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Reliability of Emergency AC Power Systems at Nuclear Power Plants

Prepared by R. E. Battle, D. J. Campbell

Oak Ridge National Laboratory

Prepared for
U.S. Nuclear Regulatory Commission

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GLOSSARY OF TERMS

Basic event. An initiating fault requiring no further development in a fault tree.

Basic event importance. A measure of the fraction of system undependability contributed by a basic event. It is the sum of the probabilities of all cutsets containing the basic event of interest divided by the probability of the top event.

Common-cause failure (CCF). Multiple failures attributed to a single cause.

Cutset importance. A measure of the fraction of system undependability contributed by a cutset. It is the probability of the cutset of interest divided by the probability of the top event.

Dependability. See undependability.

Diesel generator (DG). A diesel engine(s), auxiliary subsystems, and ac generator connected to generate ac power.

Distribution system. That portion of a power system in a power plant that delivers electric energy to the plant loads.

Division. A system or set of components designed to have physical, electrical, and functional independence from a redundant system. Train and channel are interchangeable with division.

Emergency ac power system. Two or more redundant, standby ac power supplies designed to furnish electric energy when the offsite ac power system is not available. The emergency ac power system may also be called the onsite ac power system.

Failure on demand. Failure of a system to start when it receives a start signal (see Table 4.1).

Failure to run. Failure of a system to continue to function after it has successfully started (see Table 4.1).

Gas turbine generator (GT). A gas turbine, ac generator, and auxiliary subsystems connected to generate ac power. The system may simply be called a gas turbine.

Generic configuration. A system that is representative of typical systems, but that is not modeled after any specific plant.

Hardware common-cause failure. A CCF that resulted from a design error or hardware failure.

Human-error common-cause failure. A CCF that resulted from operator or maintenance personnel error.

Minimal cutset. A unique group of basic events all of which must occur to cause the top event mission. For an emergency ac power system, the mission is to supply sufficient ac power to cool the reactors while offsite ac power is unavailable.

Nuclear plant. One or more nuclear units at a single site.

Nuclear unit. A single nuclear steam supply system and its associated equipment.

Offsite ac power system. A system that supplies ac power either from the transmission grid or from the main turbine-generator.

Reliability. The probability that device will perform its purpose adequately for the period of time intended under the operating conditions encountered.

Standby failure rate. The expected number of failures in a given time interval during which the equipment of interest is not operating.

Station blackout. An occurrence during which there is insufficient ac power available for the electrically powered equipment needed to cool a reactor core.

Success criteria. This is expressed as the number of DGs required of the number available to prevent a station blackout if offsite ac power fails.

Switchyard. The electrical buses, breakers, and associated equipment that interface between the utility transmission system and the plant distribution system.

Test and maintenance (T&M) unavailability. The probability that a system will be inoperable when it is required because of scheduled maintenance.

Top event. In a fault tree, the top event is system failure (e.g., failure of an onsite power system to provide sufficient ac power).

Undependability. The probability that a system will fail to start or fail to continue to run for the entire mission.

HIGHLIGHTS

Reliability of emergency onsite ac power systems at nuclear power plants has been questioned within the Nuclear Regulatory Commission (NRC) because of the number of diesel generator failures reported by nuclear plant licensees and the reactor core damage that could result from diesel failure during an emergency. Because of these considerations, the NRC classified the loss of all ac power (station blackout) at a nuclear plant an unresolved safety issue. The NRC requested Oak Ridge National Laboratory (ORNL) to develop a technical basis to help resolve this issue. This report contains the results of a reliability analysis of the onsite ac power system, and it uses the results of a separate analysis of offsite power systems to calculate the expected frequency of station blackout.

Included is a design and operating experience review. Eighteen plants representative of typical onsite ac power systems and ten generic designs were selected to be modeled by fault trees. Operating experience data were collected from the NRC files and from nuclear plant licensee responses to a questionnaire sent out for this project. A total of 1526 events are categorized by failure type for 120 diesel generators, along with data on the number of starts, scheduled maintenance, and repair times for 86 diesel generators.

Important contributors to onsite power system reliability vary from plant to plant, but among the important contributors are the following:

(1) diesel generator failure probability, for which the industry-average is 2.5×10^{-2} and the range is 8×10^{-3} to 1×10^{-1},

(2) human-error and hardware failure common-cause failure, for which the unavailabilities range from 1×10^{-4} to 4.2×10^{-3},

(3) scheduled maintenance unavailability during reactor operation for which the industry-average is 6×10^{-3} and the range is 0 to 3.7×10^{-2},

(4) diesel repair time, for which the average is 20 h and the range is 4 to 92 h,

(5) plant service-water system unavailability, for which the independent failure probability is 2×10^{-3}, the common-cause failure probability is 8×10^{-5}, and the unavailability for scheduled maintenance is 2×10^{-3}.

For the 18 plants modeled, the median probabilities that the onsite power system will fail on demand vary from 2.2×10^{-4} to 4.8×10^{-2}. Sensitivity of the onsite system unreliability to contributors 1-3 listed above is analyzed, and costs of decreasing the probabilities of failure for these contributors are estimated. The important factors affecting onsite ac power system reliability are dependent upon plant-specific features. These features may be independent diesel failure, scheduled diesel downtime, service water unavailability, or common-cause failure of the diesels.

Independent failure of diesel generators is an important contributor to the probability of failure of an onsite ac power system, but significantly reducing the industry-average probability of independent diesel failure will be difficult because there is no single subsystem that dominates the failure probability. Common-cause failure probability may be reduced inexpensively by improving operating and maintenance procedures and eliminating some design features which have a common-cause failure potential. Plants which have two reactors and which require two-of-three diesels to cool both reactors after a loss of offsite power have the least reliable diesel configuration. By adding a diesel, such a plant could improve the onsite ac system reliability by a factor of 5 to 10. However, the approximate cost to add a 3000-kW diesel is $20-$30 million. The costs and reliability improvement for other, less expensive modifications are also included in this report.

1. INTRODUCTION

This report discusses and gives results of a reliability study of emergency onsite ac power systems at U.S. nuclear power plants. The results of a study of offsite power reliability[1] are incorporated with the results of this study to estimate the frequency of the loss of all ac power (station blackout). Station blackout at a nuclear power plant severely hinders the ability to provide cooling to the reactor core by disabling all normal and most emergency cooling systems. Furthermore, station blackout disables most other engineered safety feature systems whose function is to contain radioactive material in the event of a reactor accident. This wideranging dependence of safety systems on ac power is why a number of nuclear power plant risk assessments have identified station blackout as a major contributor to risk.[2,3]

The results of this study are useful to the U.S. Nuclear Regulatory Commission (NRC) as part of their analysis of unresolved safety issue A-44, Station Blackout,[4] and to nuclear power plant licensees who seek to improve the reliability performance of their onsite ac power systems. The NRC's analysis of station blackout, summarized by Task Action Plan A-44, calls for assessment of the frequency of station blackout and assessment of the risk associated with accident sequences initiated by station blackout. This study, the study reported in ref. 1, and a study of station blackout initiated accident sequences[5] complete these assessments.

Onsite power system reliability was calculated for 18 nuclear power plants or units and for 10 generic designs. The frequency of station blackout or failure of an onsite ac power system for the plants or units identified in this report are based on the available design and operational information, but there may be features unknown to us which could affect the reliability of a plant. Specific plants were selected to estimate onsite ac power system reliability based on the most realistic data available, but the reliability estimates calculated for the specific plants should be considered to be representative of a plant with the design and operational features identified in this report. A purpose of this report was to identify design and operational features that are important to onsite ac power system reliability, not to estimate reliabilities for 18 plants.

1.1 BACKGROUND AND SCOPE

Most nuclear power plants have three sources of ac power: plant generator, offsite power grid, and onsite emergency ac power system.

When a normally operating reactor is shut down, ac power for core cooling pumps and other equipment is supplied from either an offsite power grid (normal condition) or an onsite ac power system (emergency condition).

Because of the potentially undesirable consequences of a station blackout, the NRC has declared that station blackout is an unresolved safety issue. To develop a technical basis for resolving this issue, the NRC has initiated a program described in Task Action Plan A-44, Station Blackout, and has funded several projects under this program. The goals of these projects include the following two tasks:

(1) estimate the frequency of station blackout at operating U.S. nuclear power plants, and
(2) determine plant responses to station blackout and the risk associated with station blackout-initiated accident sequences.

Task 1 is divided into two subtasks:

(1) estimate the frequency of loss of offsite power for the various plant locations, and
(2) estimate the probability that the onsite ac power system will fail to supply sufficient ac power for core cooling, given a loss of offsite power.

This study reports the results for Subtask 2. This study also estimates the frequency of station blackout at U.S. nuclear power plants by incorporating the results of Subtask 1.

The initiating event of interest to this study is a loss of offsite power. A simultaneous loss-of-coolant accident (LOCA) and loss of offsite power is not considered. The expected frequency of a LOCA is estimated to be small enough that it need not be considered here.

1.2 OBJECTIVES

The objectives of this study are threefold:

(1) Assess the range of onsite ac power system reliabilities at operating U.S. nuclear power plants.
(2) Determine major factors that influence onsite ac power system reliability.
(3) Incorporate the results of the offsite power system reliability analysis to assess the frequency of station blackout at operating U.S. nuclear power plants.

