavailability (Q_T):

  mean: 1.61×10^{-11}
  variance: 5.72×10^{-22}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Buses 5A and 6A with Diesel Generator 32 or Diesel Generator 33 inoperable yields:

  Maintenance contribution to unavailability (Q_M):

  mean: 2.50×10^{-9}
  variance: 3.96×10^{-18}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.2, unavailability of Diesel Generators 32 and 33 due to fuel oil supply failure:

  mean: 2.40×10^{-4}
  variance: 6.93×10^{-8}

  Applying this to the conditional unavailability of power at Buses 5A and 6A with Diesel Generators 32 and 33 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):

  mean: 1.21×10^{-9}
  variance: 2.94×10^{-18}

TABLE 9.2-11

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 3A, and 5A

<u>Hardware Failure Contribution</u>

- Unavailability over 6 hours (Q_H):
  mean: 2.97×10^{-9}
  variance: 1.59×10^{-17}

- Unavailability on demand (at event initiation): Bus 5A remains energized at event initiation.

- Dominant failure contributors:

  Failure of the station auxiliary transformer over 6 hours and failure of Diesel Generators 31 and 33 to start on demand:
  mean: 1.24×10^{-9}
  variance: 3.44×10^{-18}

<u>Conditional Unavailability With Diesel Generators Inoperable</u>

- Diesel Generator 31: mean: 1.15×10^{-7}
  variance: 1.54×10^{-14}

- Diesel Generator 32: No effect

- Diesel Generator 33: mean: 1.15×10^{-7}
  variance: 1.54×10^{-14}

- Diesel Generators 31 and 33:
  mean: 5.06×10^{-6}
  variance: 2.29×10^{-11}

<u>Testing Contribution to Unavailability</u>

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 3A, and 5A

Applying this to the conditional unavailability of power at Buses 2A, 3A, and 5A with Diesel Generator 31 or Diesel Generator 33 inoperable yields:

mean: 5.82×10^{-12}
variance: 1.65×10^{-22}

- From Section D.2, unavailability of two diesel generators due to testing errors:

mean: $Q_{TE2} = 2.03 \times 10^{-6}$
variance: 2.34×10^{-11}

Applying this to the conditional unavailability of power at Buses 2A, 3A, and 5A with Diesel Generator 31 and Diesel Generator 33 inoperable yields:

mean: 1.03×10^{-11}
variance: 4.29×10^{-22}

- Testing contribution to unavailability (Q_T):

mean: 1.61×10^{-11}
variance: 5.74×10^{-22}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

mean: 1.09×10^{-2}
variance: 1.48×10^{-5}

Applying this to the conditional unavailability of power at Buses 2A, 3A, and 5A with Diesel Generator 31 or Diesel Generator 33 inoperable yields:

Maintenance contribution to unavailability (Q_M):

mean: 2.50×10^{-9}
variance: 3.96×10^{-18}

TABLE 9.2-11 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 3A, and 5A

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.2, unavailability of Diesel Generators 31 and 33 due to fuel oil supply failure:

  mean: 2.40×10^{-4}
  variance: 6.93×10^{-8}

  Applying this to the conditional unavailability of power at Buses 2A, 3A, and 5A with Diesel Generators 31 and 33 inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):

  mean: 1.21×10^{-9}
  variance: 2.91×10^{-18}

TABLE 9.2-12

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 3A, and 6A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 2.97×10^{-9}
  variance: 1.59×10^{-17}

- Unavailability on demand (at event initiation): Bus 6A remains energized at event initiation.

- Dominant failure contributors:

  Failure of the station auxiliary transformer over 6 hours and failure of Diesel Generators 31 and 32 to start on demand:
  mean: 1.24×10^{-9}
  variance: 3.44×10^{-18}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: mean: 1.15×10^{-7}
  variance: 1.54×10^{-14}

- Diesel Generator 32: mean: 1.15×10^{-7}
  variance: 1.54×10^{-14}

- Diesel Generator 33: No effect

- Diesel Generators 31 and 32:
  mean: 5.06×10^{-6}
  variance: 2.29×10^{-11}

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:
  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

TABLE 9.2-12 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 3A, and 6A

Applying this to the conditional unavailability of power at Buses 2A, 3A, and 6A with Diesel Generator 31 or Diesel Generator 32 inoperable yields:

mean: 5.82×10^{-12}
variance: 1.65×10^{-22}

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

Applying this to the conditional unavailability of power at Buses 2A, 3A, and 6A with Diesel Generator 31 and Diesel Generator 32 inoperable yields:

mean: 1.03×10^{-11}
variance: 4.29×10^{-22}

- Testing contribution to unavailability (Q_T):

  mean: 1.61×10^{-11}
  variance: 5.74×10^{-22}

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

Applying this to the conditional unavailability of power at Buses 2A, 3A, and 6A with Diesel Generator 31 or Diesel Generator 32 inoperable yields:

Maintenance contribution to unavailability (Q_M):
mean: 2.50×10^{-9}
variance: 3.96×10^{-18}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.2, unavailability of Diesel Generators 31 and 32 due to fuel oil supply failure:

  mean: 2.40×10^{-4}
  variance: 6.93×10^{-8}

TABLE 9.2-12 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 3A, and 6A

Applying this to the conditional unavailability of power at Buses 2A, 3A, and 6A with Diesel Generators 31 and 32 inoperable yields:

Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):

mean: 1.21×10^{-9}
variance: 2.91×10^{-18}

TABLE 9.2-13

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 5A, and 6A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 8.42×10^{-11}
  variance: 1.89×10^{-20}

- Unavailability on demand (at event initiation): Buses 5A and 6A remain energized at event initiation.

- Dominant failure contributors:

  The station auxiliary transformer fails over 6 hours and all three diesel generators fail to start on demand:
  mean: 2.41×10^{-11}
  variance: 2.03×10^{-21}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: mean: 2.96×10^{-9}
  variance: 1.59×10^{-17}

- Diesel Generator 32: mean: 2.96×10^{-9}
  variance: 1.59×10^{-17}

- Diesel Generator 33: mean: 2.96×10^{-9}
  variance: 1.59×10^{-17}

- Diesel Generators 31 and 32:
  mean: 1.14×10^{-7}
  variance: 1.54×10^{-14}

- Diesel Generators 31 and 33:
  mean: 1.14×10^{-7}
  variance: 1.54×10^{-14}

- Diesel Generators 32 and 33:
  mean: 1.14×10^{-7}
  variance: 1.54×10^{-14}

- All three diesel generators:
  mean: 5.04×10^{-6}
  variance: 2.29×10^{-11}

TABLE 9.2-13 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 5A, and 6A

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:

  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Buses 2A, 5A, and 6A with Diesel Generator 31, 32, or 33 inoperable yields:

  mean: 2.23×10^{-13}
  variance: 2.40×10^{-25}

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at Buses 2A, 5A, and 6A with each combination of two diesel generators inoperable yields:

  mean: 7.06×10^{-13}
  variance: 1.67×10^{-24}

- From Section D.2, unavailability of three diesel generators due to testing errors:

  mean: $Q_{TE3} = 1.63 \times 10^{-7}$
  variance: 2.02×10^{-13}

  Applying this to the conditional unavailability of power at Buses 2A, 5A, and 6A with all three diesel generators inoperable yields:

  mean: 8.22×10^{-13}
  variance: 3.16×10^{-24}

- Testing contribution to unavailability (Q_T):

  mean: 1.75×10^{-12}
  variance: 4.89×10^{-24}

TABLE 9.2-13 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 2A, 5A, and 6A

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:
  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Buses 2A, 5A, and 6A with Diesel Generator 31, 32, or 33 inoperable yields:

  Maintenance contribution to unavailability (Q_M):
  mean: 9.65×10^{-11}
  variance: 5.78×10^{-21}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.2, unavailability of Diesel Generators 31, 32, and 33 due to fuel oil supply failure:
  mean: 1.40×10^{-5}
  variance: 2.79×10^{-10}

  Applying this to the conditional unavailability of power at Buses 2A, 5A, and 6A with all three diesel generators inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
  mean: 7.06×10^{-11}
  variance: 1.07×10^{-20}

TABLE 9.2-14

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 3A, 5A, and 6A

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 8.42×10^{-11}
  variance: 1.89×10^{-20}

- Unavailability on demand (at event initiation): Buses 5A and 6A remain energized at event initiation.

- Dominant failure contributors:

  The station auxiliary transformer fails over 6 hours and all three diesel generators fail to start on demand:
  mean: 2.41×10^{-11}
  variance: 2.03×10^{-21}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: mean: 2.96×10^{-9}
  variance: 1.59×10^{-17}

- Diesel Generator 32: mean: 2.96×10^{-9}
  variance: 1.59×10^{-17}

- Diesel Generator 33: mean: 2.96×10^{-9}
  variance: 1.59×10^{-17}

- Diesel Generators 31 and 32:
  mean: 1.14×10^{-7}
  variance: 1.54×10^{-14}

- Diesel Generators 31 and 33:
  mean: 1.14×10^{-7}
  variance: 1.54×10^{-14}

- Diesel Generators 32 and 33:
  mean: 1.29×10^{-7}
  variance: 1.91×10^{-14}

- All three diesel generators:
  mean: 5.03×10^{-6}
  variance: 2.29×10^{-11}

TABLE 9.2-14 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours

Failure State: Failure of Power at Buses 3A, 5A, and 6A

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:

  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at Buses 3A, 5A, and 6A with Diesel Generator 31, 32, or 33 inoperable yields:

  mean: 2.23×10^{-13}
  variance: 2.40×10^{-25}

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at Buses 3A, 5A, and 6A with each combination of two diesel generators inoperable yields:
  mean: 7.33×10^{-13}
  variance: 1.82×10^{-24}

- From Section D.2, unavailability of three diesel generators due to testing errors:

  mean: $Q_{TE3} = 1.63 \times 10^{-7}$
  variance: 2.02×10^{-13}

  Applying this to the conditional unavailability of power at Buses 3A, 5A, and 6A with all diesel generators inoperable yields:
  mean: 8.22×10^{-13}
  variance: 3.16×10^{-24}

- Testing contribution to unavailability (Q_T):
  mean: 1.78×10^{-12}
  variance: 4.99×10^{-24}

TABLE 9.2-14 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at Buses 3A, 5A, and 6A

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

  Applying this to the conditional unavailability of power at Buses 3A, 5A, and 6A with Diesel Generator 31, 32, or 33 inoperable yields:

  Maintenance contribution to unavailability (Q_M):
  mean: 9.65×10^{-11}
  variance: 5.78×10^{-21}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.2, unavailability of Diesel Generators 31, 32, and 33 due to fuel oil supply failure:

  mean: 1.40×10^{-5}
  variance: 2.79×10^{-10}

  Applying this to the conditional unavailability of power at Buses 3A, 5A, and 6A with all three diesel generators inoperable yields:

  Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
  mean: 7.04×10^{-11}
  variance: 1.07×10^{-20}

TABLE 9.2-15

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at all 480V Switchgear Buses

Hardware Failure Contribution

- Unavailability over 6 hours (Q_H):
  mean: 8.42×10^{-11}
  variance: 1.89×10^{-20}

- Unavailability on demand (at event initiation): Buses 5A and 6A remain energized at event initiation.

- Dominant failure contributors:

  The station auxiliary transformer fails over 6 hours and all three diesel generators fail to start on demand:
  mean: 2.41×10^{-11}
  variance: 2.03×10^{-21}

Conditional Unavailability With Diesel Generators Inoperable

- Diesel Generator 31: mean: 2.96×10^{-9}
  variance: 1.59×10^{-17}

- Diesel Generator 32: mean: 2.96×10^{-9}
  variance: 1.59×10^{-17}

- Diesel Generator 33: mean: 2.96×10^{-9}
  variance: 1.59×10^{-17}

- Diesel Generators 31 and 32:
  mean: 1.14×10^{-7}
  variance: 1.53×10^{-14}

- Diesel Generators 31 and 33:
  mean: 1.14×10^{-7}
  variance: 1.53×10^{-14}

- Diesel Generators 32 and 33:
  mean: 1.14×10^{-7}
  variance: 1.53×10^{-14}

- All three diesel generators:
  mean: 5.03×10^{-6}
  variance: 2.29×10^{-11}

TABLE 9.2-15

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at all 480V Switchgear Buses

Testing Contribution to Unavailability

- From Section D.2, unavailability of one diesel generator due to testing errors:

  mean: $Q_{TE1} = 2.51 \times 10^{-5}$
  variance: 7.20×10^{-9}

  Applying this to the conditional unavailability of power at all four buses with Diesel Generator 31, 32, or 33 inoperable yields:

  mean: 2.23×10^{-13}
  variance: 2.40×10^{-25}

- From Section D.2, unavailability of two diesel generators due to testing errors:

  mean: $Q_{TE2} = 2.03 \times 10^{-6}$
  variance: 2.34×10^{-11}

  Applying this to the conditional unavailability of power at all four buses with each combination of two diesel generators inoperable yields:

  mean: 7.06×10^{-13}
  variance: 1.67×10^{-24}

- From Section D.2, unavailability of three diesel generators due to testing errors:

  mean: $Q_{TE3} = 1.63 \times 10^{-7}$
  variance: 2.02×10^{-13}

  Applying this to the conditional unavailability of power at all four buses with all diesel generators inoperable yields:

  mean: 8.22×10^{-13}
  variance: 3.16×10^{-24}

- Testing contribution to unavailability (Q_T):

  mean: 1.75×10^{-12}
  variance: 4.89×10^{-24}

TABLE 9.2-15 (continued)

Boundary Condition: Offsite Power Available
No Recovery from Failures
Study Period of 6 Hours
Failure State: Failure of Power at all 480V Switchgear Buses

Maintenance Contribution to Unavailability

- From Section D.3, unavailability of any diesel generator due to maintenance:

  mean: 1.09×10^{-2}
  variance: 1.48×10^{-5}

Applying this to the conditional unavailability of power at all four buses with each of the diesel generators inoperable yields:

Maintenance contribution to unavailability (Q_M):
mean: 9.65×10^{-11}
variance: 5.78×10^{-21}

Diesel Fuel Oil Supply Contribution to Unavailability

- From Section D.4.2, unavailability of Diesel Generators 31, 32, and 33 due to fuel oil supply failure:

  mean: 1.40×10^{-5}
  variance: 2.79×10^{-10}

Applying this to the conditional unavailability of power at all four buses with all three diesel generators inoperable yields:

Diesel fuel oil supply failure contribution to unavailability (Q_{FS}):
mean: 7.04×10^{-11}
variance: 1.07×10^{-20}

TABLE 10.1

INDIAN POINT UNIT 3 ELECTRIC POWER SYSTEM NONMUTUALLY-EXCLUSIVE FAILURE STATES

Boundary Conditions: Offsite Power Not Available
No Recovery From Failures
Study Period of 6 Hours

						Common Cause			Total				
State	Failure of Power At Bus(es)	Hardware Failures	Testing	Mainte-nance	Fuel Oil Supply	Diesel Fires	Human Error	Other	Mean	Median	Variance	5th Percentile	95th Percentile
2	2A	2.27-2*	2.51-5	1.09-2	5.49-6	1.82-4	4.50-4	1.57-6	3.40-2	3.33-2	7.14-5	2.14-2	4.70-2
3	3A	2.55-2	2.51-5	1.09-2	5.49-6	1.82-4	4.50-4	1.57-6	3.60-2	3.60-2	8.24-5	2.32-2	5.08-2
4	5A	2.27-2	2.51-5	1.09-2	5.49-6	1.82-4	4.50-4	1.57-6	3.40-2	3.33-2	7.14-5	2.14-2	4.70-2
5	6A	2.27-2	2.51-5	1.09-2	5.49-6	1.82-4	4.50-4	1.57-6	3.40-2	3.33-2	7.14-5	2.14-2	4.70-2
6	2A and 3A	2.27-2	2.51-5	1.09-2	5.49-6	1.82-4	4.50-4	1.57-6	3.40-2	3.33-2	7.14-5	2.14-2	4.70-2
7	2A and 5A	5.97-4	3.17-6	4.93-4	1.01-5	8.26-6	5.69-5	9.09-7	1.17-3	1.07-3	1.73-7	5.87-4	1.83-3
8	2A and 6A	5.97-4	3.17-6	4.93-4	1.01-5	8.26-6	5.69-5	9.09-7	1.17-3	1.07-3	[illegible]	5.87-4	1.83-3
9	3A and 5A	6.65-4	3.24-6	5.24-4	1.01-5	8.77-6	5.82-5	9.29-7	1.27-3	1.17-3	2.03-7	6.39-4	1.99-3
10	3A and 6A	6.65-4	3.24-6	5.24-4	1.01-5	8.77-6	5.82-5	9.29-7	1.27-3	1.17-3	2.03-7	6.39-4	1.99-3
11	5A and 6A	5.97-4	3.17-6	4.93-4	1.01-5	8.26-4	5.69-5	9.09-7	1.17-3	1.07-3	1.73-7	5.87-4	1.83-3
12	2A, 3A, and 5A	5.97-4	3.17-6	4.93-4	1.01-5	8.26-6	5.69-5	9.09-7	1.17-3	1.07-3	1.73-7	5.87-4	1.83-3
13	2A, 3A, and 6A	5.97-4	3.17-6	4.93-4	1.01-5	8.26-6	5.69-5	9.09-7	1.17-3	1.07-3	1.73-7	5.87-4	1.83-3
14	2A, 5A, and 6A	1.76-5	3.46-7	1.95-5	1.40-5	3.26-7	6.24-6	9.34-8	5.81-5	5.65-5	4.48-10	2.86-5	9.18-5
15	3A, 5A, and 6A	1.95-5	3.55-7	2.09-5	1.40-5	3.51-7	6.41-6	1.01-7	6.16-5	6.03-5	5.01-10	3.05-5	9.73-5
16	2A, 3A, 5A, and 6A	1.76-5	3.46-7	1.95-5	1.40-5	3.26-7	6.24-6	9.34-8	5.81-5	5.65-5	4.48-10	2.86-5	9.18-5

*2.27×10^{-2}

TABLE 10.2

INDIAN POINT UNIT 3 ELECTRIC POWER SYSTEM NONMUTUALLY-EXCLUSIVE FAILURE STATES

Boundary Conditions: Offsite Power Available
No Recovery From Failures
Study Period of 6 Hours

<table>
<tr><th rowspan="2">State</th><th rowspan="2">Failure of Power At Bus(es)</th><th rowspan="2">Hardware Failures</th><th rowspan="2">Testing</th><th rowspan="2">Mainte-nance</th><th rowspan="2">Fuel Oil Supply</th><th colspan="3">Common Cause</th><th colspan="5">Total</th></tr>
<tr><th>Diesel Fires</th><th>Human Error</th><th>Other</th><th>Mean</th><th>Median</th><th>Variance</th><th>5th Percentile</th><th>95th Percentile</th></tr>
<tr><td>2</td><td>2A</td><td>3.21-5*</td><td>3.51-8</td><td>1.52-5</td><td>4.55-6</td><td>2.55-7</td><td>6.30-7</td><td>1.01-8</td><td>5.28-5</td><td>4.23-5</td><td>8.16-10</td><td>1.82-5</td><td>9.98-5</td></tr>
<tr><td>3</td><td>3A</td><td>1.40-3</td><td>3.54-8</td><td>1.53-5</td><td>4.58-6</td><td>2.57-7</td><td>6.35-7</td><td>1.02-8</td><td>1.42-3</td><td>1.18-3</td><td>1.07-6</td><td>3.09-4</td><td>3.21-3</td></tr>
<tr><td>4</td><td>5A</td><td>1.52-6</td><td>1.47-9</td><td>6.36-7</td><td>1.90-7</td><td>1.06-8</td><td>2.63-8</td><td>4.21-10</td><td>2.38-6</td><td>2.21-6</td><td>6.78-13</td><td>1.25-6</td><td>3.76-6</td></tr>
<tr><td>5</td><td>6A</td><td>1.52-6</td><td>1.47-9</td><td>6.36-7</td><td>1.90-7</td><td>1.06-8</td><td>2.63-8</td><td>4.21-10</td><td>2.38-6</td><td>2.21-6</td><td>6.78-13</td><td>1.25-6</td><td>3.76-6</td></tr>
<tr><td>6</td><td>2A and 3A</td><td>2.03-7</td><td>2.24-10</td><td>9.71-8</td><td>2.91-8</td><td>1.63-9</td><td>4.02-9</td><td>6.47-11</td><td>3.35-7</td><td>2.78-7</td><td>2.82-14</td><td>1.27-7</td><td>6.10[illegible]</td></tr>
<tr><td>7</td><td>2A and 5A</td><td>1.25-8</td><td>6.76-11</td><td>1.05-8</td><td>5.11-9</td><td>1.77-10</td><td>1.21-9</td><td>1.94-11</td><td>2.96-8</td><td>2.73-8</td><td>1.18-16</td><td>1.45-8</td><td>4.80-8</td></tr>
<tr><td>8</td><td>2A and 6A</td><td>3.01-9</td><td>1.62-11</td><td>2.50-9</td><td>1.23-9</td><td>4.19-11</td><td>2.91-10</td><td>4.64-12</td><td>7.09-9</td><td>6.30-9</td><td>1.[illegible]-17</td><td>2.73-9</td><td>1.28-8</td></tr>
<tr><td>9</td><td>3A and 5A</td><td>4.39-9</td><td>1.78-11</td><td>3.22-9</td><td>1.23-9</td><td>5.39-11</td><td>3.20-10</td><td>5.10-12</td><td>9.24-9</td><td>8.26-9</td><td>1.50-17</td><td>3.91-9</td><td>1.55-8</td></tr>
<tr><td>10</td><td>3A and 6A</td><td>3.73-7</td><td>4.67-10</td><td>1.83-7</td><td>5.11-9</td><td>3.07-9</td><td>8.38-9</td><td>1.34-10</td><td>5.73-7</td><td>5.24-7</td><td>5.36-14</td><td>2.60-7</td><td>9.35-7</td></tr>
<tr><td>11</td><td>5A and 6A</td><td>2.96-9</td><td>1.61-11</td><td>2.50-9</td><td>1.21-9</td><td>4.19-11</td><td>2.88-10</td><td>4.61-12</td><td>7.02-9</td><td>6.23-9</td><td>1.11-17</td><td>2.80-9</td><td>1.26-8</td></tr>
<tr><td>12</td><td>2A, 3A, and 5A</td><td>2.97-9</td><td>1.61-11</td><td>2.50-9</td><td>1.21-9</td><td>4.19-11</td><td>2.89-10</td><td>4.61-12</td><td>7.03-9</td><td>6.25-9</td><td>1.10-17</td><td>2.79-9</td><td>1.26-8</td></tr>
<tr><td>13</td><td>2A, 3A, and 6A</td><td>2.97-9</td><td>1.61-11</td><td>2.50-9</td><td>1.21-9</td><td>4.19-11</td><td>2.89-10</td><td>4.61-12</td><td>7.03-9</td><td>6.25-9</td><td>1.10-17</td><td>2.79-9</td><td>1.26-8</td></tr>
<tr><td>14</td><td>2A, 5A, and 6A</td><td>8.42-11</td><td>1.75-12</td><td>9.65-11</td><td>7.06-11</td><td>1.62-12</td><td>3.16-11</td><td>4.64-13</td><td>2.87-10</td><td>2.81-10</td><td>1.59-20</td><td>1.17-10</td><td>5.00-10</td></tr>
<tr><td>15</td><td>3A, 5A, and 6A</td><td>8.42-11</td><td>1.78-12</td><td>9.65-11</td><td>7.04-11</td><td>1.61-12</td><td>3.20-11</td><td>4.61-13</td><td>2.87-10</td><td>2.81-10</td><td>1.59-20</td><td>1.17-10</td><td>4.93-10</td></tr>
<tr><td>16</td><td>2A, 3A, 5A, and 6A</td><td>8.42-11</td><td>1.75-12</td><td>9.66-11</td><td>7.04-11</td><td>1.62-12</td><td>3.16-11</td><td>4.64-13</td><td>2.87-10</td><td>2.81-10</td><td>1.59-20</td><td>1.17-10</td><td>4.99-10</td></tr>
</table>

*3.21 × 10^{-5}

TABLE 11.1

ELECTRIC POWER RECOVERY ACTIONS, OFFSITE POWER NOT AVAILABLE

Failure of Power at Bus(es)	Primary Recovery Action	Estimated Action Time*	Secondary Recovery Action	Estimated Action Time*
2A	Note: This failure state is undefined for this boundary condition			
3A	Replace failed breaker 2AT3A with spare breaker	20 - 30 minutes	Shed loads and crosstie Buses 3A and 6A	20 - 30 minutes
5A	Locally start Diesel Generator 33	20 - 30 minutes	Shed loads and crosstie Buses 2A and 5A	20 - 30 minutes
6A	Locally start Diesel Generator 32	20 - 30 minutes	Shed loads and crosstie Buses 3A and 6A	20 - 30 minutes
2A and 3A	Locally start Diesel Generator 31	20 - 30 minutes	Shed loads and crosstie Buses 2A and 5A, 3A and 6A	20 - 30 minutes
2A and 5A	Note: This failure state is undefined for this boundary condition			
2A and 6A	Note: This failure state is undefined for this boundary condition			
3A and 5A	Locally start Diesel Generator 33; Replace failed breaker 2AT3A with spare	20 - 30 minutes; 20 - 30 minutes	Shed loads and crosstie Buses 2A and 5A, 3A and 6A	20 - 30 minutes
3A and 6A	Locally start Diesel Generator 32; Replace failed breaker 2AT3A with spare	20 - 30 minutes; 20 - 30 minutes	Repair Diesel Generator 32	2 - 24 hours
5A and 6A	Locally start Diesel Generators 32 and 33	30 - 40 minutes	Shed loads and crosstie one bus; Repair failed Diesel Generator	20 - 30 minutes; 2 - 24 hours
2A, 3A, and 5A	Locally start Diesel Generators 31 and 33	30 - 40 minutes	Crosstie Buses 3A and 6A; Repair Diesel Generator 33	20 - 30 minutes 2 - 24 hours
2A, 3A, and 6A	Locally start Diesel Generators 31 and 32	30 - 40 minutes	Crosstie Buses 2A and 5A; Repair Diesel Generator 32	20 - 30 minutes; 2 - 24 hours
2A, 5A, and 6A	Note: This failure state is undefined for this boundary condition			
3A, 5A, and 6A	Locally start Diesel Generators 32 and 33; Replace failed breaker 2AT3A with spare	30 - 40 minutes; 20 - 30 minutes	Crosstie Buses 2A and 5A; Repair Diesel Generator 32	20 - 30 minutes; 2 - 24 hours
All Buses	Locally start all Diesel Generators	50 - 60 minutes	Repair at least one Diesel Generator	2 - 24 hours

*This is not an estimate of total operator response time, which depends upon the precise event scenario. Rather, it is an estimate of time required to effect the given action once that action has been identified as appropriate (i.e., it is approximately equal to total response time minus recognition and evaluation time).

TABLE 11.2

ELECTRIC POWER RECOVERY ACTIONS, OFFSITE POWER AVAILABLE

Failure of Power at Bus(es)	Primary Recovery Action	Estimated Action Time*	Secondary Recovery Action	Estimated Action Time*
2A	Attempt to close breaker UT2/ST5 from control room switch	2 minutes	Close breaker 2AT3A from local switch	10 - 15 minutes
3A	Attempt to close breaker UT3/ST6 from control room switch	2 minutes	Close breaker 2AT3A from local switch	10 - 15 minutes
5A	Locally start diesel generator 33	20 - 30 minutes	Crosstie buses 2A and 5A	10 - 15 minutes
6A	Locally start diesel generator 32	20 - 30 minutes	Crosstie buses 3A and 6A	10 - 15 minutes
2A and 3A	Locally start diesel generator 31	20 - 30 minutes	Crosstie buses 2A and 5A, buses 3A and 6A	15 - 20 minutes
2A and 5A	Replace failed breaker ST5 with spare	20 - 30 minutes	Crosstie buses 2A and 3A; locally start diesel generator 33	10 - 15 minutes 20 - 30 minutes
2A and 6A	Attempt to close breaker UT2/ST5 from control room switch	2 minutes	Crosstie buses 2A and 5A, buses 3A and 6A	15 - 20 minutes
3A and 5A	Attempt to close breaker UT3/ST6 from control room switch	2 minutes	Crosstie buses 3A and 6A, buses 5A and 2A	15 - 20 minutes
3A and 6A	Replace failed breaker ST6 with spare	20 - 30 minutes	Crosstie buses 2A and 3A; locally start diesel generator 32	10 - 15 minutes 20 - 30 minutes
5A and 6A	Crosstie buses 2A and 5A, buses 3A and 6A	15 - 20 minutes	Locally start diesel generators 32 and 33	40 - 50 minutes
2A, 3A, and 5A	Crosstie buses 3A and 6A	10 - 15 minutes	Locally start diesel generators 31 and 33	40 - 50 minutes
2A, 3A, and 6A	Crosstie buses 2A and 5A	10 - 15 minutes	Locally start diesel generators 31 and 32	40 - 50 minutes
2A, 5A, and 6A	Crosstie buses 3A and 6A	10 - 15 minutes	Locally start diesel generators 31 and 33	40 - 50 minutes
3A, 5A, and 6A	Crosstie buses 2A and 5A	10 - 15 minutes	Locally start diesel generators 31 and 32	40 - 50 minutes
All buses	Locally start all diesel generators	50 - 60 minutes	Reclose normal supply breakers from available sources Repair station auxiliary transformer	10 - 15 minutes 4 - 48 hours

*This is not an estimate of total operator response time which depends upon the precise event scenario. Rather it is an estimate of the time required to effect the given action once that action has been identified as appropriate (i.e., it is approximately equal to total response time minus recognition and evaluation time).

TABLE 12

OFFSITE POWER RECOVERY ACTIONS

Recovery Action	Estimated Action Time*
Energize 6.9 kV buses 5 and 6 from Buchanan 13.8 kV supply (if available)	5 - 10 minutes
Reset transfer trips and sectionalizing relays to reenergize Buchanan 138 kV or 13.8 kV supply from an available feecer	10 - 20 minutes
Start Gas Turbine Generator Unit #1	30 - 60 minutes
Start Gas Turbine Generator Units at Buchanan Substation	30 - 60 minutes
Repair at least one 138 kV or 13.8 kV feeder to the station	2 - 24 hours
Provide auxilary portable generation equipment to the station	24 - 72 hours

*This is not an estimate of total response time, which depends upon the precise event scenario. Rather, it is an estimate of the time required to effect the given action once that action has been identified as appropriate (i.e., it is approximately equal to total response time minus recognition and evaluation time).

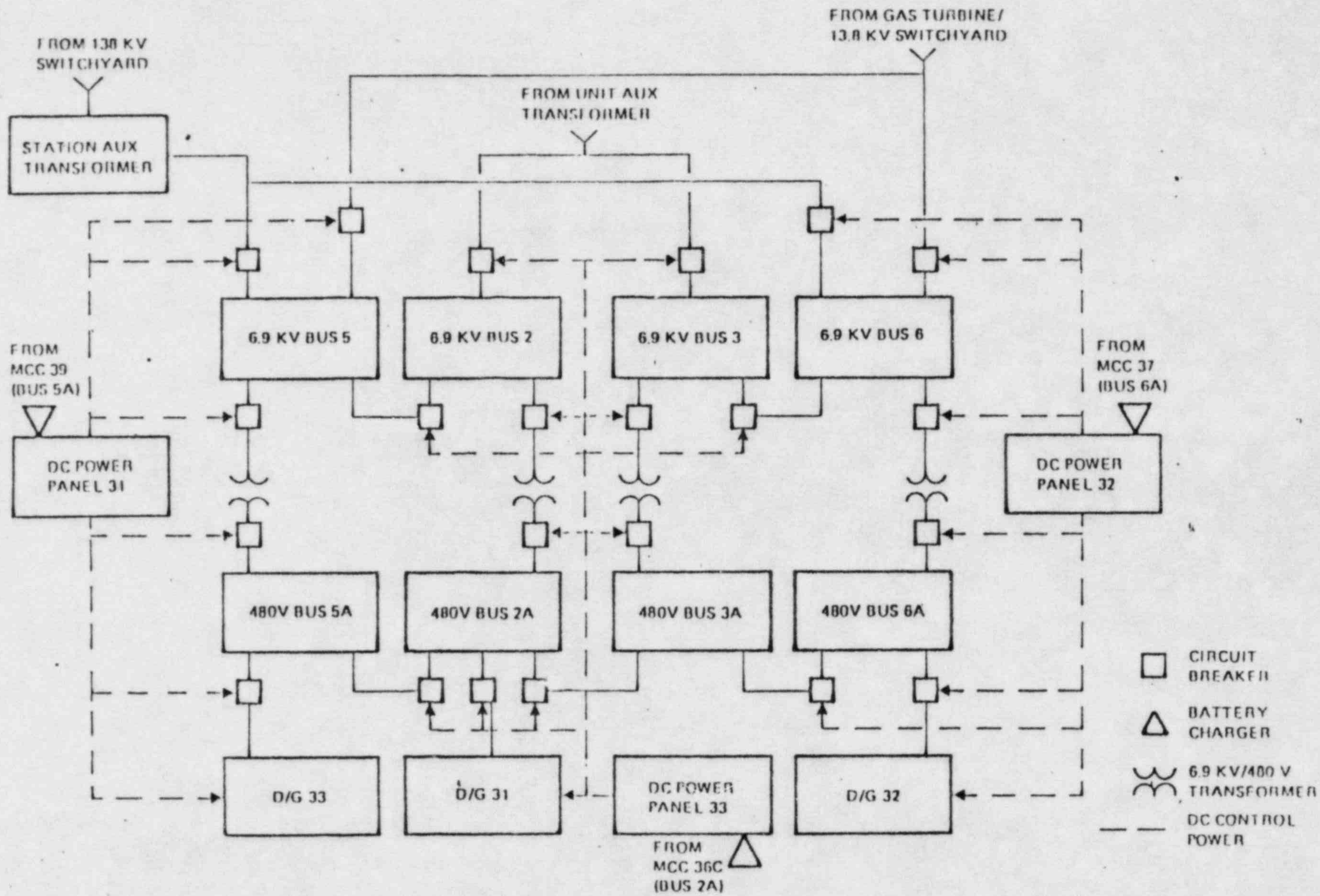


Figure 1. 480V Essential Power Supply Block Diagram

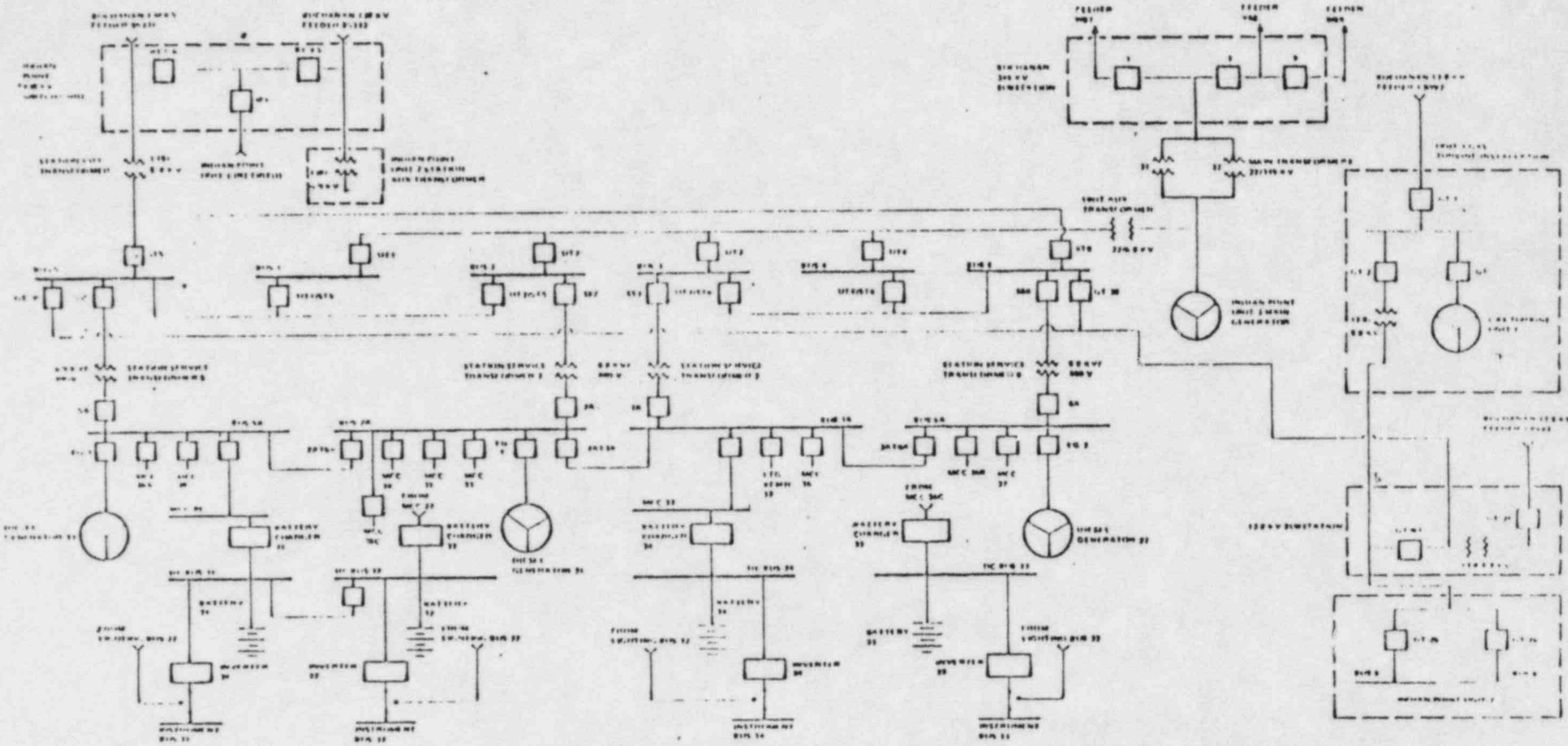
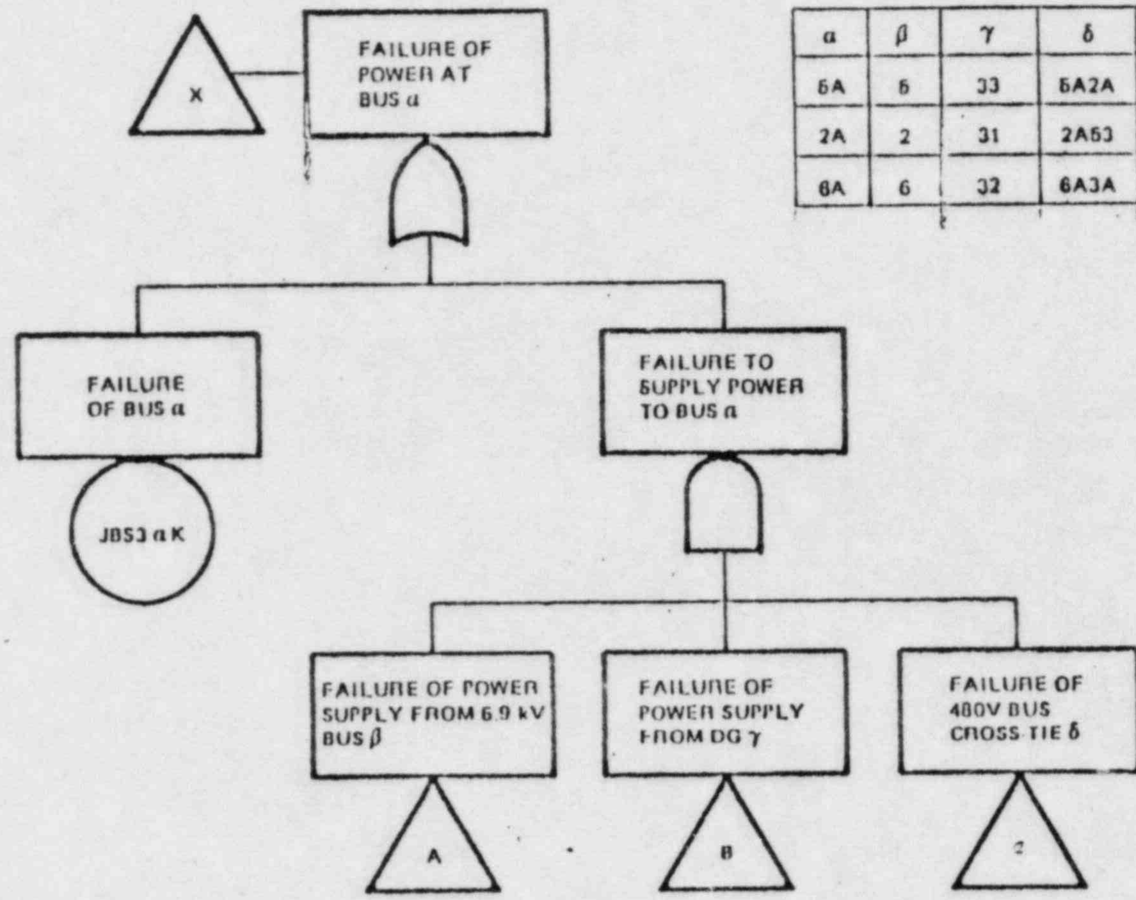