Objective 1 is accomplished by determining point estimates and uncertainty bounds for onsite ac power system undependability for 18 individual plants representing a variety of onsite ac power system design configurations and 10 representative onsite ac power system design configurations.

The undependability of a system is the probability that the system fails to start or fails to run for some mission length. (See Table 4.1 for failure definitions.) The mission length for the onsite ac power system is the length of time offsite power is unavailable.

Objective 2 is accomplished through analysis of detailed diesel generator experience data collected over the five-year period from 1976 through 1980, analysis of the importance of basic events (basic initiating faults that require no further development in a fault tree) and minimal cut sets to the onsite ac power system undependability results, and analysis of the sensitivity of the onsite ac power system results to changes in basic event failure probabilities. The diesel generator experience data analysis seeks to determine correlations between observed diesel generator reliabilities and a number of factors that might influence diesel generator reliability. The results of the importance and sensitivity analyses identify those events whose failure contributes most to onsite ac power system undependability. This allows determination of where to focus efforts to improve onsite ac power system reliability.

Objective 3 is accomplished by using the frequency and duration of loss of offsite power[1] and multiplying by onsite ac power system undependability for the duration of the loss of offsite power. The results are frequencies of station blackout as a function of duration of the loss of offsite power for the 18 specific plants and the 10 representative onsite ac power system design configurations.

1.3 TECHNICAL APPROACH

This study used fault trees to model the onsite power systems analyzed. Detailed onsite ac power system design information was collected for 18 plants. The sources of information are final safety analysis reports, licensee reponses to a questionnaire associated with NUREG/CR-0660,[6] and visits and telephone conversations with plant personnel.

In addition, the diesel generator configuration at each operating light water reactor was determined to assure that the plants selected for detailed study are representative of the U.S. nuclear power industry.

Failure probabilistics of onsite ac power system equipment used in the fault tree analyses are based on a detailed review of industry experience over the five-year period from 1976 through 1980. Detailed operating history data were obtained from licensee event reports (LERs), licensee responses to a questionnaire associated with NUREG-0737,[7] and licensee responses to a questionnaire associated with this study.

Data analyzed by the operating experience review include diesel generator failures, demands, maintenance times, and modifications.

2. SYSTEMS DESCRIPTIONS

An emergency onsite ac power system can be divided into power supplies and power distribution equipment.

Emergency ac power supplies at U.S. nuclear power plants are usually diesel generators, although one plant uses a gas turbine generator and another plant has an onsite hydroelectric generator. Emergency power distribution equipment at nuclear power plants is all class 1E (see IEEE Standard 308-1980).

Previous ac power system reliability studies have shown that failure to supply power to emergency buses is much more probable than failure to distribute power that is available on an emergency bus.[2,3] Therefore, the analyses in this study focus on the emergency power diesel generators. Design features which affect the onsite power system reliability are the ac power subsystems and the diesel generator configuration. Some types and designs of diesel subsystems were shown to be more reliable than others. The diesel generator configuration refers to the number of diesel generators at a plant and the number required for successful operation of the onsite ac power system. Diesel generator configuration is identified by the success logic at each plant in this report (e.g., 1 of 2 refers to a plant with 2 diesel generators, 1 of which is required for success).

The method of cooling diesels is actually a specific diesel subsystem design feature, but it is included as part of the system design configuration because the system failure probability is strongly dependent on whether the diesels are water-cooled or air-cooled. System design configurations are identified by the diesel generator configuration and the method of cooling the diesel generators (e.g., 1 of 2: service-water-cooled refers to a plant with two water-cooled diesel generators, 1 of which is required for success).

The following subsections discuss: 1) diesel generator subsystems, 2) diesel generator configurations, 3) normal and emergency ac power flow in a typical nuclear power plant, and 4) special or significant design features of onsite ac power systems. These special design features include diesel generator cooling methods and dc power supplies.

2.1 DIESEL GENERATOR SUBSYSTEMS

A diesel generator consists of a diesel engine, a generator, and a number of support subsystems required for operation. These include air- or electric-start, combustion air, control, cooling, exciter, exhaust, fuel oil, governor, load sequencer, lube oil, output breaker, turbocharger, ventilation, and voltage regulator subsystems.

Most of these support subsystems serve one diesel generator and no other plant equipment. Possible exceptions are cooling (which may depend on plant service water), fuel oil, and air-start. Some plants have connections between fuel oil subsystems and air-start subsystems for different diesel generators.

Diesel generators also rely on dc power for starting and control. This power is supplied by station batteries or dedicated diesel generator batteries.

Appendix 9.1 discusses failure modes and operation of the diesel generator subsystems that have caused most of the diesel failures.

2.2 DIESEL GENERATOR CONFIGURATION

An emergency ac power system consists of at least two separate Class 1E divisions to provide power needed to cool the reactor core during a reactor accident or loss of offsite power. In Table 9.1 (Appendix 9.1) most of the operating plants in the U.S. are categorized by their diesel generator configuration, that is, the plants are grouped by the number of diesel generators and whether they are dedicated, shared, or swing. A dedicated diesel generator serves only one division in one unit, but in some units there may be a connection between divisions that permits the operator to supply power from one division to the other. This connection is usually interlocked such that two diesel generators cannot supply the same bus simultaneously. A shared diesel generator normally supplies a division in one reactor unit, but it can be connected to a division in another unit. A swing diesel generator supplies either division in a single unit. A diesel generator that is shared and swing can be connected to either division in either of two units.

2.3 NORMAL AND EMERGENCY AC POWER FLOW FOR A TYPICAL UNIT WITH TWO DIESELS

This section describes, for a typical nuclear plant, the normal power flow, circuit breaker actuation after a unit trip or loss of offsite power, and diesel generator start and load after loss of all offsite power. Unit trip and loss of offsite power are the most important initiating events for this study. The physical system described here is Millstone 2, but some of the descriptions of transfer logic are based on what is typical for the industry and may not apply specifically to Millstone 2.

The normal power flow from the main plant generator to the main stepup transformer, to the switchyard, and then to the utility transmission network is shown in Fig. 2.1. A portion of the main generator power flows to the normal station service transformer, where the voltage is transformed through secondary windings X and Y to 6.9 kV and 4.16 kV, respectively. Power to all of the plant loads flows through this transformer during normal operation. The reserve station service transformer

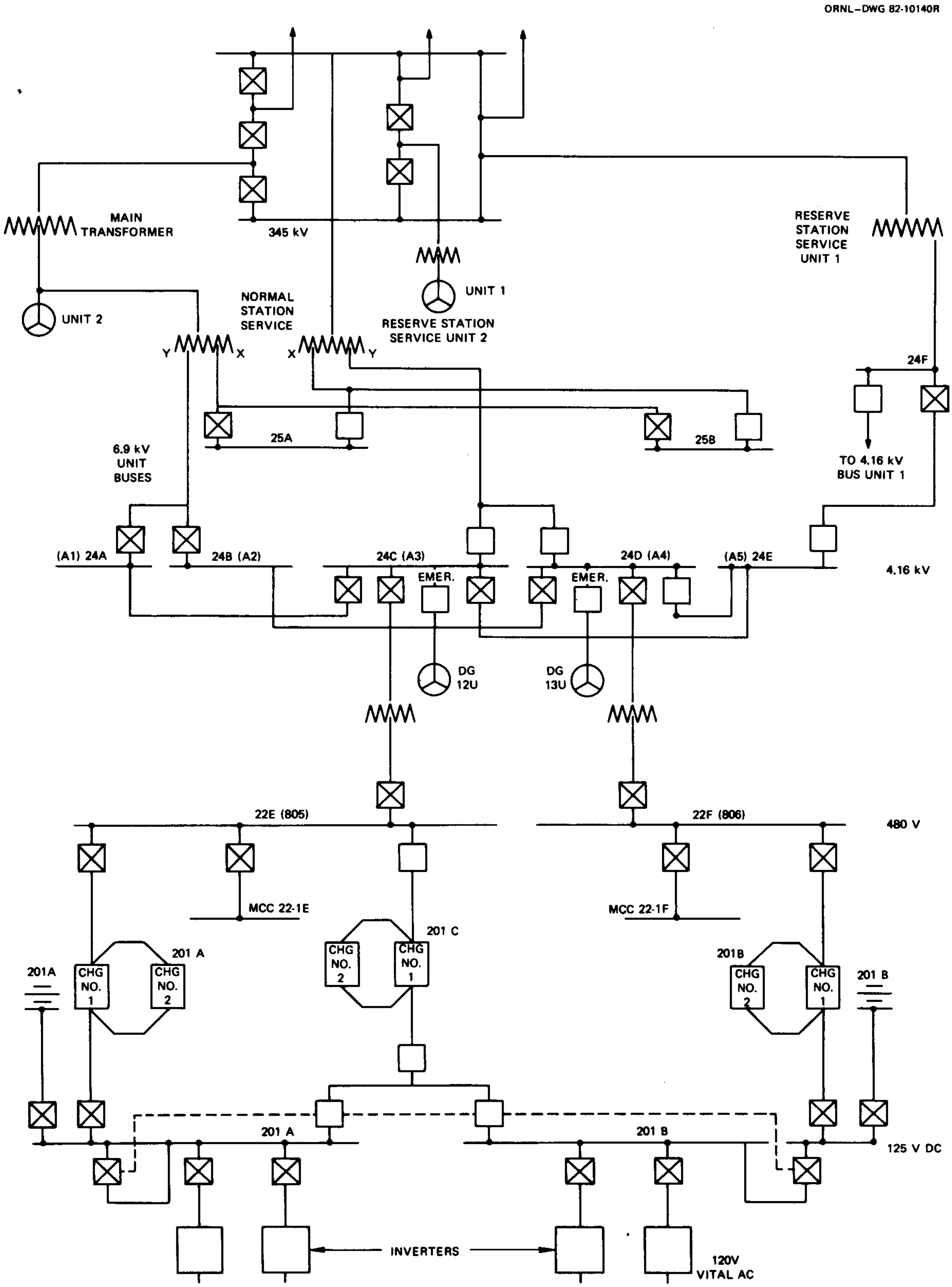

Fig. 2.1. Typical power distribution system.

(preferred source) is energized from the 345-kV switchyard during normal operation, but there is no load on this transformer because the feeder breakers for connecting it to the 6.9-kV and 4.16-kV buses are open during normal operation.

In response to a unit trip signal, the unit trip relays cause two switchyard breakers to open and isolate the main generator. The 6.9-kV and 4.16-kV bus feeder breakers from the unit transformer automatically open, and the normally open breakers connected to the reserve station service transformer close. This transfer of power is a fast, dead-bus transfer (one source is removed before the other is connected) that must be done within about six cycles of the power frequency; otherwise the transfer is blocked. This transfer must be done rapidly to ensure that the motors remain synchronized with the source. Voltage-decay, delayed transfer may be used as a backup to the "fast" transfer. In this "slow" transfer, voltage generated by the decelerating motor loads is allowed to decay to approximately 30% before the preferred source breaker is closed. Manual breaker control can be used if necessary.

All nuclear plants are required by GDC-17, Part 50, Appendix A,[8] to have two sources of preferred power, but only one source has to be immediately available. Millstone 2 has three 345-kV lines and another source from the reserve station service transformer that normally supplies Unit 1. This transformer in Unit 1 can be manually connected to supply the shutdown loads for Unit 2, but it does not have the capacity to supply the startup loads for Unit 2.

If preferred power from the reserve station service transformer is lost, the feeder breakers to the 6.9-kV and 4.16-kV buses open. Undervoltage relays on the 4.16-kV emergency buses provide a start signal to the diesel generators. When the diesel generator terminal voltage and frequency reach a preset value, the output breaker closes automatically. Breaker interlocks prevent connecting the diesel to a bus that is already connected to another power source.

After the diesel generator output breaker closes, a load sequencer begins to connect emergency loads to the 4-kV bus. These loads are sequenced onto the bus at different times to avoid overloading the diesel with the heavy startup load of several motors.

2.4 SPECIAL DESIGN FEATURES

The methods of cooling diesel generators and supplying dc control power to them are two design features that affect reliability of onsite ac power systems and can affect other plant safety systems as well. The diesels are cooled by water or forced ambient air. The dc control power is supplied either by Station 1E batteries or batteries dedicated to each diesel generator.

2.4.1 Diesel Generator Cooling

Diesels cooled by plant service water are equipped with heat exchangers. Hot water from the diesel jacket flows through one side of the heat exchanger and cooling water flows through the other. When the diesel generator is not operating, cooling water does not flow through the heat exchanger; but when the diesel starts, a tachometer generates a signal that opens a valve through which cooling water flows to the heat exchanger.

Diesels cooled by air have radiators through which hot water from the diesel jacket flows. Air is forced through the radiator by an engine-driven or electric-motor-driven fan. The advantage of an air-cooled diesel is that it is independent of the plant service water system. Therefore, service water system failure does not contribute to onsite ac power system failure.

2.4.2 Diesel Generator DC Control Power Source

At most installations, dc power for control of a diesel generator is supplied by a Station 1E battery, but in some plants it is supplied by a dedicated battery. A dedicated battery supplies power to control the diesel generator, but it does not supply power to control the generator output breaker or to control power for other emergency bus feeder breakers. For this reason, a plant with a dedicated diesel battery cannot supply emergency power unless the Plant 1E battery and the dedicated battery are both available.

2.5 PLANTS SELECTED FOR DETAILED ANALYSIS

Eighteen plants were selected for detailed ac power system reliability analysis. These plants are a representative sample of the onsite ac power system design configurations at U.S. nuclear power plants. The ac power system descriptions for these plants are presented in Appendix 9.1.

3. STATION BLACKOUT FAULT TREES

By fault tree analysis the failure logic associated with station blackout was delineated for each of the selected 18 plants. This section describes the development of three of these fault trees, Davis-Besse, Millstone 1, and Millstone 2. The Davis-Besse tree represents a logic that exists at most plants, but those for Millstone 1 and 2 are significantly different from a typical plant. The trees for other plants are similar to the Davis-Besse tree except that their generator failure logic may differ and some may have air-cooled diesels rather than water-cooled diesels. Appendix 9.2 contains system definitions and fault tree diagrams for each of the remaining 15 plants selected for review.

3.1 DAVIS-BESSE FAULT TREE

3.1.1 System Definition

Redundant divisions supply ac power for safety-related equipment at Davis-Besse. Appendix 9.1 discusses the Davis-Besse distribution system. Each division has a 4-kV safety bus that distributes power to emergency loads, including a battery charger for the associated dc division. During reactor operation, the main generator is the source of power to the 4-kV safety buses. During shutdown, the normal source of power is offsite. If offsite power is unavailable, each 4-kV safety bus receives power from its diesel generator. If offsite power is unavailable and neither diesel generator is available, station blackout exists.

It is possible for a 4-kV safety bus to be energized, yet be unable to supply power to any of its loads. The most likely cause would be failure of the diesel generator's load sequencer. Since the load sequencer is considered to be an integral part of the diesel generator, this event is implicitly modeled in the fault tree. The only other likely cause would be multiple failure of breakers and/or transformers. Since such event combinations are rare, they are neglected in this study with little effect on the quantitative results.

A diesel generator system includes a diesel engine, generator, output breaker, load sequencer, logic and control systems, and support equipment required to start or run the diesel generator. Service water and station dc power are modeled separately in a fault tree because they provide support to plant equipment other than the diesel generators. Support systems included with a diesel generator are those that serve only the diesel generator; these include air-start, jacket water cooling, lube oil, fuel oil, combustion air, exhaust, turbocharger, governor, exciter, and voltage regulator. Appendix 9.1 discusses these diesel generator subsystems in detail.

3.1.2 Fault Tree Development

The Davis-Besse station blackout fault tree (Fig. 3.1) is typical for a single-unit plant with two diesels cooled by water. Station blackout occurs if offsite power is unavailable and the emergency onsite ac power sources fail to supply adequate power. Loss of offsite power is analyzed in ref. 1.

Four distinct types of events or event combinations contribute to failure of onsite ac power sources to supply power:

(1) independent failures of diesel generators or their support systems,
(2) common-cause failures (CCFs) of diesel generators or their support systems (this includes diesel generator human error contributions),
(3) testing and maintenance (T&M) of diesel generators, and
(4) T&M of service water systems.

Independent Failures. Two redundant diesel generator systems supply onsite ac power when the reactor is shut down and offsite power is unavailable. System success is guaranteed if one diesel generator, its associated service water train, and its dc power division start and operate for the duration of the loss of offsite power. On the other hand, if both diesel generators are simultaneously unavailable coincident with a loss of offsite power, station blackout results.

Diesel generator and support system CCF. There are four different components or systems identified to be analyzed for common-cause failure:

(1) diesel generators resulting from hardware failure,
(2) diesel generators resulting from human error contributions,
(3) service water systems,
(4) station batteries.[9]

Items 1 and 2 are discussed in Sect. 5, and items 3 and 4 are discussed in ref. 5. Additional information on station batteries is in ref. 9. A brief discussion of these events follows.

Failures of service water systems because of common causes include all events that completely disable both service water trains. However, it is possible that one or both trains could be available but not able to cool the diesel heat exchangers because of valve or pipe failures. These latter events are explicitly accounted for in the common-cause analysis of the diesel generators, and are not accounted for in the common-cause analysis of the service water.