Figure 2. Indian Point Unit 3 Electric Power System Diagram



α	β	γ	δ	ε
5A	5	33	5A2A	C
2A	2	31	2A53	L
6A	6	32	6A3A	C

Figure 3. Indian Point Unit 3 Electric Power System Fault Tree (Sheet 1 of 24)

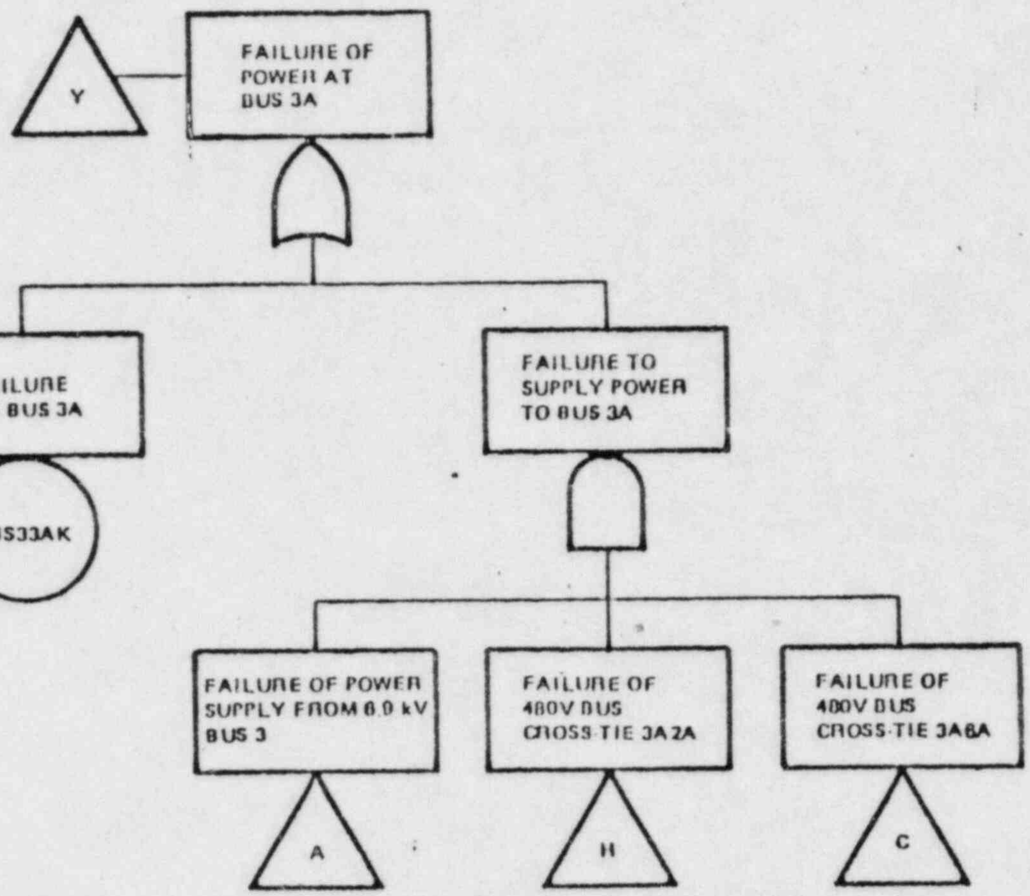
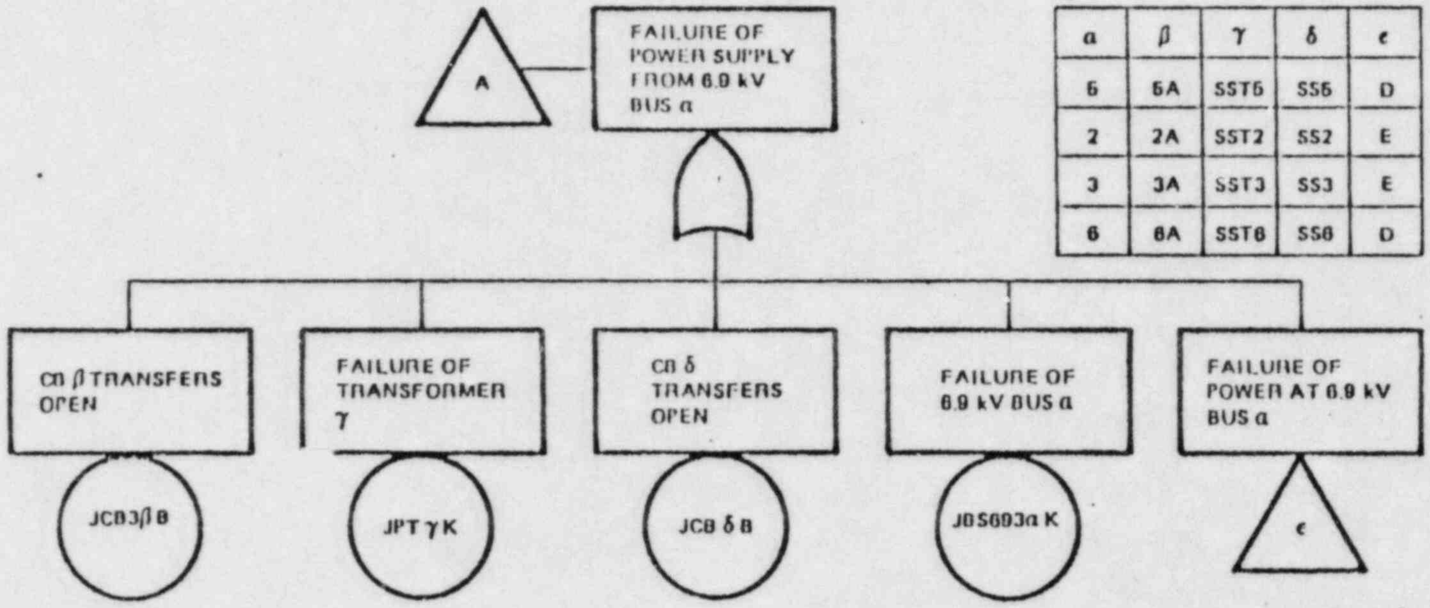


Figure 3. (Sheet 2 of 24)



α	β	γ	δ	ε
5	5A	SST5	SS5	D
2	2A	SST2	SS2	E
3	3A	SST3	SS3	E
6	6A	SST6	SS6	D

Figure 3. (Sheet 3 of 24)

α	β	γ	δ
5	ST5	GT5	31
6	ST6	GT6	32

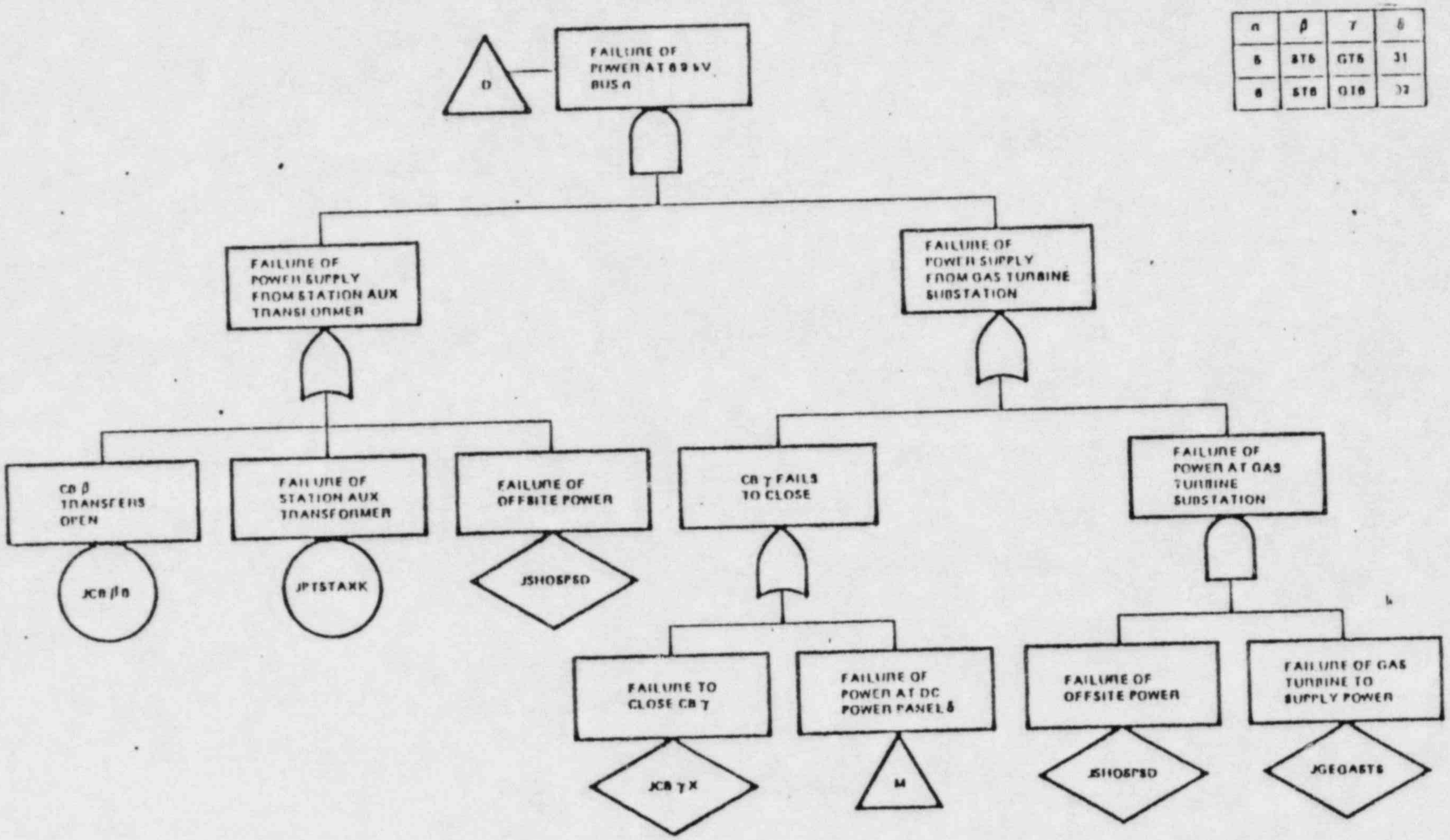
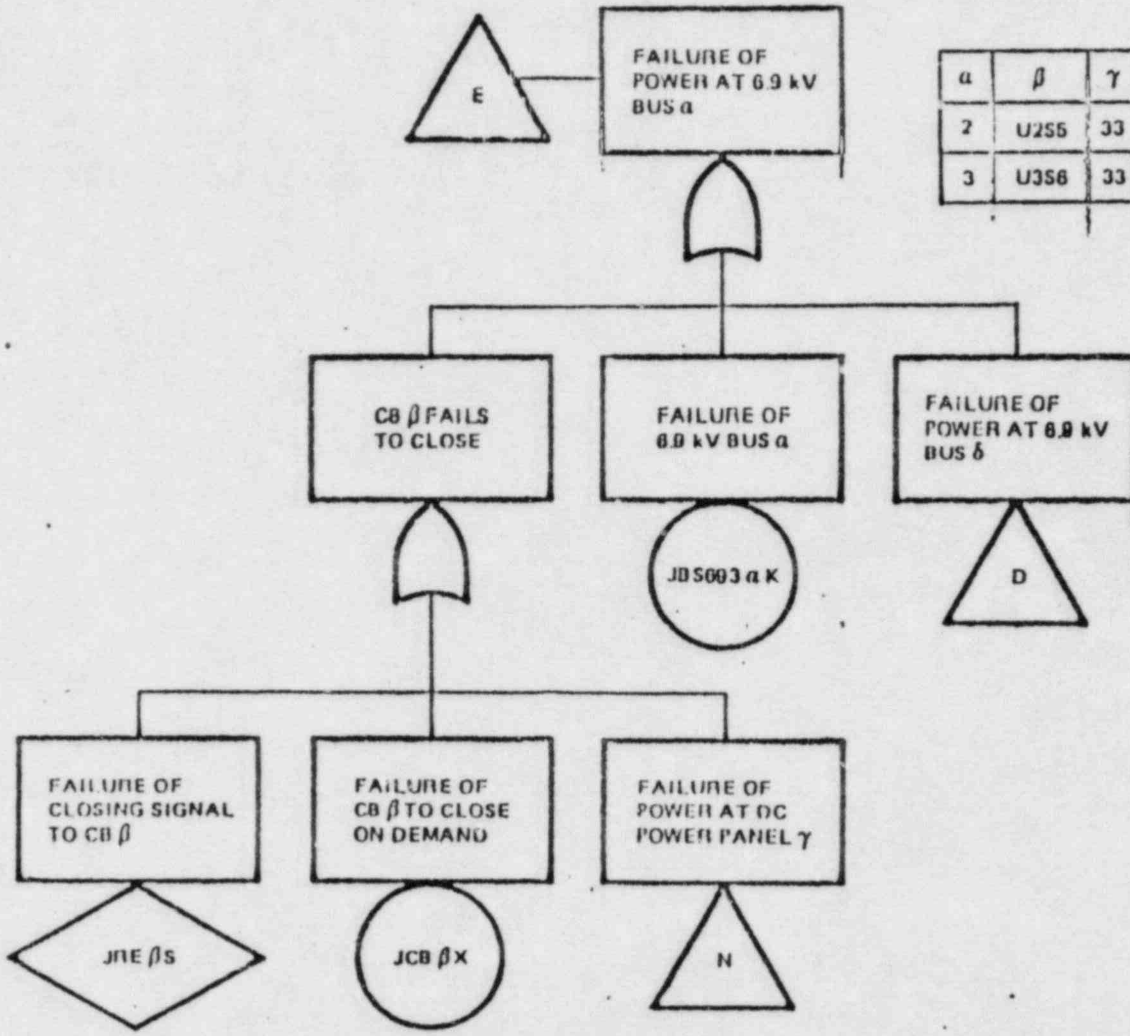
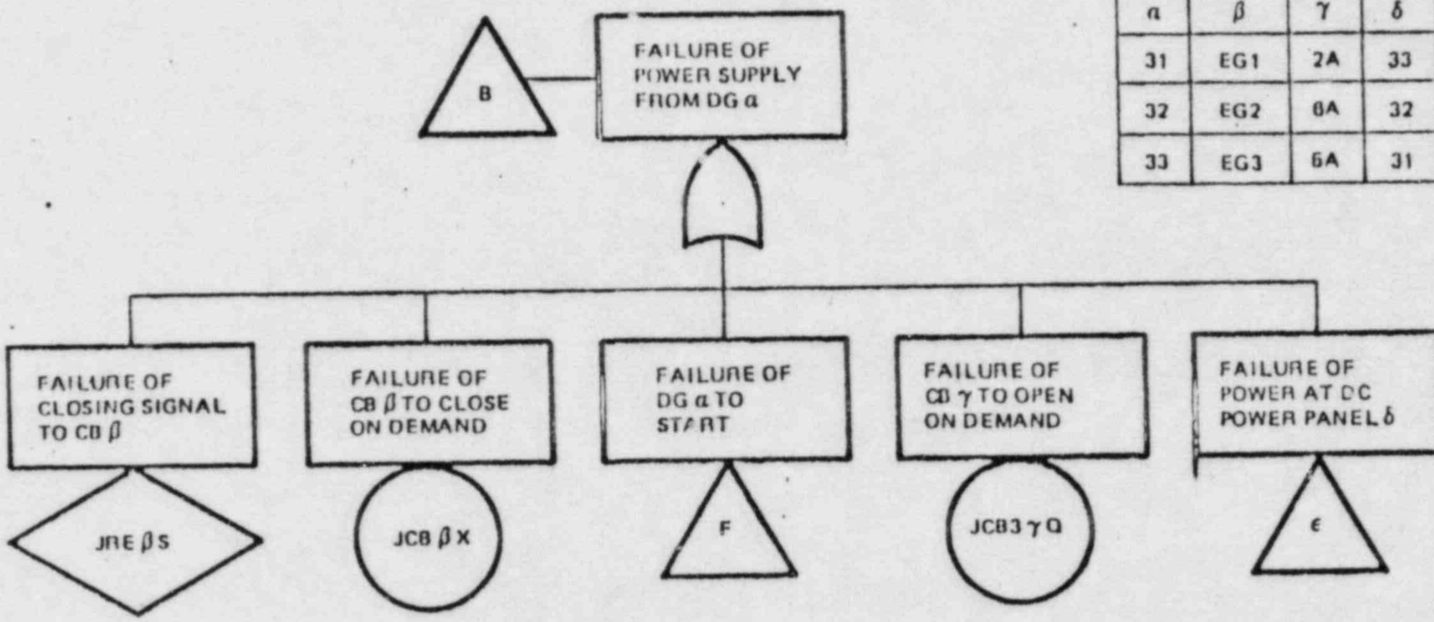


Figure 3. (Sheet 4 of 24)