The station battery common-cause analysis includes any event that simultaneously deenergizes both station dc buses. When ac power is available to a dc bus, the battery on the bus is being charged. After a

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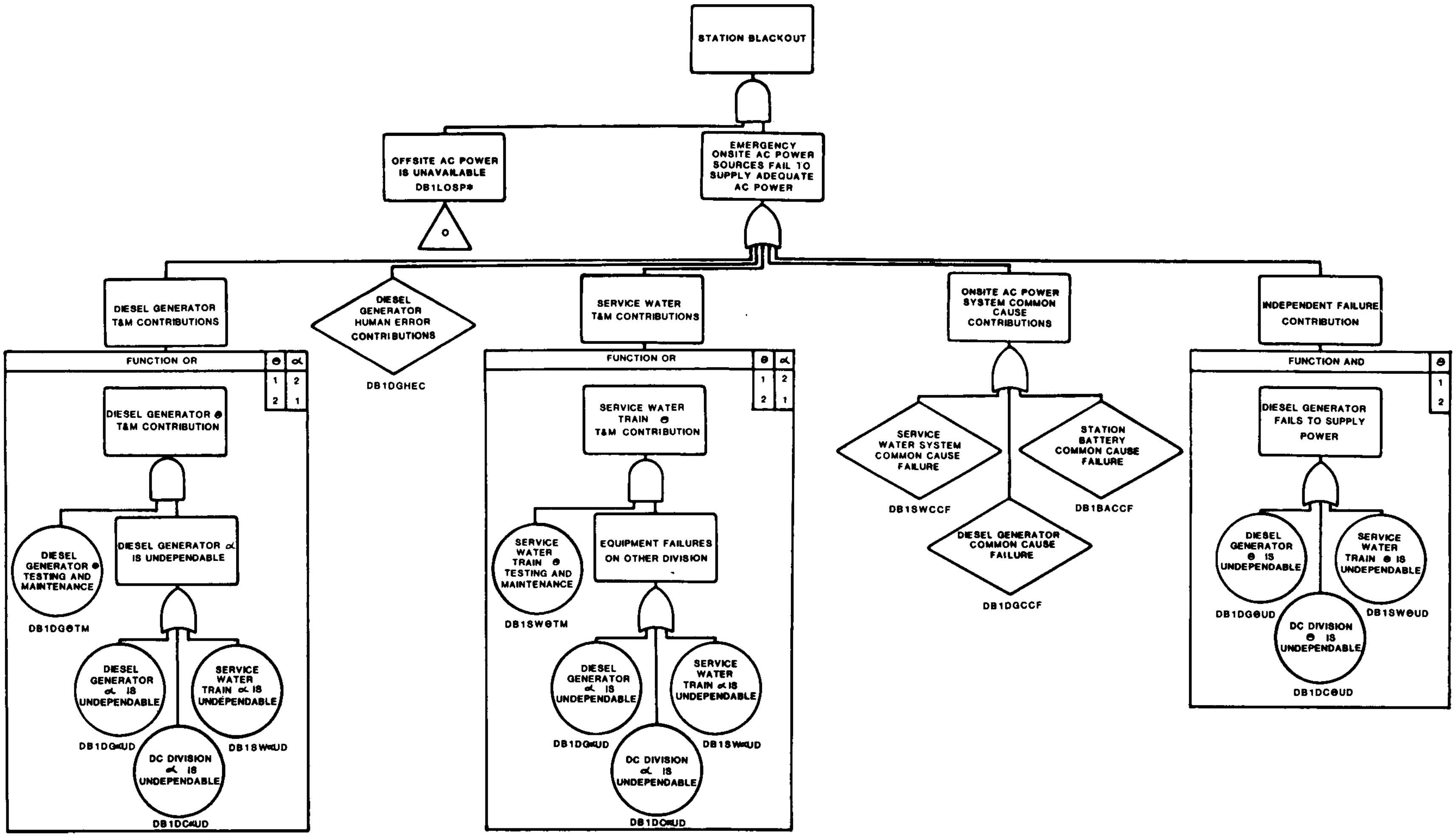

Fig. 3.1. Davis-Besse fault tree.

loss of offsite power but before the diesel generators are connected, station batteries are the only power sources to the dc buses. Diesel generators cannot be put into service without dc power. It is only during this time period that common-cause failure of the station batteries alone can cause failure of the onsite power system. Even though this time period is short, nearly all of the contribution to the probability that both dc buses are deenergized occurs during this period.

Diesel Generator T&M Contributions. Only one of the two diesel generators is allowed by technical specifications to be out of service for testing and maintenance during normal reactor operation. If offsite power is lost while a diesel generator is down for T&M, a coincident failure of the redundant onsite power division results in station blackout. This type of combination of events makes up the diesel generator T&M contribution.

Although it is a violation of technical specifications to simultaneously shut down both diesels for T&M, such events have occurred. This violation is considered by analysis of common-cause failures to be caused by human error.

Service Water T&M Contributions. These contributions are similar to those attributable to diesel generator T&M except that a service water train is down for maintenance. It is also a technical specification violation to remove a diesel generator from service for T&M at the same time the redundant division's service water train is out of service and vice-versa.

3.2 MILLSTONE 1 AND 2 FAULT TREES

Table 3.1 defines the Millstone 1 system. The fault tree for Millstone 1 (Fig. 3.2) is similar to that for Davis-Besse; however, Millstone 1 has one diesel generator and one gas turbine generator. Otherwise, the failure logic is the same as that for Davis-Besse because either onsite power source is capable of supplying the emergency load.

Table 3.2 defines the Millstone 2 system. The Millstone 2 fault tree (Fig. 3.3) differs from that for Davis-Besse and Millstone 1 in that the sources of control power for the switchyard breakers are the station dc buses (the same buses that supply the diesel generators), and in that the offsite and one division of onsite power both rely on dc bus "1." At Millstone 2, if dc bus 1 is deenergized, the reactor trips and both emergency 4-kV buses are deenergized. In this case, when loss of dc bus 1 is the initiating event, diesel generator 1 can not start, and the only way to avoid a station blackout is for diesel generator 2 to start and run until power is restored to dc bus 1. The left side of the Millstone 2 tree models this situation.

The right side of the Millstone 2 tree is the same as that for Davis-Besse, except a loss of both dc divisions from a common-cause

Table 3.1. Millstone 1 fault tree systems definitions

Emergency generator success criterion

One of two emergency generators is required. There is an emergency diesel generator and an emergency gas turbine generator.

Cooling requirements

The emergency diesel generator is cooled by service water train 1. The gas turbine generator is air cooled.

DC power requirements

DC power division 1 provides power to start and control the emergency diesel generator and to control breakers within ac power division 1. DC division 2 provides power to control ac division 2 breakers.

Special features

A dedicated dc battery provides power to start and control the emergency gas turbine generator.

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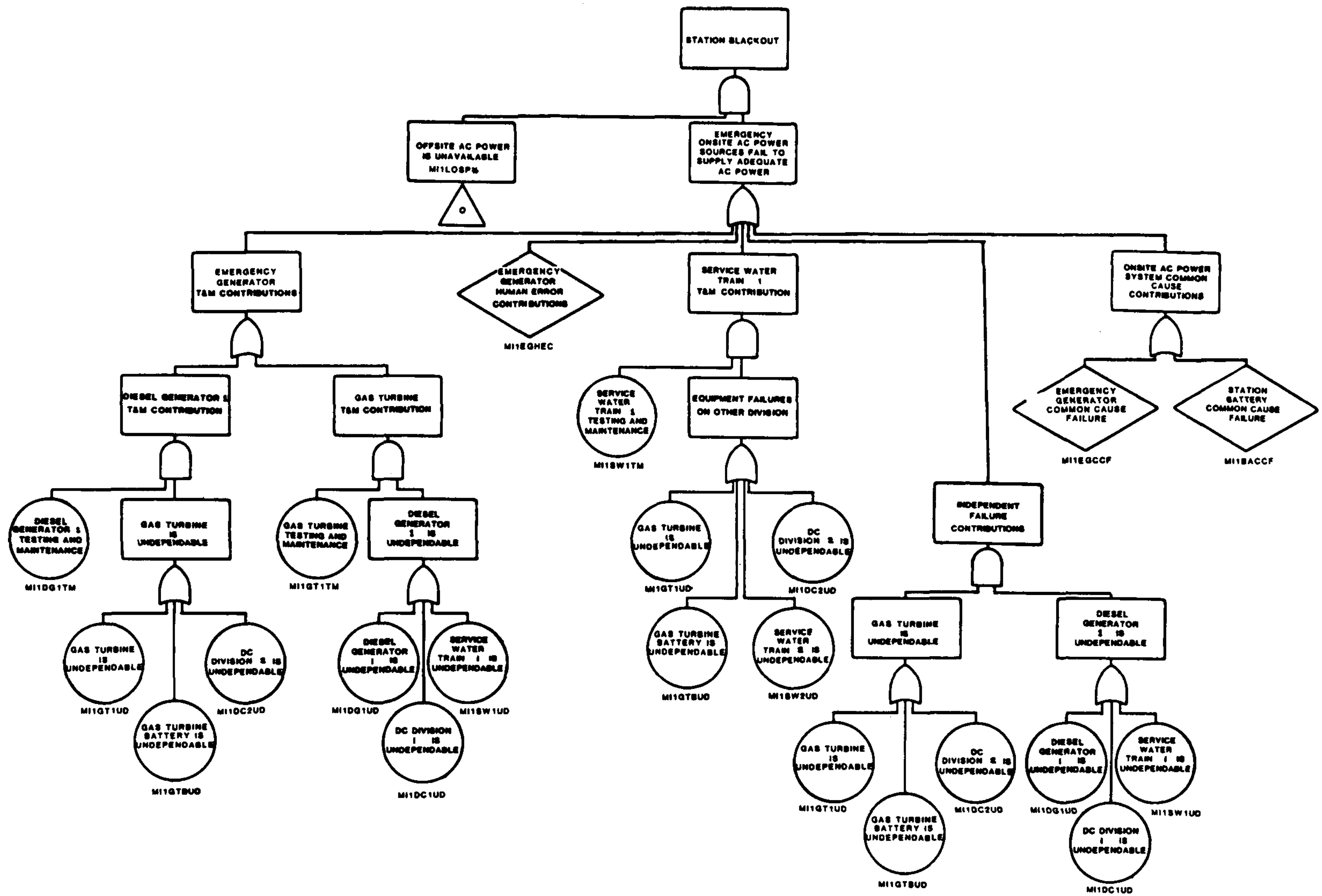

Fig. 3.2. Millstone 2 fault tree.