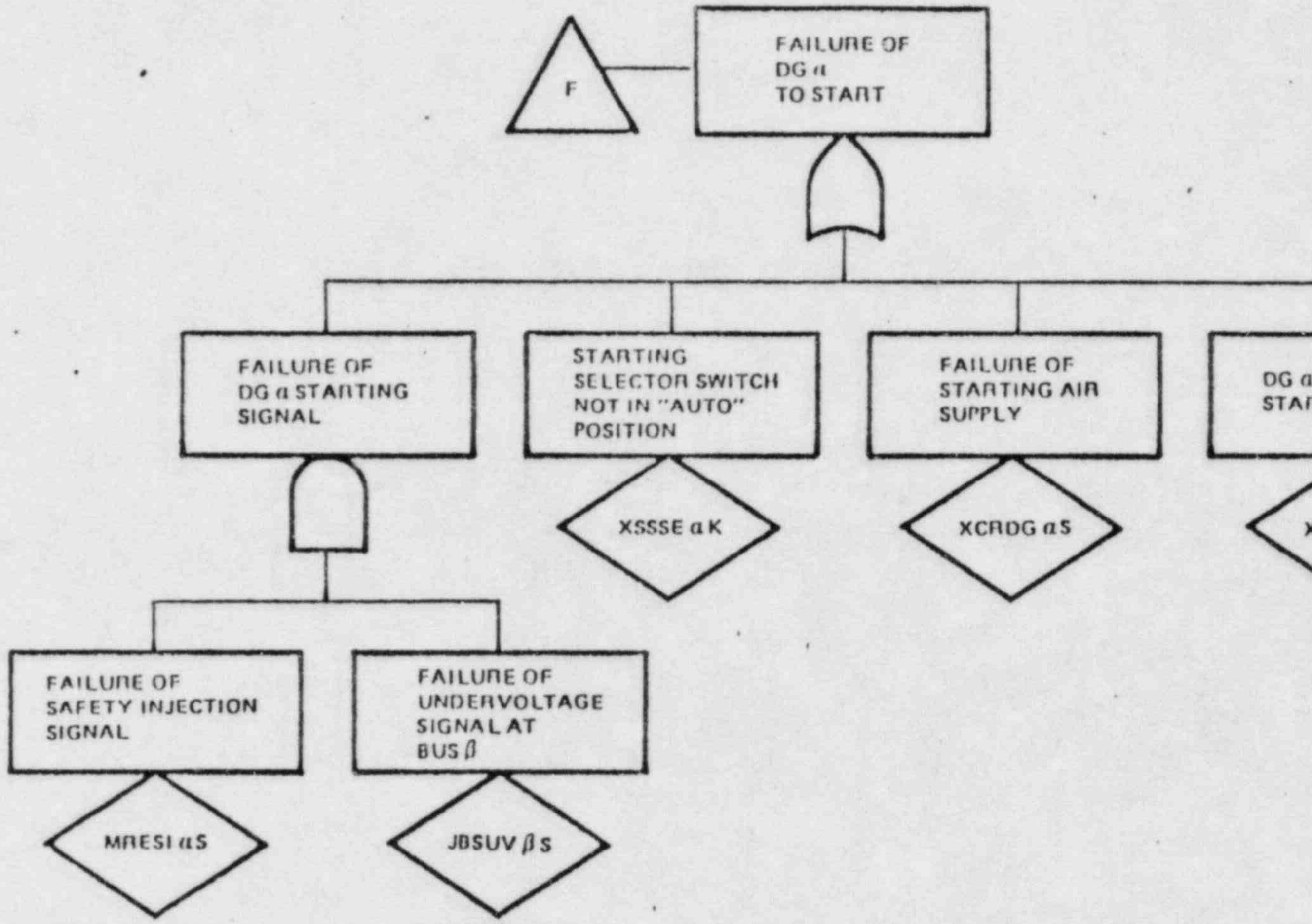
α	β	γ	δ
2	U2S6	33	6
3	U3S6	33	8

Figure 3. (Sheet 5 of 24)



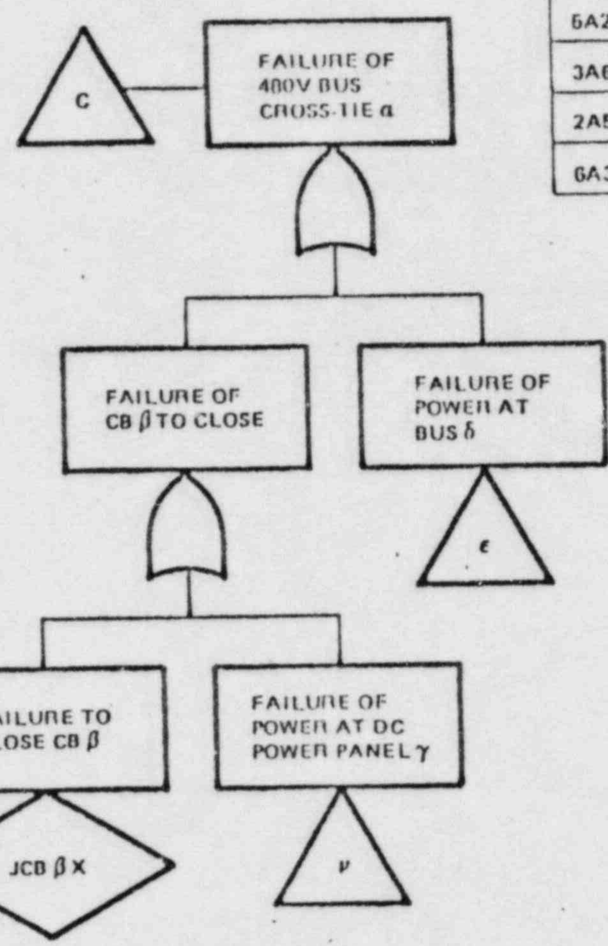
α	β	γ	δ	ε
31	EG1	2A	33	N
32	EG2	8A	32	M
33	EG3	6A	31	M

Figure 3. (Sheet 6 of 24)



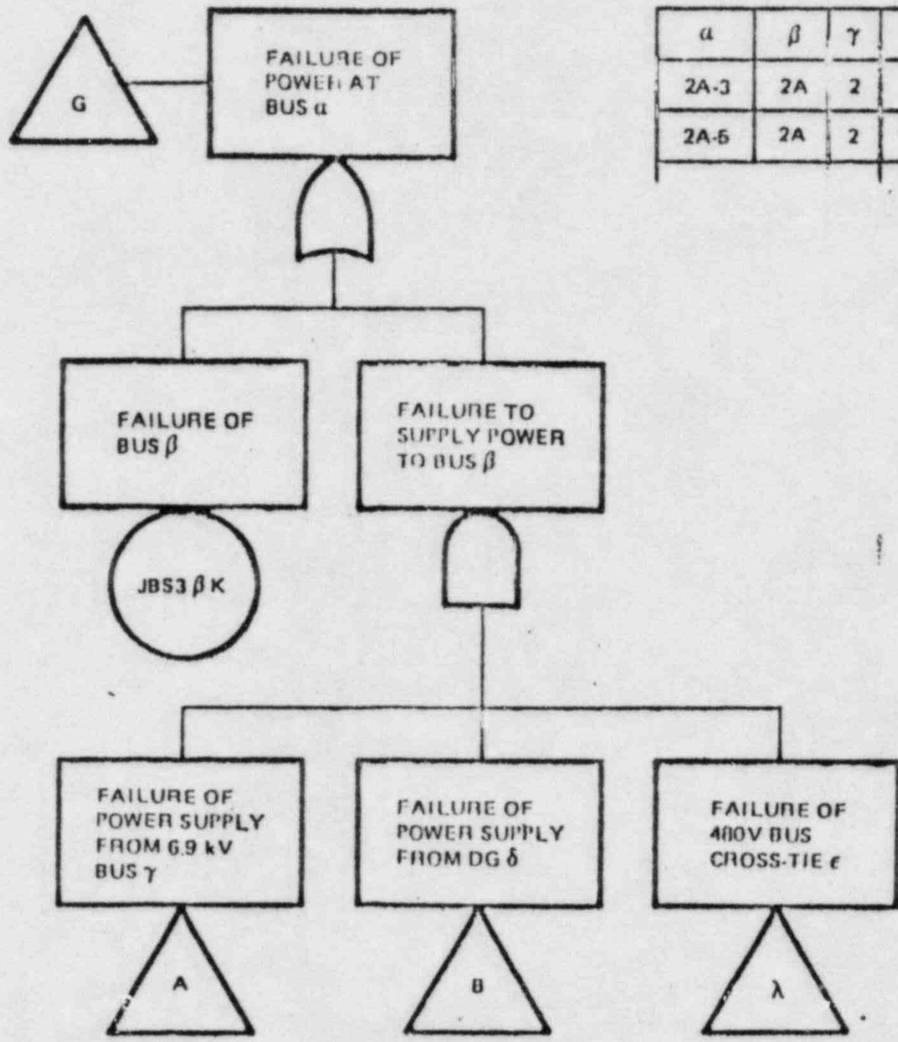
α	β
31	2A
32	8A
33	6A

Figure 3. (Sheet 7 of 24)



α	β	γ	δ	ε	ν
6A2A	2A6A	33	2A-3	G	N
3A8A	3A6A	32	8A	K	M
2A5A	2A5A	33	6A	K	N
6A3A	3A6A	32	3A-2	J	M

Figure 3. (Sheet 8 of 24)



α	β	γ	δ	ε	λ
2A-3	2A	2	31	2A3A	H
2A-5	2A	2	31	2A5A	C

Figure 3. (Sheet 9 of 24)

α	β	γ
2A3A	3A-6	J
3A2A	2A-5	G

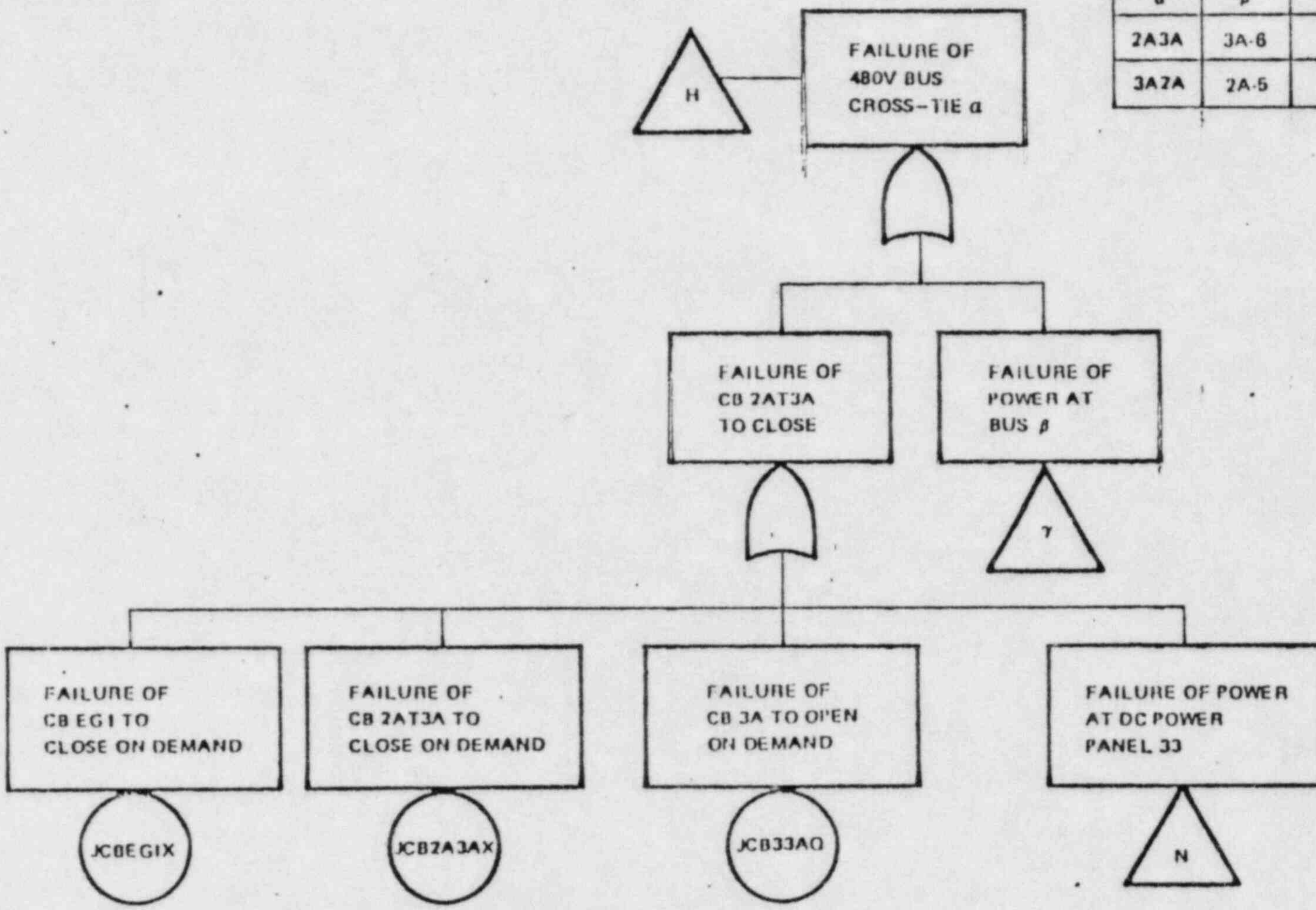
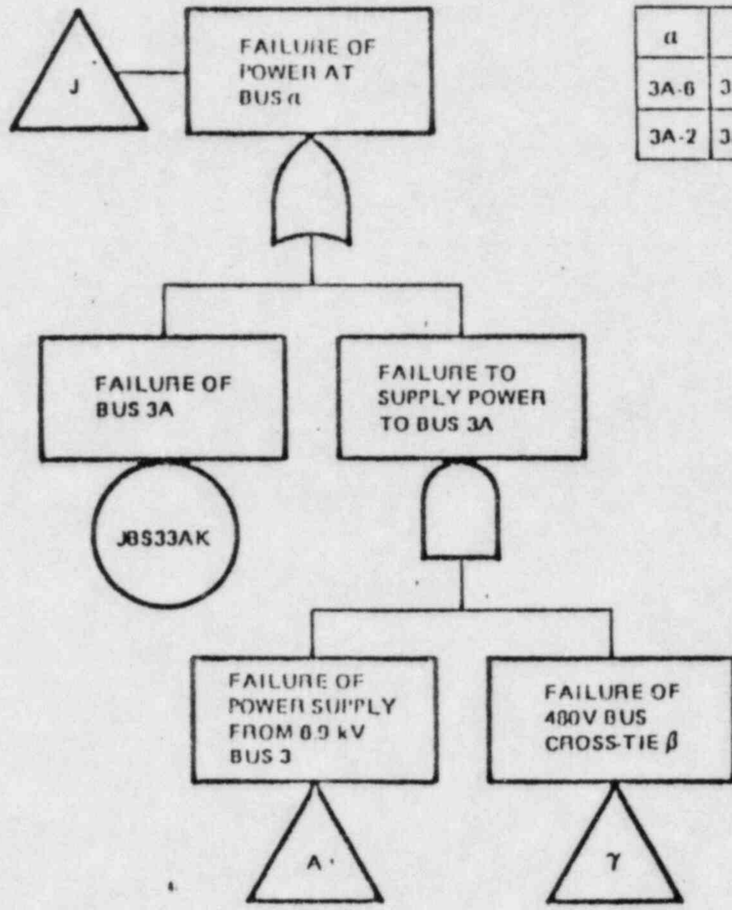
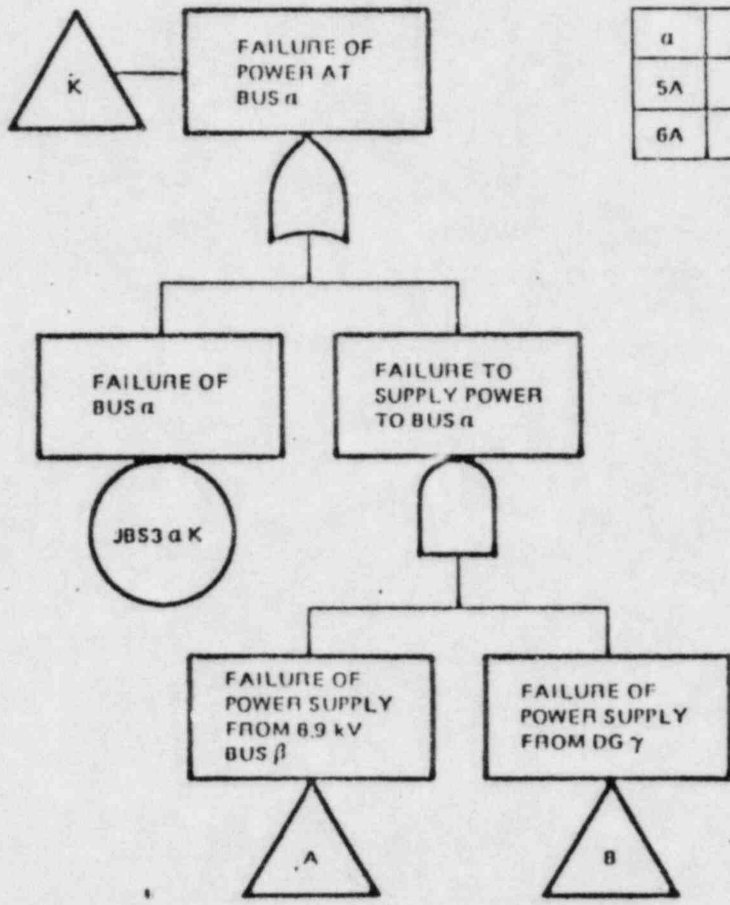


Figure 3. (Sheet 10 of 24)



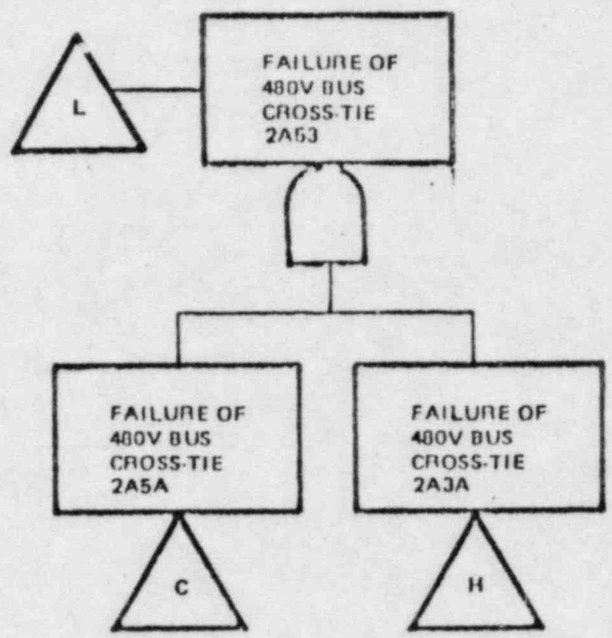
α	β	γ
3A-6	3A6A	C
3A-2	3A2A	H

Figure 3. (Sheet 11 of 24)



α	β	γ
5A	5	33
6A	6	32

Figure 3. (Sheet 12 of 24)