Table 3.2. Millstone 2 fault tree systems definitions

Diesel generator success criterion

One of two emergency diesel generators is required.

Cooling requirements

Each emergency diesel generator is cooled by a separate service water train. Service water train 1 cools diesel generator 1, and train 2 cools diesel generator 2.

DC power requirements

Each dc power division provides power to start and control its dedicated diesel generator and to control the breakers within the associated ac power division distribution system. DC division 1 supplies power to diesel generator 1, and dc division 2 supplies power to diesel generator 2.

Special features

A station blackout can occur from failure of dc power division 1 (which disables offsite power and division 1 of ac power) and failure of ac power division 2. The failure of ac power division 2 can be caused by:

diesel generator 2 is undependable,
dc power division 2 is undependable,
service water train 2 is undependable,
diesel generator 2 is in test and maintenance, or
service water train 2 is in test and maintenance

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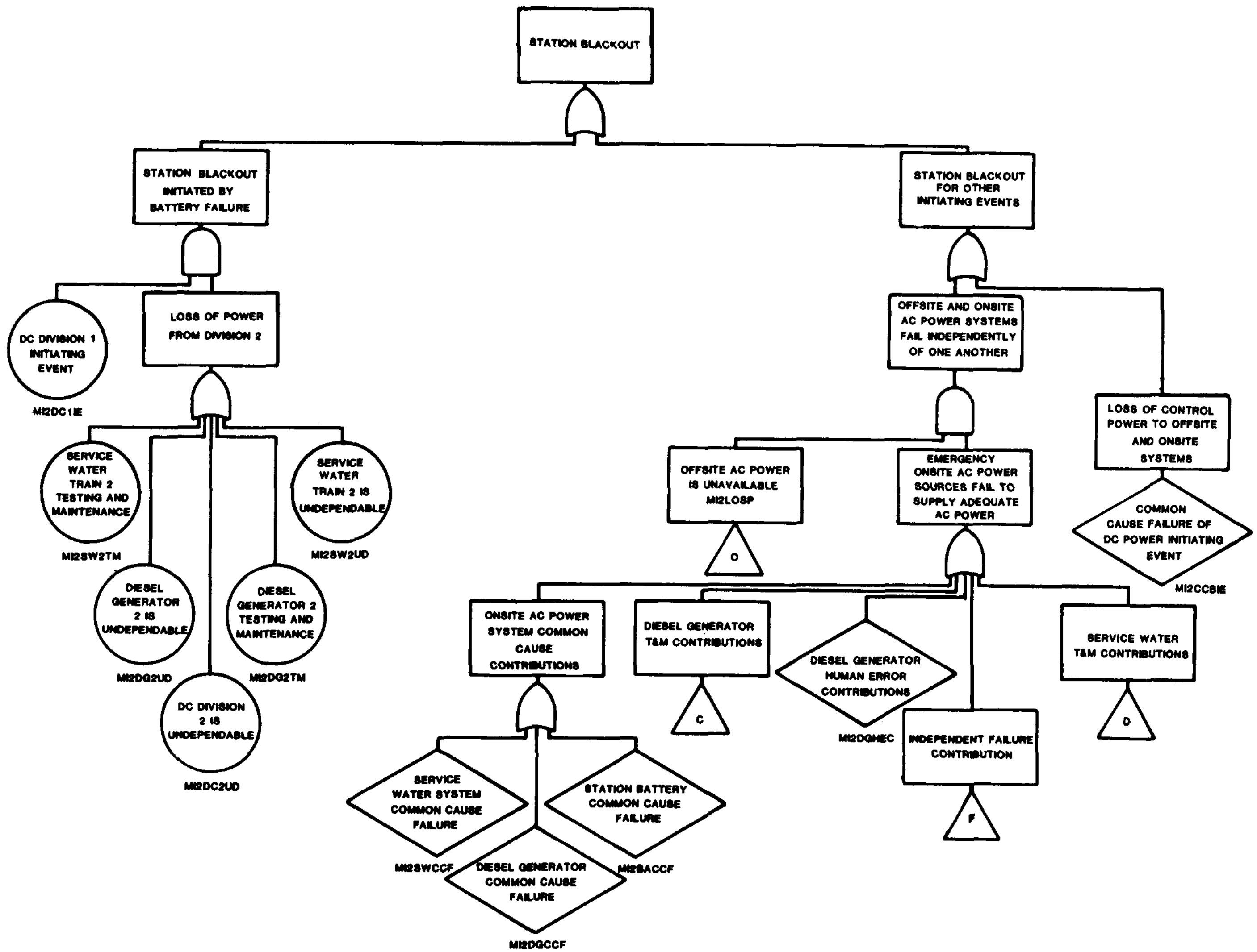

Fig. 3.3. Millstone 1 fault tree.

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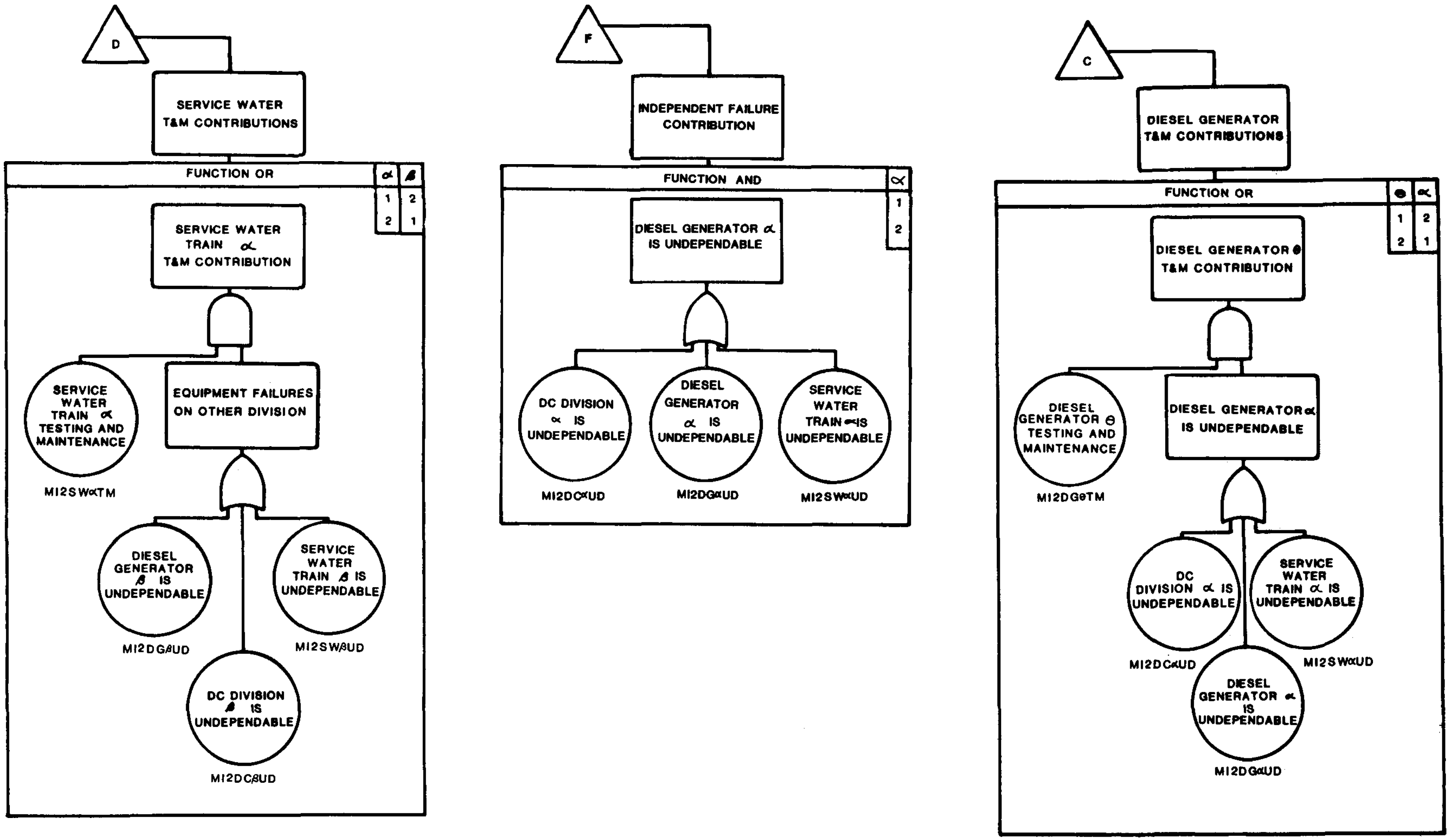

Fig. 3.3. Continued.

will, by itself, cause a station blackout. The likelihood of this event is extremely small if the two dc buses are never cross-connected.

3.3 OTHER FAULT TREES

The remaining information concerning fault trees and systems definition (Appendix 9.2) contains events similar to those described in this section. The fault trees differ because the ac power system designs have different failure (or success) logic. Other differences arise because some plants cool their diesel generators with radiators instead of heat exchangers. Table 3.3 lists the diesel generator success logic and the method of diesel cooling for the 18 plants analyzed in this study.

Table 3.3. Design features that affect fault trees

Plant	Diesel generator	
	Success logic	Cooling
Arkansas Nuclear One 1	1 of 2	water
Brunswick 1 and 2	2 of 4	water
Calvert Cliffs 1 and 2	2 of 3	water
Donald C. Cook 2	1 of 2	water
Crystal River 3	1 of 2	air
Davis-Besse	1 of 2	water
Dresden 2 and 3	2 of 3	water
Joseph M. Farley 1 and 2	2 of 5	water
James A. FitzPatrick	1 of 4	water
Edwin I. Hatch 1 and 2	2 of 5	water
Millstone 1	1 diesel generator or 1 gas turbine	water (DG) air (GT)
Millstone 2	1 of 2	water
Nine Mile Point	1 of 2	water
Peach Bottom 2 and 3	2 of 4	water
St. Lucie	1 of 2	air
San Onofre	1 of 2	air
Turkey Point 3 and 4	1 of 2	air
Yankee (Rowe, Mass.)	1 of 3	air

4. DIESEL GENERATOR HISTORICAL DATA

The analysis of the diesel experience data had two main objectives: (1) to estimate reliability parameters needed to quantify the station blackout fault tree events involving diesel generators, and (2) to learn which are the important factors that affect the reliability of diesel generators.

This section primarily addresses objective 1, with supporting data that also address objective 2 (Sects. 9.4 and 9.5). Diesel generator failures attributable to common causes are treated separately in Sect. 5.

4.1 DATA SOURCES

Detailed historical data were collected for this study, including failures, start attempts for testing or for actual demands, scheduled and unscheduled maintenance outage times, repair times, and diesel generator modifications. The period concerned is from 1976 through 1980, or for newer plants, from the date of initial criticality through 1980.

The sources of data were as follows:

(1) abstracts of LERs from the Nuclear Safety Information Center (NSIC) computer file,
(2) emergency component cooling system (ECCS) equipment outage data submitted to the NRC by licensees in response to a questionnaire associated with NUREG-0737,[7]
(3) diesel generator data submitted to the NRC by licensees in response to a questionnaire prepared as a part of this study (Appendix 9.3).

4.2 EVENT SCREENING

Each event from the data sources was screened and assigned to one of several event types as listed and defined in Table 4.1. Figure 4.1 is a flow chart of the classification procedures.

Section 9.4 in the Appendix tabulates each diesel generator event. The data presented are the LER number (for those events which are described by an LER), the event date, the diesel generator involved, the downtime (either repair time or maintenance outage time), the event type, the subsystem responsible, a brief description of the cause, and comments.

Table 4.1. Event type definitions

Event type	Definition
Primary failure to start	A diesel generator fails to start on a test or actual demand because of an "end-of-life" or intrinsic component failure that prevents the diesel from supplying power to the emergency bus on a loss of offsite power.
Primary failure to start, no start attempt	The same definition as a "primary failure to start" except that this failure is detected by inspection instead of by a start attempt.
Primary failure to run	Similar to a "primary failure to start" except that the diesel generator must reach rated speed and voltage, supply the desired load, and reach equilibrium conditions prior to the failure.
Secondary failure to start	Similar to a "primary failure to start" except that this failure is caused by an external influence and the failed component is not accountable for the failure.
Secondary failure to start, no start attempt	The same as a "secondary failure to start" except that this failure is detected by inspection instead of by a start attempt.
Secondary failure to run	Similar to a "primary failure to run" except that this failure is caused by an external influence.
Autostart failure	A diesel generator fails to start on test or actual demand, but it is capable of being started manually immediately after it does not start automatically.
Autostart failure, no start attempt	The same as an "autostart failure" except failure is detected by inspection instead of by a start attempt.

Table 4.1. (continued)

Event type	Definition
Nonfailure I	A technical specification is violated (e.g., a surveillance test is not performed on time), but the diesel generator involved is fully operable and requires no maintenance in order to supply power to the emergency bus on a loss of offsite power.
Nonfailure II	A diesel generator is capable of supplying power to the emergency bus on a loss of offsite power, but it is declared inoperable and removed from service for scheduled or unscheduled maintenance.

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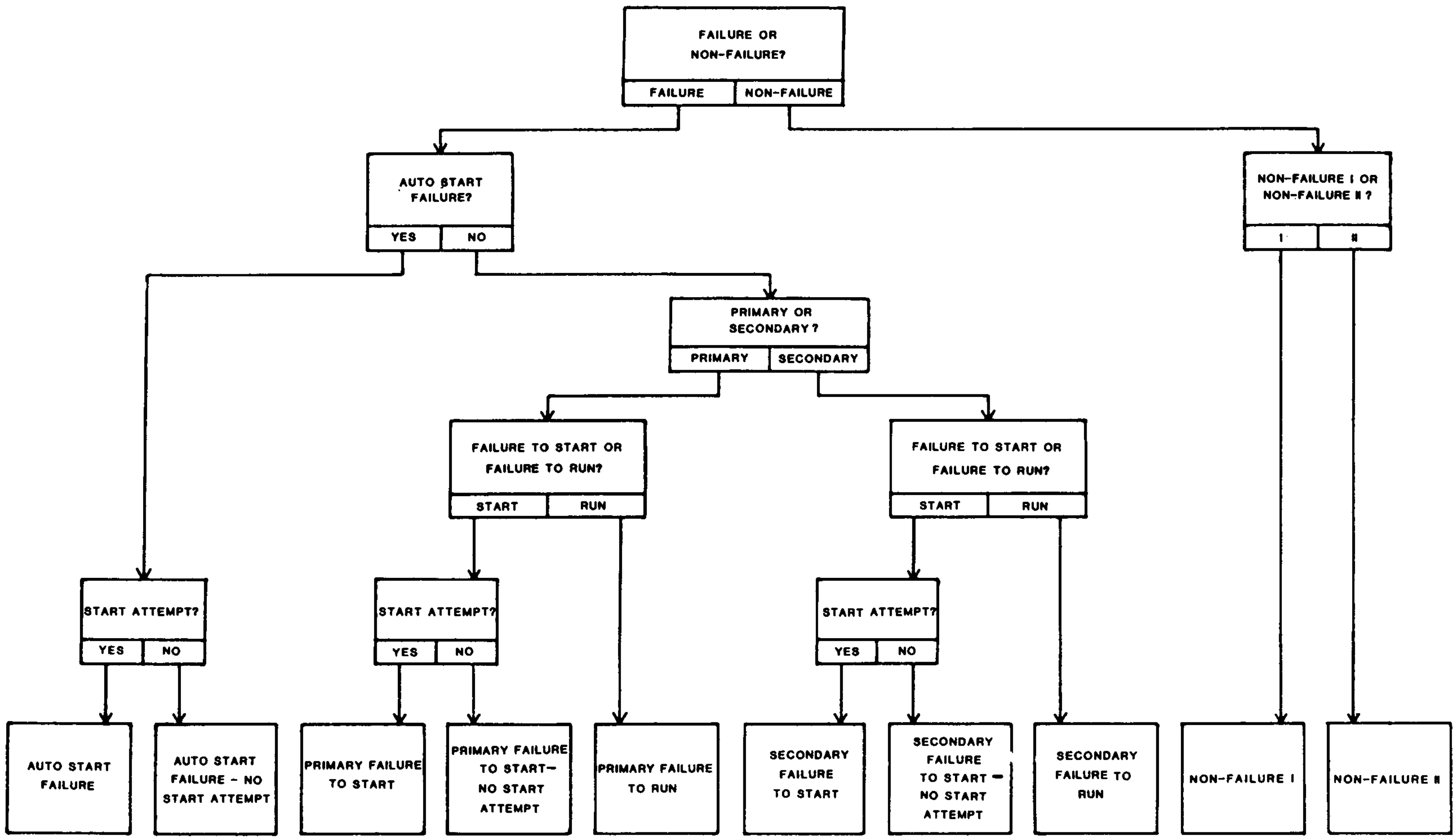

Fig. 4.1. Event classification flowchart.

4.3 DEMAND DATA

Licensee responses to the station blackout questionnaire included the number of demands placed on each diesel generator during each year from 1976 through 1980. These demands arose from routine surveillance tests, special tests, verification of repairs, safety injection actuations, and bus undervoltage actuations.

Some start attempts were not counted as demands. Although several plants started each diesel generator twice during a routine surveillance test, only one start per test was counted as a demand. Start attempts to verify maintenance or repairs were not counted as demands, nor were failures that occurred during these attempts counted as failures.