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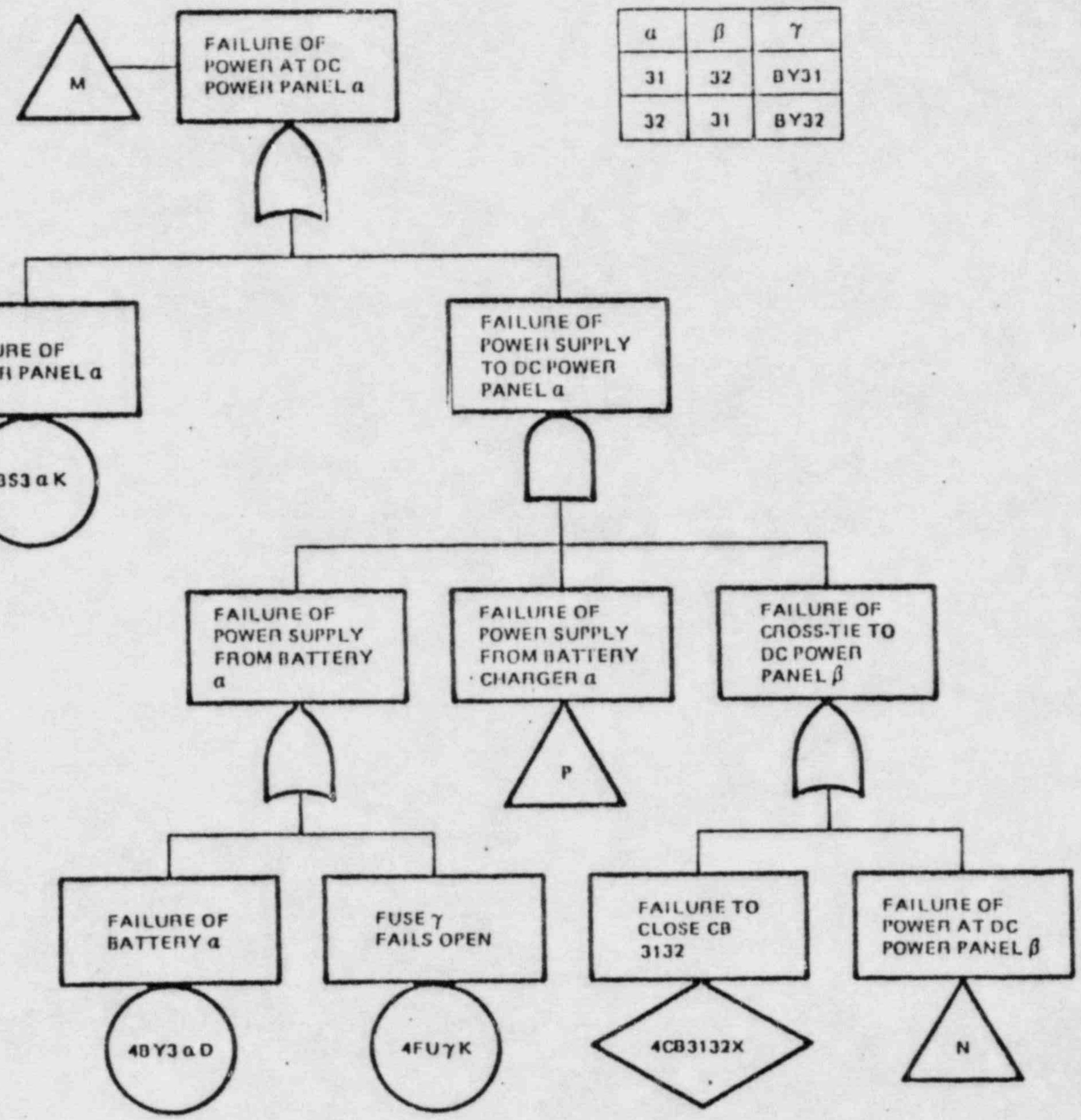
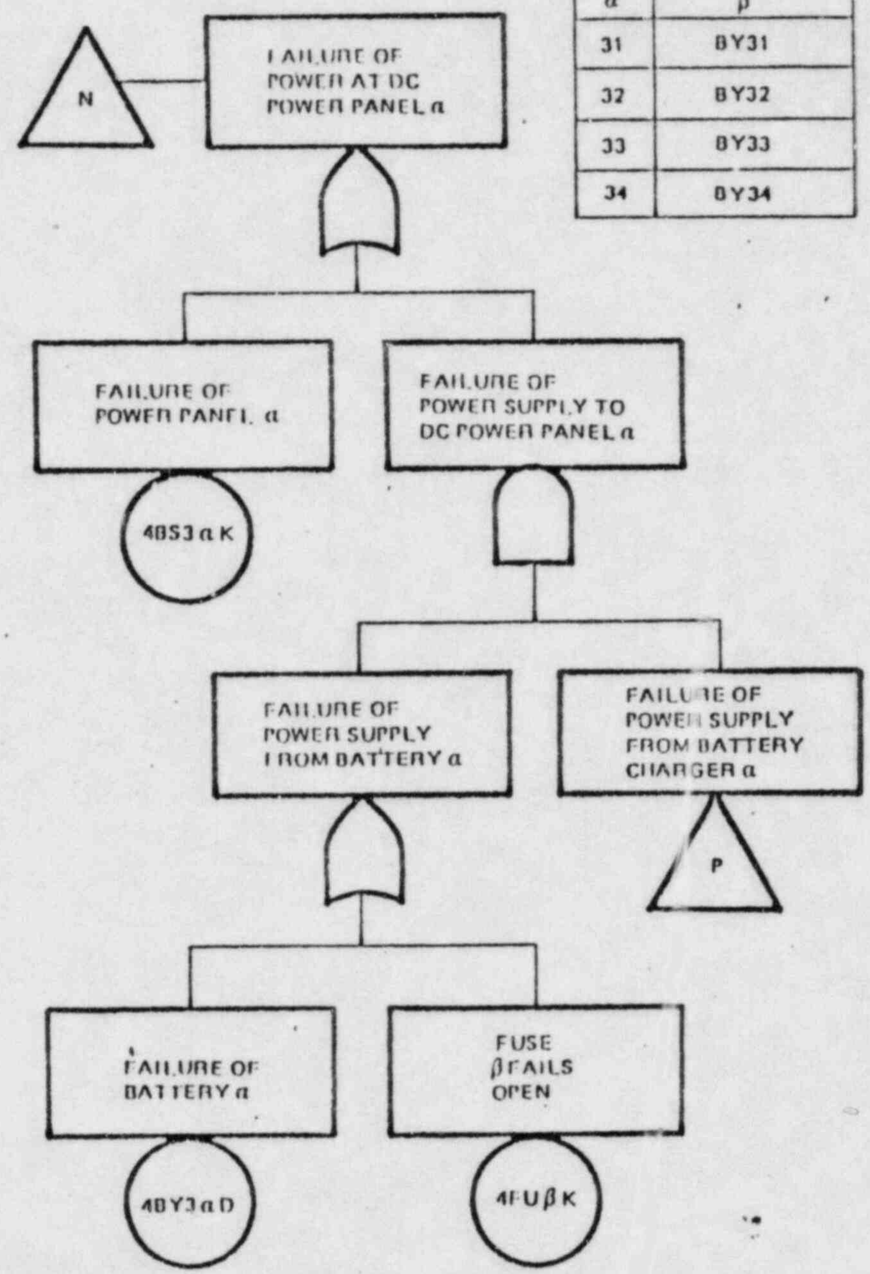


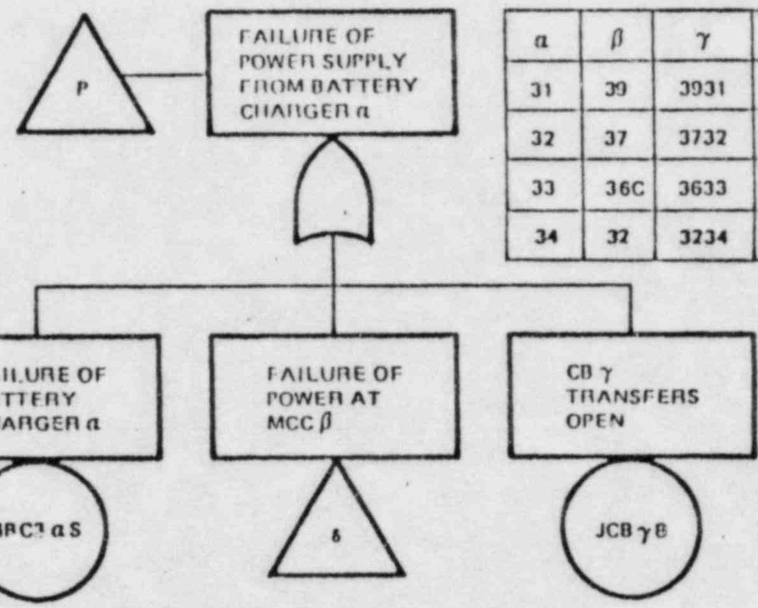
α	β	γ
31	32	BY31
32	31	BY32

Figure 3. (Sheet 14 of 24)



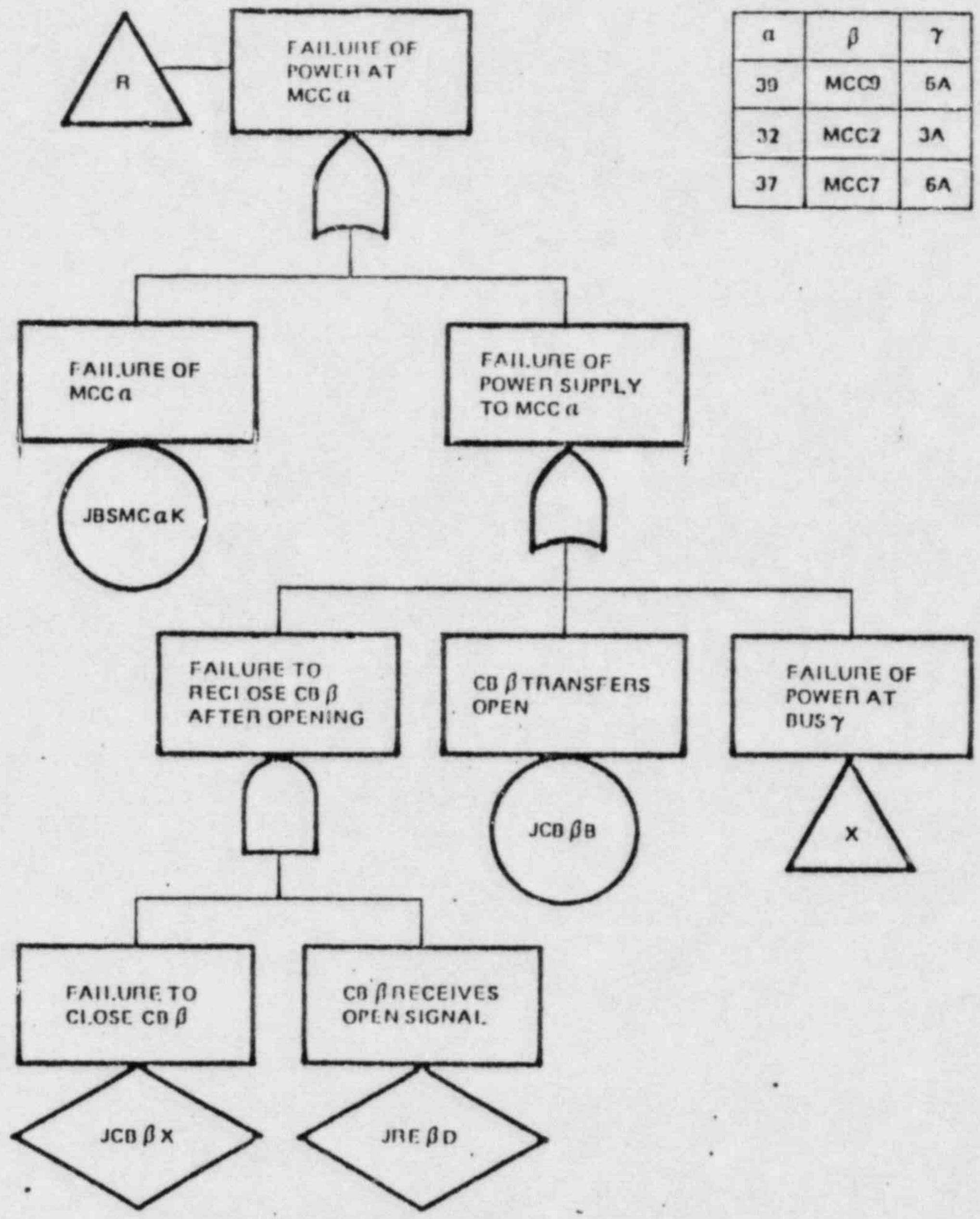
α	β
31	BY31
32	BY32
33	BY33
34	BY34

Figure 3. (Sheet 15 of 24)



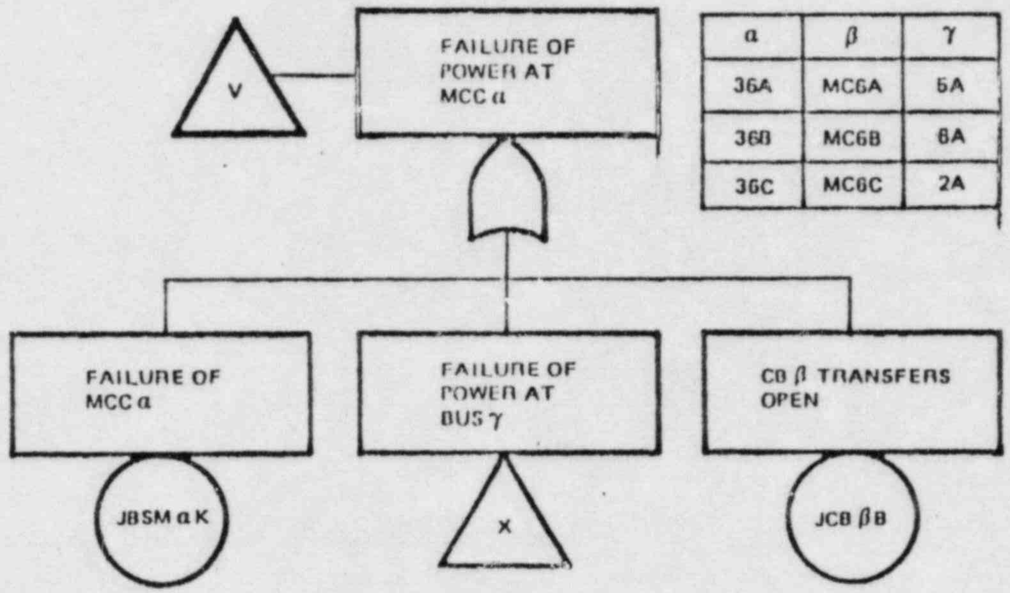
α	β	γ	δ'
31	39	3931	R
32	37	3732	R
33	36C	3633	V
34	32	3234	R

Figure 3. (Sheet 16 of 24)



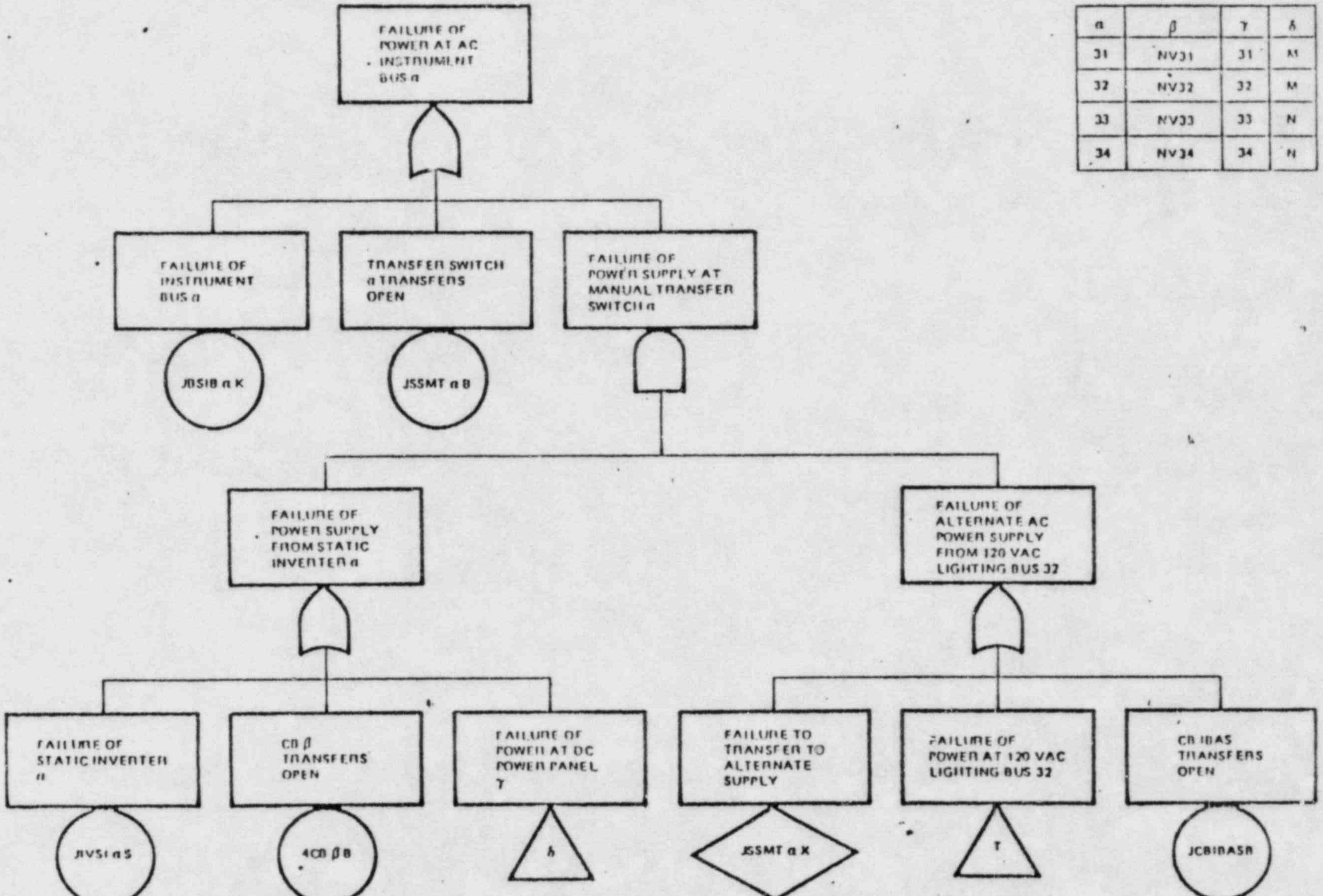
α	β	γ
39	MCC9	5A
32	MCC2	3A
37	MCC7	6A

Figure 3. (Sheet 17 of 24)



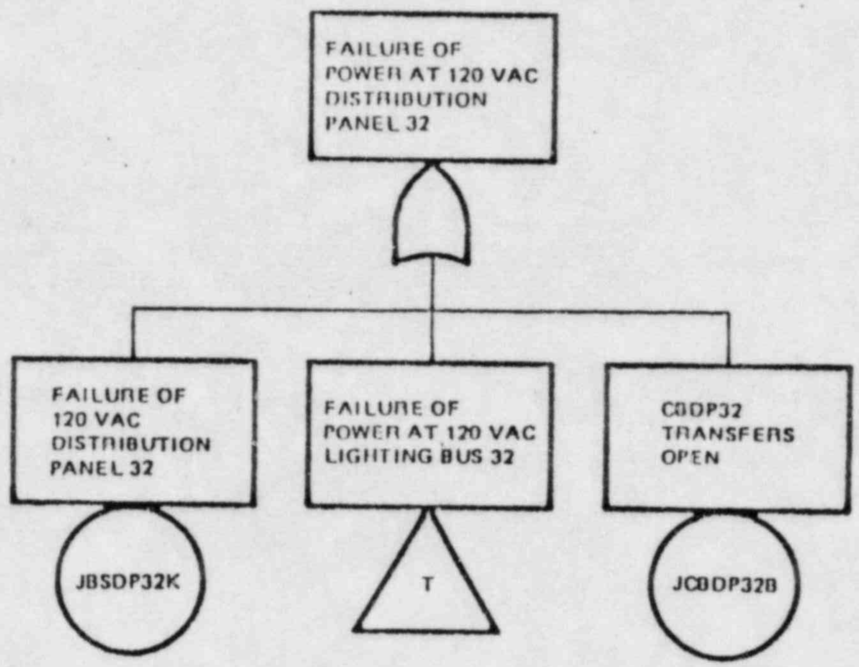
α	β	γ
36A	MC6A	5A
36B	MC6B	6A
36C	MC6C	2A

Figure 3. (Sheet 18 of 24)



α	β	γ	δ
31	NV31	31	M
32	NV32	32	M
33	NV33	33	N
34	NV34	34	N

Figure 3. (Sheet 19 of 24)