Section 9.5.1 presents and discusses the diesel generator demand data. Figure 4.2 summarizes the demand data as a histogram of the average number of demands per diesel generator per year (averaged over a 5-y period for each diesel). This distribution is for 86 diesels for which demand data were reported in response to our questionnaire. The number of demands ranges from 12 to nearly 100 per year.

4.4 MODIFICATION DATA

Licensees responding to the station blackout questionnaire reported diesel generator modifications. Equipment and procedures are modified to avoid recurring failures or to improve the operator's ability to monitor and control the diesel. The frequency of modifications varies from one in 5 y to about four per year.

Vendors of diesel generators recommend modifications based on their field experience or on general design improvements. Some licensees have reported that they modified their diesels as recommended by their vendors, but other licensees with the same kind of diesels reported none.

In most cases, the data are insufficient for assessment of the effects of modification of a diesel on its reliability. One exception is as follows: Prior to November 1978, the Joseph M. Farley diesels experienced seven air-start subsystem failures attributable to moisture in the air. Air driers and stainless steel piping were installed in November 1978, and since then no air-start subsystem failures have occurred.

4.5 DATA ANALYSIS

This section is concerned with quantification of the probabilities of the basic events in fault tree analysis of station blackouts. The diesel generator events in these trees are independent failures, T&M unavailabilities, and common-cause failures. Common-cause failure probabilities are treated separately in Sect. 5. Probabilities of

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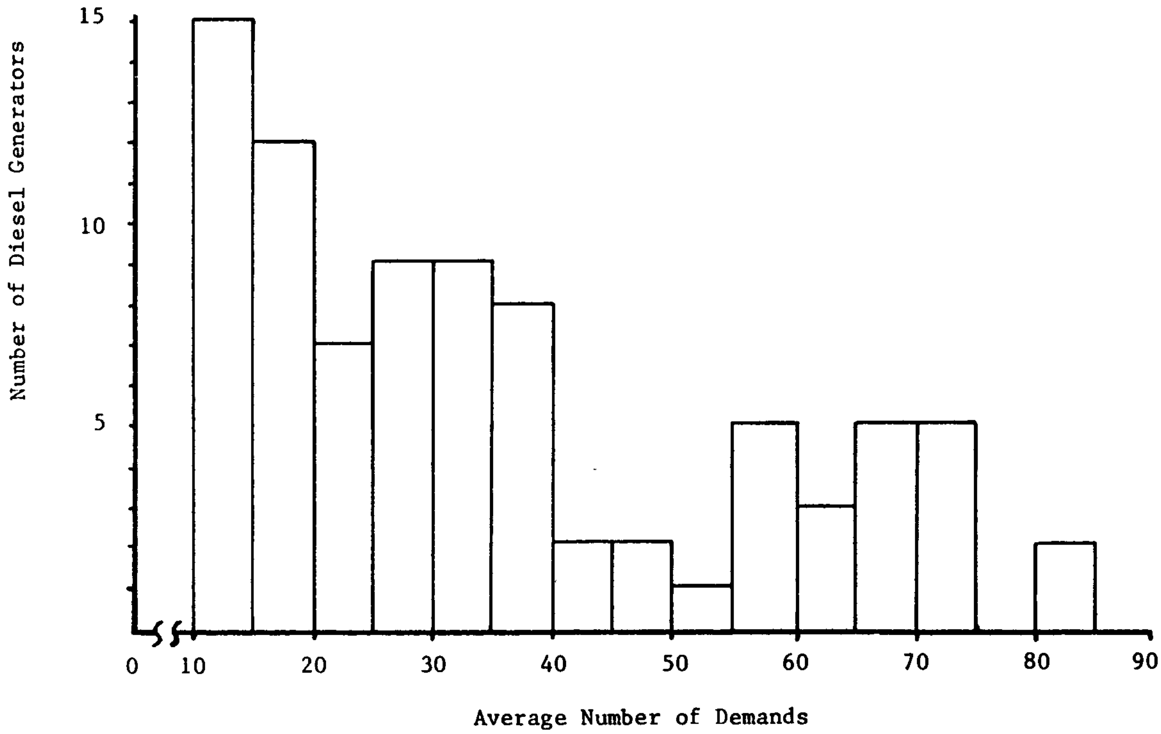

Fig. 4.2. Number of diesel generators vs number of demands per year (1976-1980).

independent failures, T&M, and diesel repair are treated in the following subsections. Section 9.5 of the Appendix presents an analysis of diesel failure data, which although it is not essential to quantification of the station blackout fault trees, it is useful to help understand the factors affecting diesel reliability.

4.5.1 Failure to start

Most of the diesel failures are classified by event screening as primary and secondary failures to start. Primary and secondary failures to run are infrequent because most of the data come from tests in which the diesels run for only 1 h. The relatively large number of failures to start provides sufficient data for one to estimate the probability that a diesel will fail to start on both an industry-wide basis and a plant-specific basis for most plants.

Three parameters that influence the probability that a diesel will fail to start include stresses induced by a start attempt, the failure rate for the diesel entering the state "loss of capability to start" while in standby, and the time since the last start attempt.

A general model that approximates the probability of failure to start that accounts for all three parameters, assuming standby failures have a constant failure rate, is

$$P_{FTS} = q + \lambda t \tag{4.1}$$

where P_{FTS} is the probability of a failure to start, q is probability that stresses induced by a start attempt cause a failure, λ is standby failure rate, and t is time since the last start attempt.

The error of the approximation is small if $\lambda t < 0.1$. For a particular diesel generator, q and λ are fixed but unknown quantitites, and t is a stochastic variable.

If the only attempts to start a diesel are made during regularly scheduled tests, with a time interval T between tests, the probability of a failure to start on any test is

$$P_{FTS} = q + \lambda T. \tag{4.2}$$

Also for this situation, the average probability of failure to start on a loss of offsite power is

$$P_{FTS} = q + \lambda T/2 \tag{4.3}$$

if the expected rate of loss of offsite power is constant during the interval between tests.

Values for q and λ can be estimated from failure data collected for a diesel. However, the analyst must be able to distinguish time-dependent failures that occur during standby from those caused by stresses induced by start attempts. This study found that these two causes of failure are indistinguishable in most cases because the information contained in event reports is insufficient for this purpose. Some failures are discovered by inspection, and, without a subsequent start attempt made, these failures are assumed to be the result of time-dependent failures that occurred during standby.

For this study, the general model given by Eq. (4.3) could not be used since both λ and q cannot be determined. Therefore, two other models for the probability of failure to start can be analyzed. The first assumes that all failures to start are caused by stresses induced by start attempts. Failures discovered by inspection are ignored. The second assumes that all failures to start are time-dependent during standby and accounts for inspection-discovered failures as well as test-discovered failures.

For the first model, if all failures to start are caused by stresses induced by start attempts, we can write:

$$P_{FTS} = q. \tag{4.4}$$

The maximum likelihood estimate of q is the number of failures observed divided by the number of start attempts. If all start attempts of a diesel are equally spaced in time, this model conservatively predicts the probability of failure to start even if all failures are not caused by stresses induced by start attempts. However, if the start attempts are not evenly spaced and some failures are time-dependent during standby, this model can underestimate the probability of failure to start following a loss of offsite power.

For the second model, if all failures to start are time-dependent during standby, we can write:

$$P_{FTS} = \lambda t. \tag{4.5}$$

The maximum likelihood estimate of λ is the number of failures observed divided by the time period over which they are observed. To predict the probability of failure to start, Eq. (4.5) is averaged over the time interval between tests. If the time at which each start attempt occurs is known, an integral average failure probability can be determined.

However, since the times of many start attempts are not known in advance, this model is not applicable for prediction of a failure probability in the future. A past history of start attempts could be used to obtain an average probability of failure to start, but Sect. 9.5.1 of the Appendix shows that there are substantial variations in the number of start attempts for a given diesel from year to year. This model will conservatively predict an average failure probability if all failures are caused by equipment deterioration during standby, and if the maximum time allowed between tests by technical specifications is assumed always to be the time between start attempts. In this case,

$$P_{FTS}(av) \leq \lambda T_{\underline{max}/2} \qquad (4.6)$$

where T_{max} is the test interval specified in the technical specification. Eq. (4.4) may underestimate the probability of a diesel failure to start if the historical start attempts are not evenly spaced and a significant number of the failures are time-dependent during standby. Equation (4.6) may underestimate the probability of a diesel failure to start if routine surveillance tests account for almost all of the start attempts and a significant number of the failures are caused by stresses induced by start attempts. Since start attempts are not generally evenly spaced and most diesels are started much more frequently than required by routine surveillance test schedules, Eq. (4.6) gives a better estimate of the probability of failure to start for diesels. This model is always conservative if the actual number of start attempts is more than twice the number required for routine surveillance tests.

Table 9.5.13 summarizes the primary and secondary failure to start data collected for this study. Autostart failures can increase the probability of failure to start. Although autostart failures do not necessarily cause a diesel generator failure as defined in this study, an autostart failure not corrected by operator action can do so. The events we classified as autostart failures were corrected by operator action, but this may not always be the case in an emergency. Therefore, some fraction of the autostart failure rate should be added to the standby rate for primary and secondary failures. This study adds 20% of the autostart failure rate to the standby failure rate. There is no statistical evidence to support using 20%, but we believe it is conservative. Table 9.5.14 is similiar to Table 9.5.13, except the data apply to autostart failures.