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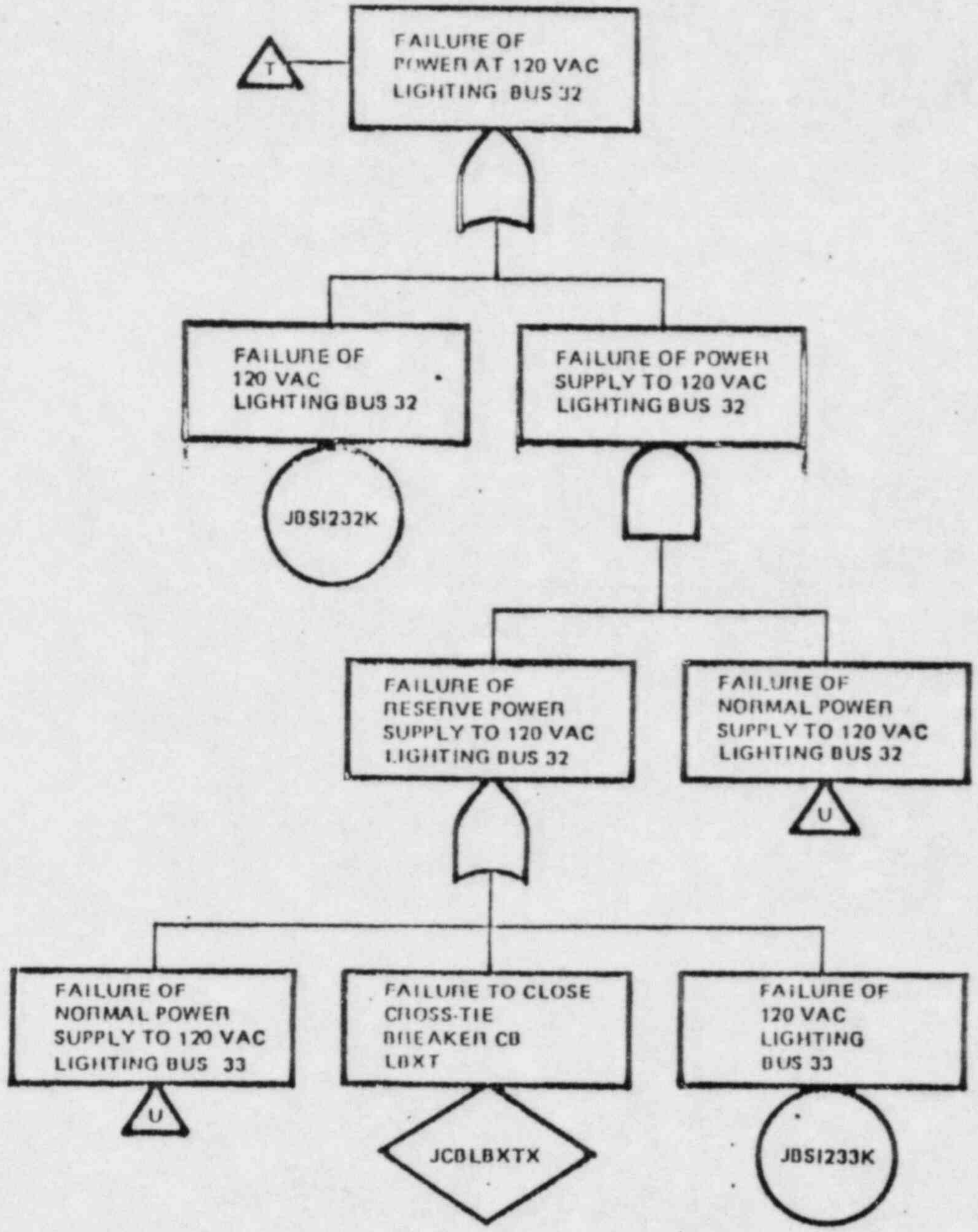

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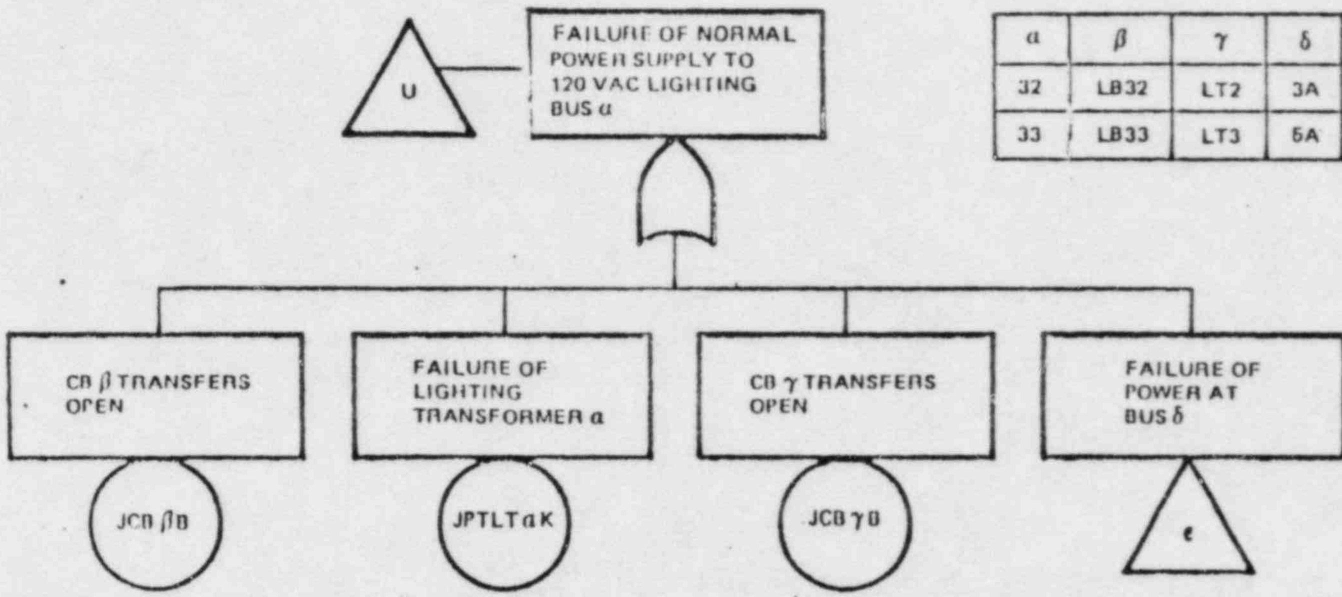
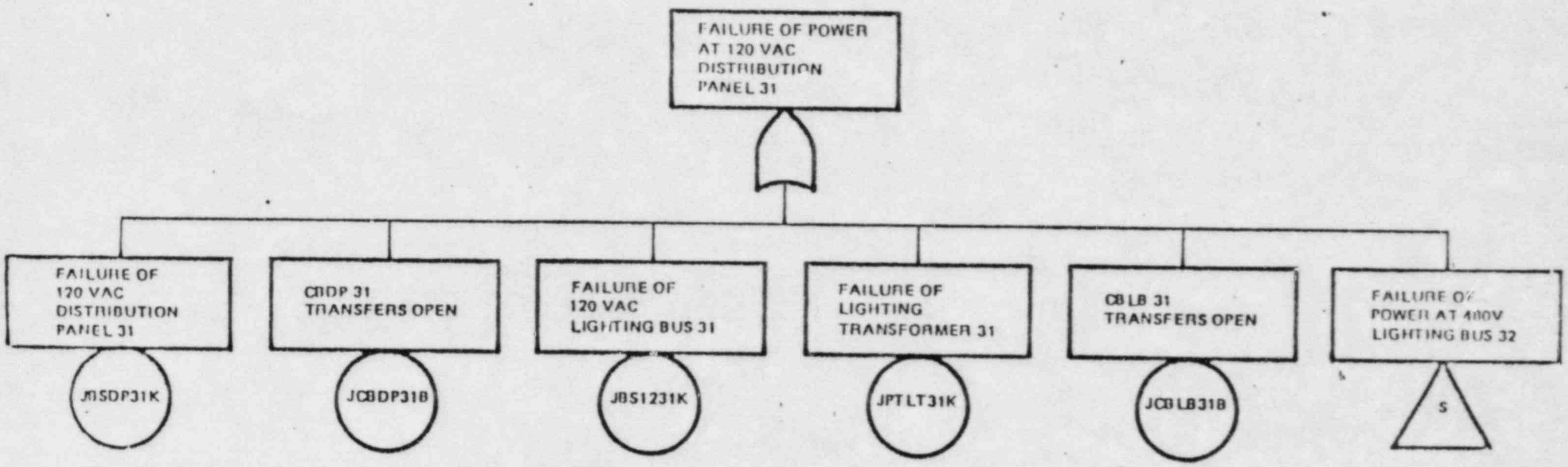


α	β	γ	δ	ε
32	LB32	LT2	3A	Y
33	LB33	LT3	5A	X

Figure 3. (Sheet 22 of 24)



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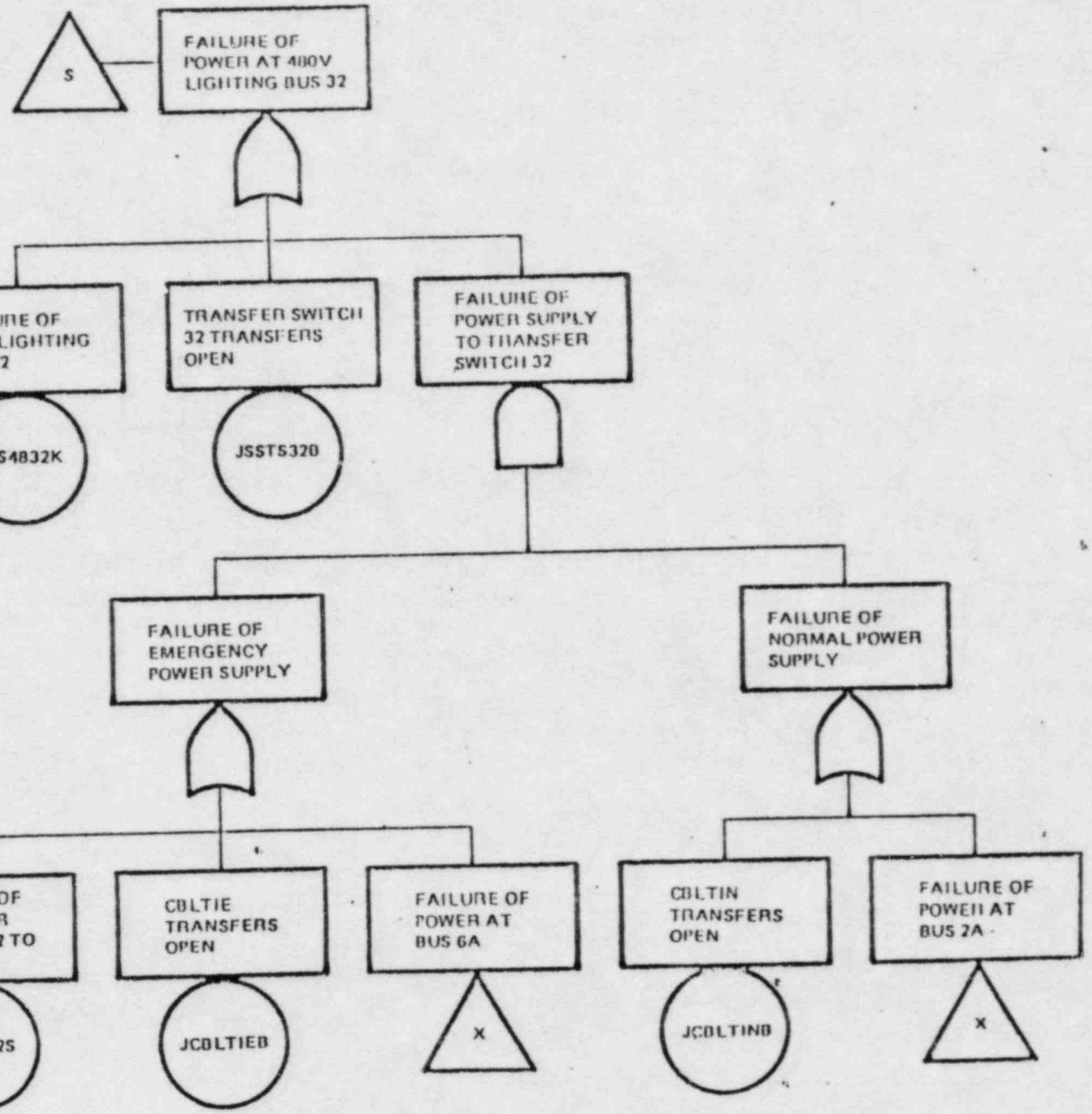

Figure 3. (Sheet 24 of 24)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

OCT 20 1981

Docket Nos.: 50-247
50-286

MEMORANDUM TO: Ashok Thadani, Chief
Reliability and Risk Assessment Branch
Division of Safety Technology, NRR

THRU: Franklin D. Coffman, Jr., Section Chief
Systems Interaction Section
Reliability and Risk Assessment Branch
Division of Safety Technology, NRR

FROM: James H. Conran, Principal Systems Engineer
Systems Interaction Section
Reliability and Risk Assessment Branch
Division of Safety Technology, NRR

SUBJECT: TRANSMITTAL OF MEETING SUMMARY AND STATUS REPORT

Attached is a combined "Meeting Summary and Status Report" relating to the Indian Point-3 systems interaction study effort. This report is principally a summary of discussions of a July 24, 1981 meeting between the Systems Interaction staff and the Indian Point-3 licensee (PASNY) and their contractor (EBASCO). The purpose of that meeting was to discuss the staff's final review comments on PASNY's preliminary submittal describing the proposed IP-3 systems interaction study program. The report is in the format of a "Meeting Summary"; however, since the report also reflects developments subsequent to the meeting (e.g. as recent as the simulator trials at the Indian Point facility on September 23-24), it is also termed "Status Report".

James H. Conran
James H. Conran
Systems Interaction Section
Reliability and Risk Assessment Branch
Division of Safety Technology, NRR

Attachments - Report as stated in text

cc: T. Murley - DST
M. Ernst - DST
J. Thoma - DL
J. Greismeyer - ACRS staff

8203030054
PDR/LPDR

Docket Nos.: 50-247
50-286

MEMORANDUM TO: Ashok Thadani, Chief
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Systems Interaction Section
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FROM: James H. Conran, Principal Systems Engineer
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James H. Conran
Systems Interaction Section
Reliability and Risk Assessment Branch
Division of Safety Technology, NRR

Attachments - Report as stated in text

cc: T. Murley - DST
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J. Thoma - DL
J. Greismeyer - ACRS staff

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MEETING SUMMARY AND STATUS REPORT
FOR
MEETING WITH PASNY/EBASCO ON PROPOSED IP-3 SYSTEMS INTERACTION PROGRAM

JULY 24, 1981

Introduction and Background

A meeting was held in Bethesda, Md., on July 24, 1981 with representatives of the Power Authority of the State of New York (PASNY) and their contractor (EBASCO) to discuss the staff's comments on PASNY's "Preliminary" submittal on the proposed systems interaction study program to be performed at the Indian Point-3 facility. The "Preliminary" submittal (2 volumes) consisted of:

Volume I - description of the objectives and scope of the program, project organization, and criteria and methodology to be applied in identifying and evaluating systems interaction.

Volume II - extensive compilation of results of application of the proposed criteria and methodology to the AFW system, for the purpose of illustrating the workability of the proposed methodology and the depth of treatment of plant systems generally in the study.

The review of the PASNY submittal was performed by the NRC systems interaction staff (Reliability and Risk Assessment Branch) assisted by contractors (LLL and SAI) and a senior reviewer from the Auxiliary Systems Branch, NRR, experienced in the review of AFW systems. The review process in its entirety extended over nearly 4 months (April-July), and included review of a number of sections of the Pickard, Lowe, and Garrick Zion/Indian Point PRA study report (April 1981 Draft) now in the final stages of completion. (Explicit reference is made to "consideration of Z/IP PRA fault trees" in the description of the IP-3 proposed systems interaction study.)

The scope of the RRAB (and LLL/SAI) review effort included all aspects of the PASNY submittal; but the main focus of this part of the review was a critical review of proposed criteria and methodology. The Auxiliary Systems Branch reviewer concentrated primarily on Vol. II of the PASNY submittal (i.e., results of application of proposed methodology to the AFW system only) from the perspective of one knowledgeable in the details of specific system design and operation (see Enclosure 6). All questions and comments developed by this extensive review process were discussed preliminarily with PASNY/EBASCO project personnel via conference calls arranged periodically during the review process. The Detailed Agenda for the July 24 meeting (see Enclosure 2) reflects the final staff comments on the "Preliminary" PASNY submittal.

Discussion

The following summary of detailed discussions at the July 24 meeting is keyed to specific items on the Detailed Agenda for the meeting (Enclosure 2).

I.A. NRC Philosophy on SI Analysis

J. Conran presented an overview of current RRAB staff thinking on the systems interaction problem in general to properly frame the staff's comments on PASNY's proposed SI program. Enclosure 3 provided the

outline for his presentation which summarized the ways that the NRR SI staff has "cross-cut" the overall SI topic, as its thinking has developed and evolved over the past 1 year. That presentation and subsequent discussion throughout the meeting developed the following important points:

o Systems interaction analysis involves (1) the systematic search for heretofore "hidden" or inadequately analyzed interconnections or couplings that link safety and non-safety systems in the reactor plant, and (2) the evaluation of the effects of non-safety system failure (or maloperation) propagated into the safety system by such interconnections/couplings.

o The SI staff stated that the treatment of SIs that aggravate accident conditions and exceed the capabilities of installed safety systems (in addition to SI's that degrade safety system capability) is considered to be within the scope of a comprehensive SI analysis. And methods are available for treating a number of types of SI's, as outlined in Enclosure 3. The SI staff acknowledged, however, that methods are not now available for treating comprehensively the so-called "higher-order" type SI's in interconnected systems. The capability does now exist for treating thoroughly specific events (or postulated events) involving higher-order SI's (e.g., as was done in the extensive analyses of the TMI-2 accident, the Crystal River loss-of-coolant event, the Brown's Ferry partial scram failure, etc.). But the SI staff believes that improved simulator/engineering analyzer capability must be developed if "higher-order" type SI's can be treated systematically and comprehensively in future SI studies.

o The staff emphasized that consideration of operating experience is an important element in the systems interaction analysis of a facility and should be treated explicitly in the IP-3 SI study. Extrapolation of events that have actually occurred is, of course, an effective and accepted method for identifying additional potential SI's with nexus to what has already actually occurred. Consideration of operating experience can also be useful in another important way. The suitability/workability of a proposed SI analysis methodology can be demonstrated if it can be shown that application of that methodology will identify and lead to correction of adverse systems interactions similar to those that have occurred in the past.

o With regard to the question of suitability/workability of various analytical methods for SI analysis purposes, the SI staff does not feel that Event Tree/Fault Tree methods have yet been satisfactorily demonstrated in the limited applications attempted to date (e.g. Sandia Phase I A-17 effort; or Battelle/BNL/LLL State-of-the Art surveys).* PASNY has proposed use of "dependency analysis" techniques (e.g., combining shutdown logic diagrams, safety system auxiliary diagrams, auxiliary safety system commonality diagrams, dependency

*Battelle, BNL, and LLL have continued efforts to adapt Event Tree/Fault Tree methodology for SI analysis purposes. Their efforts are reflected in Interim Guidance being developed; and Event Tree/Fault Tree methodology will be one proposed SI analysis technique tested in "pilot" reviews planned in the near future.

...les/matrices, FMEAs) as the primary means for identifying SI's in the IP-3 study. PASNY has proposed also the use or "consideration" of individual system Fault Trees (available from the IP-3 PRA study) as a supplemental means of identifying and evaluating SI's. This is acceptable to the staff; but PASNY should emphasize and concentrate efforts on application of "dependency analysis" methods in the actual performance of the IP-3 study.

I.B. Relationship Between PRA and SI

P. Alesso, LLL, presented an overview on the relationship between PRA and SI analysis, based on his background and experience in applying PRA techniques, and on perspectives gained from the RRAB/LLL/SAI review of both the PASNY SI submittal and Draft sections of the Z/IP-3 PRA report (provided separately by PASNY at RRAB's request to facilitate the SI submittal review). His presentation (see outline in Enclosure 4), and subsequent discussions throughout the meeting developed the following main points:

- Early PRA studies focused largely on safety systems, and (because of assumed independence between nonsafety and safety systems) did not treat nonsafety system-related effects to any great extent. This approach seemed valid in view of stringent criteria applied in the design and licensing review process (i.e., single failure criterion, separation criteria, etc.) for the express purpose of achieving and maintaining nonsafety/safety independence. Also, consideration was given in early PRA efforts to common-mode failure mechanisms and effects; but, again, the emphasis was on couplings (and their effects) between safety systems (not between safety and nonsafety systems). In this sense, some consider SI studies as merely an extension of the too-restrictive boundary conditions imposed in early PRA studies to encompass full treatment of common cause/common mode effects involving both nonsafety and safety systems. Consistent with this view, recent "enhanced" reliability and risk analyses (e.g., IREP and the Z/IP-3 PRA) do include significantly improved treatment of nonsafety front line and support systems.

- The SI staff does not agree with characterization of SI analysis as "just a part of an enhanced PRA" for the following reasons:

  (1) SI analysis is a useful exercise and has inherent value completely aside and apart from PRA. The nonsafety/safety dependency information developed by SI analyses is certainly important in assuring the accuracy of PRA results (in fact, SI analysis must be regarded logically as a prerequisite to PRA). But nonsafety/safety dependency information can be used readily and effectively to improve safety in the context of the current "deterministic" licensing approach even if PRA is never done.

  (2) Thinking of SI analysis as "simply a part of PRA" can lead to undue empahsis or reliance on use of analysis methods usually associated with PRA (i.e., Event Tree/Fault Tree Analysis), that have not yet been satisfactorily demonstrated (for SI analysis purposes) in applications attempted to date.*

*See footnote preceding page.

o As a final point in the area of PRA/SI relationship, PASNY stated that the results of the IP-3 PRA study would be an important factor in the final selection of specific systems to be treated in the IP-3 SI analysis. The SI staff stated that PASNY should not rely primarily on those PRA results in making such determinations regarding the critical parameters of the SI study. If the PRA is flawed by not taking into account some hidden dependency in the IP-3 systems that could be found by a SI analysis, there is a logical inconsistency in using the results of such a potentially flawed PRA (in any controlling manner) in determining scope or depth of treatment of the SI analysis. PRA results may be useful in confirming the selection of systems (for SI analysis) arrived at by applying the methods and criteria described by PASNY in their Preliminary submittal

II.A Definition of SI and Application of Single Failure Criterion

o PASNY and the SI staff agreed explicitly that the threshold for identification of adverse SI's will be a nonsafety system or component failure that leads to the defeat of one train of a safety system or engineered safety feature... even if the remaining trains of the affected safety system or ESF could perform the intended safety function. This is a more stringent criterion than the Single Failure Criterion currently applied in the licensing review process; but it was emphasized that it is specified by the staff at this point only as a SI search criterion. SI's identified by applying this search criterion may require design change or plant modification; but not necessarily so.

o The choice of the stringent search criterion discussed in the preceding stems from the SI staff's objective of assessing the effectiveness of existing deterministic criteria in achieving independence between safety and nonsafety systems. The assumption of nonsafety/safety systems independence (in accordance with existing design and licensing review criteria) forms an important part of the rationale for determinations of "adequate safety" for existing plants sans systematic and comprehensive analysis of nonsafety failure effects. If numerous nonsafety/safety system dependencies are found by application of the search criterion specified above, that could indicate a fundamentally different level of reliability in safety systems than is now assumed, and could (for example) indicate the need for reassessment of the adequacy of the Single Failure Criterion as currently applied.

II.B Interconnected Systems Interaction Analysis

- PASNY amplified in discussions at this meeting their description in the Preliminary submittal of how Shutdown Logic Diagrams (SLD's) Safety System Auxiliary Diagrams (SSAD's), and Auxiliary Safety System Commonality Diagrams (ASSCD's) will fit together with FMEAs and Fault Trees on individual systems, to identify and evaluate SI's (dependencies) in the IP-3 study. As the staff now understands it, SLD's, SSAD's, and ASSCD's are basically devices employed (1) for identifying the safety and support systems (including nonsafety systems) that are to be analyzed for interactions, and (2) for correlating and combining the results of FMEA's on individual systems in order to understand and portray how interconnections, couplings and dependencies among all systems can propogate nonsafety system failure(s) into the safety system. (PASNY also agreed to consider the use of matrix based methods, as suggested by the SI staff, as a refinement on the above mentioned methods in identifying dependencies among interconnected systems.)

  In addition, as a supplemental device in searching for SIs, and as one of the principle methods for the evaluation of SI's identified, PASNY will use or "consider" Fault Trees on individual systems already available from the Z/IP-3 PRA. PASNY may develop new Fault Trees for systems covered in the SI analysis, if these systems were not covered or were not modeled in sufficient detail (for SI purposes) in the PRA. All SI's identified are not expected to require use of Fault Trees for evaluation; engineering judgment, based on and appropriately reflecting existing deterministic criteria, will be used in some cases.

- A staff concern regarding the effectiveness of PASNY's proposed method for generating system/component listings corresponding to required safety functions was resolved by PASNY's statement that Table 6.1 presented in Vol. 1 of the "Preliminary" submittal was not intended to be complete in that respect (e.g., it did not include the PORV) explicitly at the time, but would do so in the final submittal). At this point the table was intended for illustrative purposes only.

- PASNY's amplifying comments referred to in the preceding also answered specifically a staff concern regarding adequacy of the FMEA approach to be applied to all systems generally on the basis of conclusions drawn from the FMEA of the AFW system alone (see Fig. A-2.1 in Vol. II). Specifically the staff questioned the validity of "Acceptable" conclusions for various failure modes postulated in the AFW system, without considering possible combined effects of failures in other systems (e.g., due to failure of support systems shared by the AFW and other systems, or other coupling mechanisms).

o An important area of disagreement between the SI staff and PASNY all along has been the question of treatment of nonsafety control system failure effects, nonsafety power system failure effects, and nonsafety instrumentation failure effects. These types of SI's have played major roles in a number of very serious operating incidents, and are of great concern and are considered high priority aspects of the overall SI problem by the staff; but PASNY indicated in the Preliminary submittal that they intended to address these types of SIs only very limitedly or not at all in the IP-3 study.

-- With regard to the treatment of SI's involving nonsafety instrumentation failure effects, PASNY stated in their "Preliminary" submittal that they did not intend to treat latent-or-dynamic human error-induced failures within the scope of their SI analysis. Consistent with this position, they specifically excluded treatment of "... failures which deprive the operator of required information for normally controlling plant conditions, or which provide confusing or incorrect information to the operator..." A part of PASNY's rationale in this respect was that it was simply too difficult to predict and analyze the many ways in which an operator might act incorrectly.
The SI staff believes that it is possible to treat one specific important type of interaction involving the human error as a coupling or linking mechanism. That type of SI has been termed "induced operator error" (see Enclosure 3), and involves a set of circumstances in which (1) a nonsafety system failure causes loss (particularly massive loss) of normal control instrumentation display, and (2) the operator is assumed to act correctly (procedurally speaking) on the basis of incorrect reading(s) produced by the initiating failure. Thus, the difficulty of trying to predict and analyze incorrect actions is eliminated.

PASNY appeared to understand and appreciate the staff's comment in this regard (provided in the initial meeting on 4/2/81), but has not yet explicitly committed to including treatment of this type SI within their intended scope of study. The SI staff continues to believe that the seriousness and likelihood of this kind of failure are both such as to warrant its treatment in the IP-3 SI study.

-- With regard to nonsafety control systems failure effects, PASNY merely referenced in their Preliminary submittal the PASNY response to IEB 79-22. This was somewhat confusing in that context because IEB 79-22 addressed control system failures only in the context of non-connected SI effects (specifically, high energy line break effects); also PASNY's response focused on only a few control systems. Further, there was no indication in the Preliminary submittal that PASNY intended to consider adequately nonsafety power system failure effects caused by or propogated by nonsafety control systems. The staff therefore considered this aspect of PASNY's Preliminary submittal inadequate.

Subsequently, PASNY added reference to their responses to IEB 79-27 and NUREG-0588 as applicable and sufficient in this context. PASNY considers anything much beyond that to fall within the scope of one or another Unresolved Safety Issue (e.g. A-47 Control Systems Dynamics), not assignable by requirement to an individual licensee for resoluiton. The staff understands PASNY's legalistic position in this regard, but has required that at a minimum PASNY's treatment of SI's in interconnected systems should consider explicitly nonsafety control system failure effects and nonsafety power system failure effects to a degree consistent with requirements imposed by current staff practice for detailed information regarding nonsafety system aspects of plant design, e.g., recent ICSB review questions to OL applicants in the SNUPPs project. (A copy of the ICSB review questions referred to have been provided to PASNY.)

Beyond this minimum requirement, the staff has requested that PASNY consider possible application of the Indian Point simulator in the treatment of "first-order" types of SI's (see Enclosure 3) involving nonsafety control and power systems. The SI staff believes that to the extent that such a training simulator accurately models at least direct interconnections between safety and nonsafety front line systems and their support systems, it may be possible to do more comprehensive and systematic analysis of their failure effects more easily and efficiently by use of the simulator. (It would not be necessary for the simulator to accurately model process couplings or systems dynamics to be useful in thisregard.) It should also be noted that a training simulator would appear to be an almost ideal tool to be applied in treating more systematically and comprehensively nonsafety instrumentation display failure effects (i.e., the induced operator error SI) as discussed in the preceding. PASNY has agreed to investigate these possibilities and has examined on a very preliminary basis some specific scenarios and failure combinations of particular interest in this respect. The SI staff was invited to observe and participate in initial trials on September 23-24, 1981 at the Indian Point Simulator facility. We believe that PASNY is to be commended for responding in this fashion, and in demonstrating the willingness to examine novel (potential) alternative approaches to this very difficult aspect of SI analysis.

II.C Non-connected Systems Interaction Analysis

- The staff considers the methods and criteria proposed by PASNY for use in identifying and evaluating seismic-initiated SI's to be acceptable. The methods and criteria proposed are similar to those which have been employed previously at the Diablo Canyon facility; but the staff has noted refinements introduced by PASNY in this area that should facilitate the evaluation and utilization of results obtained in the walk-down inspections of IP-3 systems.

o With regard to treatment of other (non-seismic) types of event-induced SI's, it appears that PASNY essentially proposes to perform"enhanced" versions of the kinds of analyses already required under existing licensing requirements in this regard (e.g., Fire Protection Analyses, Flooding Protection Analyses, HELB Analyses, etc.). The "enhanced" analyses as proposed would feature increased emphasis on, and more comprehensive consideration of, nonsafety components in the vicinity of safety system components that could be damaged by failure of the nonsafety components. This proposed effort appears to go considerably beyond what is now required under existing requirements although it relies heavily on methods and criteria in existing regulatory guidance. The staff believes that such enhanced treatment of nonseismic event-induced SI's can be safety beneficial; and the methods and criteria proposed by PASNY in this regard appear acceptable to the staff within the scope intended by PASNY.

PASNY's proposed approach however, considers only direct effects of event-induced nonsafety component failures on the functioning of safety systems, i.e., nonsafety (source)/safety (target) interactions. The SI staff believes that the IP-3 study should also include some consideration of effects of event-induced nonsafety component failures on important nonsafety systems functioning and the possible resulting impact on safety system functioning, i.e., nonsafety (source)/nonsafety (target) interactions and resulting effects on safety systems. PASNY's objections to including treatment of such interactions in the IP-3 study were based on concerns regarding how to bound such analyses (e.g., would all nonsafety (target) systems within an entire compartment have to be considered with regard to effects of an event-induced steam environment). The staff recognizes the validity of such concerns, and for that reason the subsequent to the July 24 meeting suggested a reasonably-bounded approach to an initial effort in this direction that could be accomplished within the scope of the IP-3 study.

As a first step in the suggested approach, PASNY would select (subject to agreement by the staff) a representative high-energy nonsafety system. The agreed upon (source) system would be walked-down while surveying the vicinity surrounding for (target) nonsafety systems which had already been treated in the interconnected SI analysis phase of their study and had been shown to have safety significance, i.e., could adversely affect, a safety function if their own (non-safety) functioning were impaired. If a situation is found in the walk-down of the (source) high energy system in which such (target) nonsafety systems could be damaged by failure of the high energy (source) nonsafety system, a potentially adverse "coincidence" or systems interaction would have been identified.

If such potentially adverse "coincidences" were found to occur frequently, that might indicate a need for extending such analyses generically. On the other hand, if no (or very few) such potentially adverse coincidences were identified, that could be taken as additional assurance that the existing licensing basis is adequate without the need for requiring or extending this type of SI analysis. The staff believes that this limited additional effort could contribute significantly toward better definition and understanding, if not complete resolution, of this unexplored aspect of the overall systems interaction question.

III.A Safety Classification Terminologies

- The staff emphasized that, because SI analysis involves extensively the treatment of systems ranging widely in degree of importance to safety, careful use must be made of the safety classification terms which properly reflect such differences. In this context, the SI staff provided to PASNY standard definitions for three most commonly-used safety classification terms (see Enclosure 5).

IV Schedule for Completion of IP-3 SI Analysis Progress

- PASNY agreed to prepare a Final IP-3 study submittal that incorporates or addresses the staff's review comments; the revised submittal is expected to be available in late-October.

- ACRS has tentatively scheduled a meeting of the appropriate subcommittee in mid-November to discuss the revised (Final) submittal.

- PASNY estimates that completion of the actual IP-3 SI analysis effort could take 6-12 months after initiation.

List of Attendees

Indian Point 3 Systems Interaction Study

July 24, 1981

L. Olshan	NRC
J. Kelly	SAI
P. Alesso	LLNL
J. O. Thoma	NRC
J. Lamberski	PASNY
W. D. Hamlin	PASNY
Y. Kishinevsky	PASNY
K. S. Sunder Raj	PASNY
Roberto L. Goyette	PASNY
George Wilverding	PASNY
S. S. Iyer	PASNY
Edward J. Borella	EBASCO
Ralph J. Giorgio	EBASCO
Michael G. Gagliardi	EBASCO
F. Coffman	NRC
E. Chelliah	NRC
J. Conran	NRC

Enclosure 1

DETAILED MEETING AGENDA

Discussion of Indian Point 3 Systems Interaction Analysis

July 24, 1981

I. INTRODUCTION/BACKGROUND

A. NRC Philosophy on SI Analysis (NRC)

1. Concentrate on safety/nonsafety system dependencies and nonsafety system failure effects

2. Consider significant operating experience in scoping SI analysis effort and in demonstrating effectiveness of methodology employed

B. Relationship between PRA and SI (NRC)

1. Historical perspective (PRA and SI essentially complementary)

2. Current efforts (More SI included in PRA)

3. Future direction (Comprehensive PRA could include SI)

II. DISCUSSION OF INITIAL IP-3 SUBMITTAL AND NRC REVIEW COMMENTS

A. Definition of SI and Application of Single Failure Criterion

1. Degradation of safety system vs defeat of safety function (NRC)

2. Treatment of SI that aggravate accident conditions or exceed safety system capability (NRC)

3. Identification of critical safety functions and corresponding plant systems/components (e.g., how is PORV treated?) (PASNY)

B. Interconnected Systems Interaction Analysis

1. How do shutdown logic diagrams, safety system auxiliary diagrams, and auxiliary safety system commonality diagrams fit together with FMEAs and PRA event trees/fault trees to identify adverse systems interactions? (Amplify on Vol. I description) (PASNY)

2. Treatment of nonsafety control system failure effects, nonsafety power supply effects, and nonsafety instrumentation display failure effects

a. 79-22 submittal inadequate for SI purposes (NRC)

-- considers only one type of environmentally induced failure

-- does not consider all nonsafety control systems

-- based on FW HELB analysis where break sizes/ locations are chosen for direct effects on <u>safety</u> systems

b. Misinterpretation by PASNY of NUREG-0578 "requirement" for nonsafety system analysis (NRC)

c. Possible alternative approaches for treatment in IP-3 SI program

-- investigate use of Indian Point simulator (PASNY)

-- comprehensive dependency analysis (e.g., digraph) (NRC)

-- current ICSB review approach, as reflected in SNUPPS questions provided to PASNY

C. Nonconnected Systems Interaction Analysis

1. Criteria/methodology presented in Vol. I appear generally very good (NRC)

2. Should take credit explicitly for SI analysis already done in fire protection, flooding, HELB analyses, etc. (NRC)

3. Describe in greater detail how and to-what-extent SRP/Reg. Guide guidance used for SI analyses in (2) will be applied in determining effects of fire, flooding, HELB, etc., on <u>nonsafety</u> control systems, power sources, instrumentation cabling, etc. (which could in turn adversely influence safety functions) (PASNY)

III. SAFETY CLASSIFICATION TERMINOLOGIES/IP-3 HEARING ISSUES

A. Use definitions developed in NRC TMI-1 Restart Hearing Testimony (NRC)

B. Systems Interaction--Major Issue in IP-3 Hearing (What is current hearing schedule?) (PASNY)

IV. SCHEDULE FOR COMPLETION OF IP-3 SI PROGRAM

A. Final Submittal/ACRS Meeting, Sept. 1981 (PASNY/NRC)

B. NRC Audit Review/Walk-Through (NRC)

C. SER on IP-3 SI Program, March 1982 (NRC)

SYSTEMS INTERACTION PROGRAM

SCOPE

- COMMON-CAUSE FAILURES THAT:
  - -- VIOLATE RCPB INTEGRITY
    (E.G., PIPE BREAK, RELIEF/ISOLATION VALVE FAILURE, PUMP SEAL FAILURE)
  - -- DEGRADE OR DEFEAT SAFETY SYSTEMS
    (SCRAM, ECCS, RHR, & ESF)
  - -- EXCEED SAFETY SYSTEM CAPABILITIES
    (E.G., EXTREME OVERPRESSURE, OVERCOOLING
- EMPHASIS ON NONSAFETY SYSTEM FAILURE EFFECTS
  - -- PROCESS & SUPPORT SYSTEMS
  - -- EQUIPMENT FAILURE & HUMAN ERROR
  - -- FAILURE TO OPERATE & INADVERTENT OPERATION

TYPES

- NONCONNECTED SYSTEMS INTERACTIONS
  (COUPLING IS BY SHARED SPACE OR ENVIRONMENT)
- INTERCONNECTED SYSTEMS INTERACTION
  A. FIRST-ORDER
  (CHARACTERIZED BY: DIRECT CONNECTIONS: "ONE-WAY" DEPENDENCE: NO SYSTEM DYNAMICS OR FEEDBACK EFFECTS INVOLVED)
  B. HIGHER ORDER
  (CHARACTERIZED BY: PROCESS COUPLING: SYSTEMS DYNAMICS EFFECTS)
- INDUCED HUMAN ERROR
  (INSTRUMENTATION DISPLAY ERROR: ASSUME PROCEDURALLY CORRECT OPERATOR ACTION)

Enclosure 3

METHODS

- WALK-THRU OR WALKDOWN
- ANALYTICAL METHODS

  (EVENT TREE/FAULT TREE, DEPENDENCY ANALYSIS, FMEA)
- EVALUATION & EXTRAPOLATION OF OPERATING EXPERIENCE
- SIMULATION METHODS
  - TRAINING SIMULATORS

    (INTERCONNECTIONS WELL-MODELED; DYNAMICS POORLY MODELED)
  - ENGINEERING ANALYZER

    (INTERCONNECTIONS & DYNAMICS WELL MODELED)

BASIC SAFETY FUNCTIONS

- ABILITY TO ACHIEVE & MAINTAIN ENTIRE CORE SUBCRITICAL
- ABILITY TO TRANSFER DECAY HEAT TO ULTIMATE HEAT SINK
- ABILITY TO MAINTAIN RCPB
- ABILITY TO PROVIDE ENGINEERED SAFETY FEATURES

I. PURPOSE OF PRESENTATION

- TO PRESENT THE SYSTEMS INTERACTION (SI) PROBLEM IN TERMS OF PROBABILITY RISK ASSESSMENT (PRA), AND
- TO STIMULATE DISCUSSION AND ENCOURAGE FEEDBACK FROM INTERESTED GROUPS.

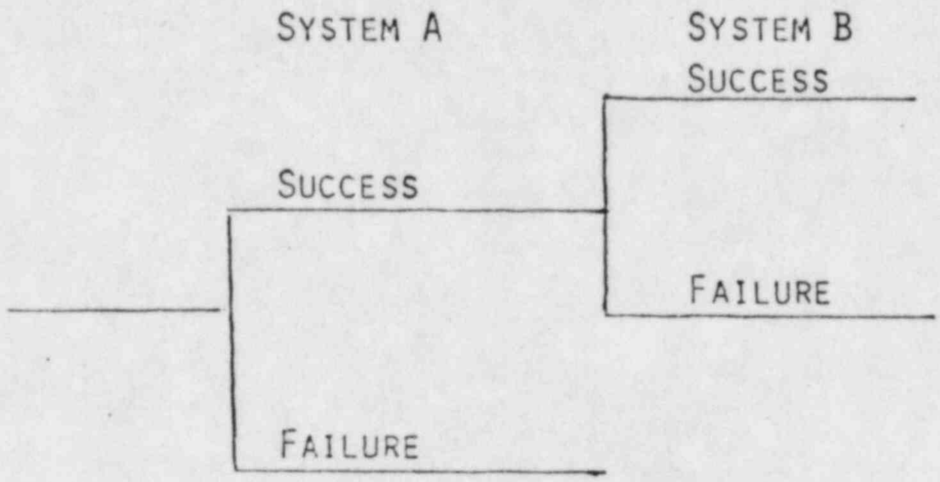
II. BACKGROUND

- EARLY REACTOR DESIGN WAS DONE WITHOUT FORMAL RISK ANALYSIS.
- THE NEED TO BALANCE THE LIKELIHOOD OF A POSTULATED SCENARIO WITH ITS CONSEQUENCES LED TO THE REACTOR SAFETY STUDY (RSS) 1975.
- SUBSEQUENT RISK ANALYSIS WAS PRA.

PRA

LEVEL 1: EVENT TREES:

- o RELATES THE SAFETY FUNCTIONS TO SYSTEMS NECESSARY TO PREVENT A CORE DAMAGE.

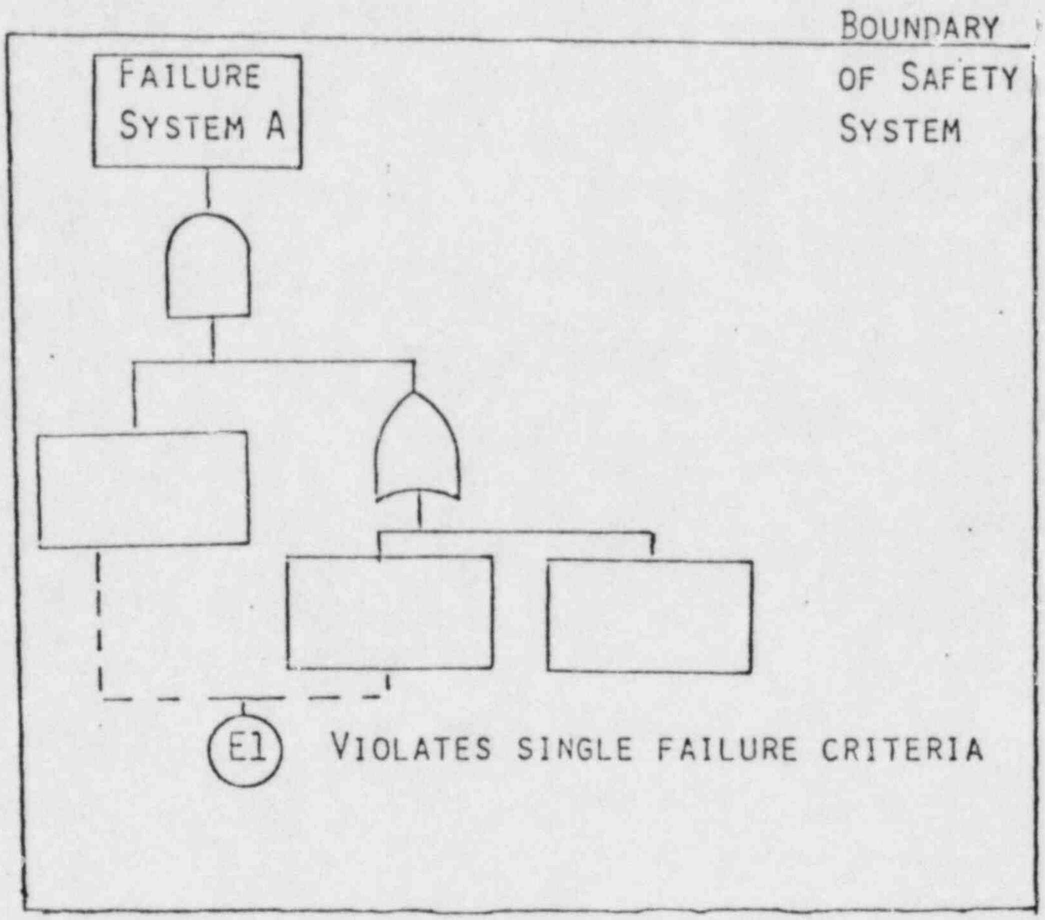


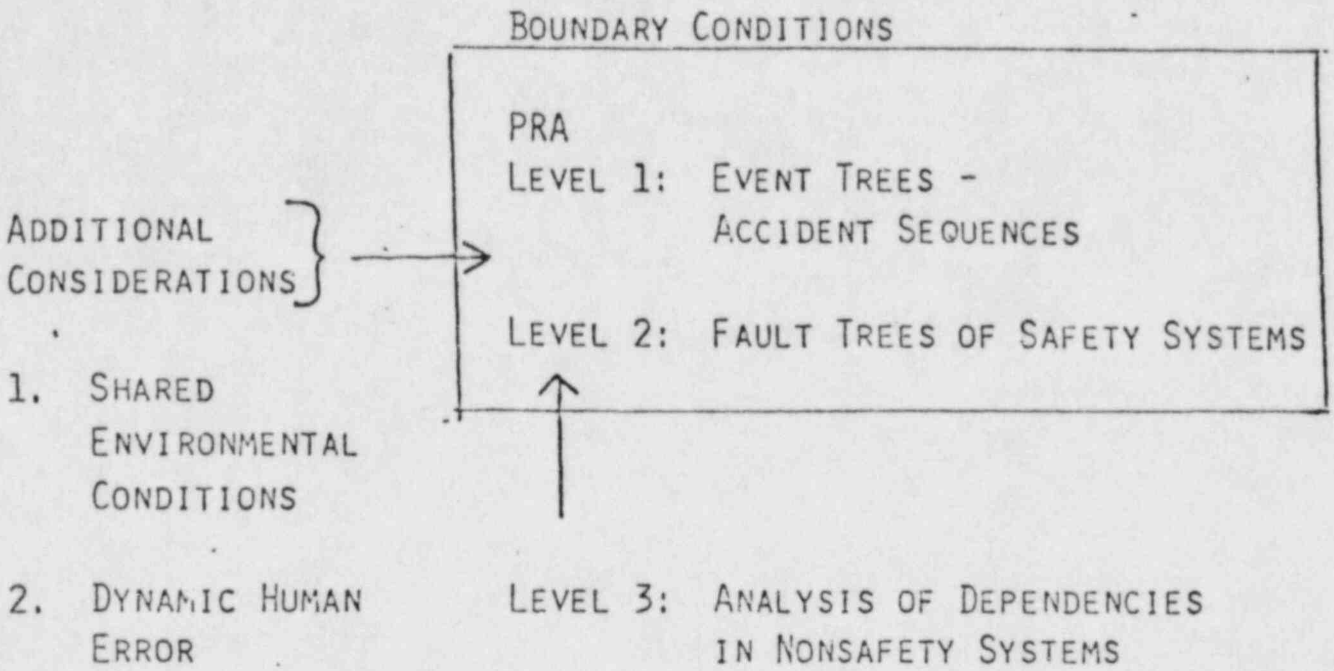
- o THE RESULTS ARE ACCIDENT SEQUENCES. USUALLY SAFETY SYSTEMS ALONG WITH THE MAIN FEEDWATER SYSTEM.

PRA

LEVEL 2: FAULT TREES:

THESE WERE USED TO DETERMINE THE FAILURE PROBABILITY FOR EACH SAFETY SYSTEM WITHIN THE ACCIDENT SEQUENCE





BOUNDARY CONDITIONS
PRA
LEVEL 1: EVENT TREES - ACCIDENT SEQUENCES
LEVEL 2: FAULT TREES OF SAFETY SYSTEMS
ADDITIONAL CONSIDERATIONS
1. SHARED ENVIRONMENTAL CONDITIONS
2. DYNAMIC HUMAN ERROR
LEVEL 3: ANALYSIS OF DEPENDENCIES IN NONSAFETY SYSTEMS

PAST LIMITATIONS OF PRA

- o LIMITED BOOLEAN COMPUTATIONAL ABILITY.
- o LACK OF FAILURE RATE DATA

RESULTS

- o SAFETY SYSTEM BOUNDARY CONDITION LIMITS.
- o APPROXIMATION FOR NONSAFETY SYSTEMS

$$P(A \wedge B) \approx P(A) \cdot P(B)$$

(OMITS SOME DEPENDENCE FROM EACH ANALYSIS)

III. THE PROBLEM

HOWEVER, ACCIDENTS SUCH AS TMI, BROWN'S FERRY, AND CRYSTAL RIVER HAVE OCCURRED, THAT HAD NOT SURFACED EXPLICITLY IN PRA.

- o ARE THE MATHEMATICAL METHODS OF PRA INADEQUATE?
- o ARE THE BOUNDARY CONDITIONS TOO RESTRICTIVE?
- o IS A NEW UNIQUE APPROACH NECESSARY?

WHY ALL THE DIVERSITY IN METHODOLOGY?

POINTS OF VIEW

- O PRA STUDIES HAVE NOT FOUND SOME SIs BEFORE AND THEREFORE MUST BE INADEQUATE.

- O SIs SHOULD BE EXAMINED IN ISOLATION.

OTHER PROBLEMS

- 0 IDENTIFYING SYSTEMS INTERACTIONS
- 0 EVALUATING SYSTEMS INTERACTIONS
  - 0 LACK OF FAILURE RATE DATA (IF PRA METHODS USED)
  - 0 CRITICISMS OF SHORTCOMINGS/LIMITATIONS USING ENGINEERING JUDGMENT, DETERMINISTIC CRITERIA, HEURISTIC TECHNIQUES ETC.

COMPUTATIONAL EFFICIENCIES HAVE IMPROVED FOR HANDLING INDEPENDENT EVENTS

- INDEPENDENT MODULES
- SUPERCOMPONENTS

WHAT ABOUT METHODS OF HANDLING DEPENDENT EVENTS?

SUCH METHODS ARE METHODS OF SYSTEMS INTERACTIONS. THEY INCLUDE:

- HEURISTIC TECHNIQUES (HAZARD INDEX)
- GRAPHED BASED LOGIC ANALYSIS
- ENHANCED PRA

COMMON CAUSE FAILURE (CCF) ANALYSIS OVERVIEW

PROBABILITY MODELS HAVE BEEN DEVELOPED TO ESTIMATE COMMON CAUSE PROBABILITIES FROM DATA

PROBABILITY MODELS ARE BEING APPLIED TO LER AND NPRDS DATA TO OBTAIN CCF PROBABILITY ESTIMATES

CCF DATA ARE BEING CLASSIFIED BY SCENARIO VARIABLES TO IDENTIFY FACTORS CAUSING HIGH CCF PROBABILITIES

SUBJECTIVE ENGINEERING APPROACHES BEING DEVELOPED TO QUANTIFY CCF PROBABILITIES BY PLANT VARIABLES

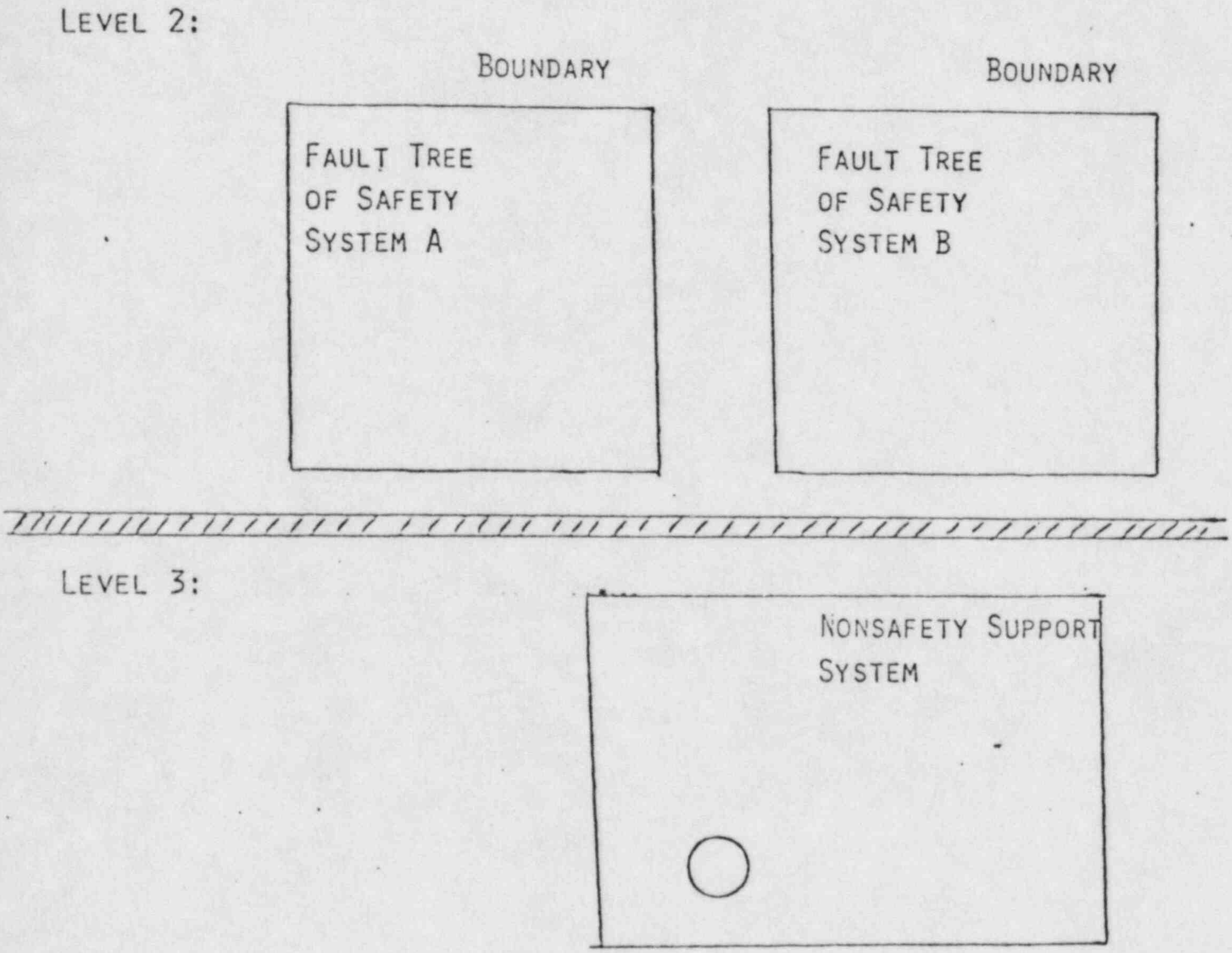
IV. ENHANCED PRA

THERE IS NOTHING FUNDAMENTALLY WRONG WITH THE MATHEMATICAL METHODS USED IN PRA.

ITS BOUNDARY CONDITIONS SHOULD BE EXTENDED WITH EMPHASIS ON DEPENDENT FAILURES SUCH AS:

- SHARED ENVIRONMENTAL CONDITIONS
- NONSAFETY SUPPORT SYSTEMS
- DYNAMIC HUMAN ERROR

WE SEEK


LEVEL 2:
BOUNDARY
FAULT TREE
OF SAFETY
SYSTEM A
BOUNDARY
FAULT TREE
OF SAFETY
SYSTEM B
LEVEL 3:
NONSAFETY SUPPORT
SYSTEM

V. SUMMARY

SYSTEMS INTERACTION ANALYSIS CAN BE AN EXPANSION OF THE BOUNDARY CONDITIONS OF PROBABILITY RISK ASSESSMENT ANALYSIS USING THE SAME TOOLS AS THE PRA, BUT DEVELOPING A MORE DETAILED EMPHASIS ON DEPENDENT FAILURES.

DEFINITION OF TERMS

Important to Safety

- Definition - From 10 CFR 50, Appendix A (General Design Criteria) - see first paragraph of "Introduction."

  "Those structures, systems, and components that provide reasonable assurance that the facility can be operated without undue risk to the health and safety of the public."

- Encompasses the broad class of plant features, covered (not necessarily explicitly) in the General Design Criteria, that contribute in important way to safe operation and protection of the public in all phases and aspects of facility operation (i.e., normal oepration and transient control as well as accident mitigation).

- Includes Safety-Grade (or Safety-Related) as a subset.

Safety-Related

- Definition - From 10 CFR 100, Appendix A - see sections III.(c), VI.a.(1), and VI.b.(3).

  "Those structure, systems, or components designed to remain functional for the SSE (also termed 'safety features') necessary to assure required safety functions, i.e.:

  (1) the integrity of the reactor coolant pressure boundary;

  (2) the capability to shut down the reactor and maintain it in a safe shutdown condition; or

  (3) the capability to prevent or mitigate the consequences of accidents which could result in potential off-site exposures comparable to the guideline exposures of this part.

- Subset of "Important to Safety"

- Regulatory Guide 1.29 provides a LWR-generic, function-oriented listing of "safety-related" structures, systems, and components needed to provide or perform required safety functions. Additional information (e.g., NSSS type, BOP design A-E, etc.) is needed to generate the complete listing of safety-related SSC's for any specific facility.

  Note: The term "safety-related" also appears in 10 CFR 50, Appendix B (Q.A. Program Requirements); however, in that context it is framed in somewhat different language than its definition in 10 CFR 100, Appendix A. That difference in language between the two appendices has contributed to confusion and misunderstanding regarding the exact meaning of "safety-related" and its relationship to "important to safety" and "safety-grade." A revision to the language of Appendix B has been proposed to clarify this situation and remove any ambiquity in the meaning of these terms.

Safety-Grade

- Term not used explicitly in regulations but widely used/applied by staff and industry in safety review process.

- Equivalent to "Safety-Related," i.e., both terms apply to the same subset of the broad class "Important to Safety."

ASB REVIEW COMMENTS

A-3.2 Loss of Air to Speed Controller TDAFW?

Not on Table A-3 or Fig. A-2.1

A-1.2 Did not consider loss of non-safety grade control systems. Justified by response to IE notice 79-22 via IPN-79-74, Oct. 11, 1979.

A-2.1.1 Acceptance criteria that AFW is delivered within 30 minutes of initial demand - How can this be backed up as the required time for AFW initiation for all accidents - It may take 30 minutes to boil dry but flow may have to be initiated earlier for the AFW system to "catch up" and prevent dryout.

Also, is dryout sufficient criteria since the accident analyses in Chapter 15 uses other criteria.

A-2.2.3 & A-2.2.5 What about toronado protection for the condensate storage tank?

Fig. A-2.1 Sheet 3 of 9 M-6, M-7 - Should mention that pumps are protected by automatic trip. (Will correct operator action assumption - JHC, per PASNY 7/24/81)

Should have PAS/RRAB look at Fault Trees and ICSB look at logic diagrams and electrical failures; on surface the electrical failures look OK.

General

Power/Air failures are evaluated with respect to individual components and their effect on the system. What about a combination of these components if one electrical/air failure can affect groups of components? For instance, a complete loss of A-C power (on & off) would affect many of the components in Fig. A-2.1. How is the scenario followed in this report?

Enclosure 6