4.5.2 Failure to Run

A number of problems arise in estimating the failure rates of operating diesels. For one, most diesel generator experience comes from tests in which the running time is short. Then the cumulative operating time between failures to run is not a good estimate of the time to failure because many startup and shutdown transients occur between failures to run; and a lot of standby time, which contributes to failures to run, is accumulated. In addition, the operating failure rate will be higher during the earliest part of a run because of failures which existed when the diesel started but did not cause immediate failure of the diesel.

To calculate a failure to run rate, this study examined all events in which diesel generator runs were scheduled for 6 h or longer. The number of failures occurring during these extended runs was divided by the cumulative run time to estimate the operating failure rate. Table 9.5.15 summarizes these data.

The same operating failure rate is applied to all diesels analyzed by this study. The rate is 2.4×10^{-3} failure/h.

4.5.3 Repair

The estimated mean-time-to-repair for the diesel generators is the average repair time for all primary and secondary failures. The mean-time-to-repair is the parameter in an exponential repair distribution used in the onsite ac power system reliability analysis. Section 9.4.3 of the Appendix presents the repair times for each plant and discusses the diesel repairs. The median of the plant-specific mean-time-to-repair used in the generic fault tree analysis is 20 h.

4.5.4 Testing and Maintenance

Testing and maintenance outage times for diesel generators are based on experience at the plants. Section 9.4 of the Appendix discusses and tabulates T&M unavailabilities. The industry-average unavailability for T&M is 6×10^{-3}.

5. DIESEL GENERATOR COMMON-CAUSE FAILURE ANALYSIS

Fault trees developed in this work (Sect. 4 and Appendix Sect. 9.2) contain single events that represent the failure of multiple diesel generators. These events, called CCFs, are the result of design or operational dependencies that exist among diesel generators within a plant. A review of diesel generator system designs and operating experience provides the basis for the CCF analysis.

Diesel generator CCF susceptibility was assigned to two causes: hardware failure and human error. All of the events in Sect. 9.4 categorized as secondary failures were reviewed to determine if a hardware failure or human error CCF occurred or if there was potential for CCF. During this review the events were ranked by importance for use in the calculation of CCF rates. (See Tables 9.6.1 and 9.6.4 for event ranks.)

The diesel generator hardware CCF events were further classified into specific CCF susceptibility groups (see Tables 9.6.2 and 9.6.3). Each plant susceptible to specific CCF mechanisms would be a member of those susceptibility groups. Some CCF susceptibilities are common to all plants. Thus, each plant is susceptible to a generic CCF susceptibility and may be a member of one or more specific CCF groups as well.

Estimation of diesel generator CCF rates for this analysis was based on a binomial failure rate (BFR) model.[10,11] The BFR computer program was used to calculate generic and group-specific CCF rates. The CCF failure rate for a specific plant was taken as the sum of the generic CCF rates and the specific CCF rates.

The following two sections describe the methods and results of an analysis of CCFs attributed to hardware failures and human errors.

5.1 QUALITATIVE HARDWARE CCF ANALYSIS

A review of LERs identified 32 hardware-related potential or actual common-cause events. Each event was assigned a significance rank. A rank of C1 was applied to events that are CCFs of two or more diesel generators and a C2 rank to single failures that would not be easily detected and could result in a CCF. Some single failures with secondary causes were not considered important from a CCF standpoint. Assignment of a significance rank to events involves subjective judgment. Therefore, two reviewers performed the ranking and reached agreement on the significance ranking of each event.

Table 9.6.1 lists 12 events that have a rank of C1 or C2. These events were classified into six areas of CCF susceptibility (Table 9.6.2). Two of these areas represent generic susceptibility to

CCF (fuel blockage and room temperature), and the remaining four are applicable only to specific groups of plants.

Fuel system blockage is a generic susceptibility because all diesel generator fuel supply systems have fuel suction lines from a day tank or an integral fuel oil tank that could become blocked by sludge or solid objects. A review of the fuel system designs revealed no outstanding characteristic that would make one plant more susceptible to fuel blockage than another.

Several diesel generator LERs described single or multiple diesel generator failures caused by low or high room temperatures because of inadequate room heating or diesel lube oil preheating and to inadequate room ventilation, respectively. All plant designs include diesel generator room ventilation and lube oil preheating. No plant design characteristics exist that make one plant more susceptible to room temperature than another plant.

The design and operating experience of each of the 65 plants was reviewed, and each plant was assigned to one or more of the four subpopulations (Table 9.6.3).

Fifteen plants were found susceptible to water in the fuel system because they have all of the following defects: the fuel pump suction is not above the bottom of the day tank, there is no day-tank condensate drain, and the bulk fuel oil transfer pump suction is not above the bottom of the bulk storage tank.

Four plants were found susceptible to corrosion of the jacket by cooling water because the water is not treated with an effective corrosion inhibitor. No distinction was made between plants with air-cooled (smaller tubes to plug) vs water-cooled (larger heat exchanger tubes) diesels.

Thirty plants with water cooled diesels were found susceptible to blockages by such material as sludge or solid objects. These plants form the third susceptibility group.

Eleven plants were found susceptible to a lack of sufficient air in their air-start systems because of air leakage from connections between the starting air tanks serving different diesels.

5.2 ANALYSIS OF CCFs ATTRIBUTED TO HUMAN ERRORS

From a review of LERs, 88 events were reported in which human error caused or potentially caused the simultaneous unavailability of two or more diesel generators. These are categorized in Table 9.6.4 as H1, H2, or H3, of which 59 are H1 or H2. Events categorized as H1 were actual common-cause failures because of human errors. Events categorized as H2 were single failures but, based on our evaluation, the failure may not be found immediately and could result in a CCF. The events categorized as H3 were human errors that resulted in a single failure, but the failure was immediately annunciated or easily detected. The H3 events were considered insignificant contributors to CCF and were not included in the CCF analysis, but the events are included because of interest in human errors at nuclear plants. Maintenance errors had caused all but one of these events. The generic events are listed in Table 9.6.5. Plant maintenance and surveillance testing procedures were reviewed to determine their adequacy for preventing multiple human errors.

Tables 9.6.6 and 9.6.7 summarize this evaluation of plant procedures and list the number of human errors of each type for each plant. The procedures were ranked on a scale from 1 to 3 — worst to best. Procedures were evaluated for the following characteristics: clarity, detailed checklists, instructions for returning equipment to normal, indication of normal test values, instructions for testing after maintenance, and test and maintenance precautions. Procedures that were evaluated to be above average contained these characteristics. Procedures that were ranked as average were deficient in one or two of the characteristics listed above. Procedures that were ranked below average lacked clarity, detailed checklists, and instructions. The comments in Table 9.6.7 lists characteristics of the procedures reviewed. Plant susceptibility groups for human-error-caused events are based on the procedure evaluations.

Based on the evaluation of the human error events, the BFR computer program was used to calculate four different human error rates:

(1) a generic rate applicable to all plants,
(2) a subpopulation rate for plants with procedures rank 1,
(3) a subpopulation rate for plants with rank 2, and
(4) a subpopulation rate for plants with rank 3.

The applicable human error rate for a particular plant is the sum of the generic rate and the rate for the susceptibility group to which the plant belongs.

5.3 QUANTITATIVE ANALYSIS OF CCFs

Common-cause failure rates were calculated with the BFR model as a basis. A brief description of this model is presented below. (Detailed descriptions are presented in refs. 10 and 11.)

The BFR model assumes that CCFs occur because external events, called "shocks," can cause multiple component failures. In a system of "n" identical components, a shock could cause failure of any number of the components (between zero and n). A shock that causes at least one failure is a visible shock.

Not all component failures are caused by shocks. The qualitative analysis presented in the preceding sections above identifies those single and multiple failures that resulted from shocks.

Given the occurrence of a shock, a component fails with probability "p." Thus, the number of like components that would fail given a shock occurs is a binomial (n,p) random variable.

The BFR computer program was run once for each set of generic data and once for each subpopulation (nine runs altogether). Input data for a particular run included the number of single and multiple diesel failures attributed to a particular susceptibility group and the exposure hours for all plants in the group. The rate for a plant is the sum of the generic rates and the rates for the subpopulations to which the plant belongs. Program options selected in each case were that single failures resulting from shocks were identifiable, and that a Bayesian estimation with an approximately noninformative prior distribution was used.

The present version of the BFR program calculates rates for complete system failure (e.g., two-of-two diesel failures, or three-of-three diesel failures) but not rates for partial failure (e.g., two-of-three diesel failures). Rates for partial system failure were estimated using appropriate polynomial functions of the rates calculated by the BFR program. (See Sect. 9.7 for the derivation of these polynomials.)

Table 9.6.8 lists the failure rates for CCFs for each subpopulation and for each success logic configuration encountered in the analyses described in this report. These rates are standby failure rates.

6. QUANTITATIVE FAULT TREE ANALYSIS

Table 6.1 lists acronyms for the names and descriptions of the basic events used in this study. This table provides a reference for use of the tables in this section and Appendix Sect. 9.5. The five-character alphanumeric suffixes are combined with a three-character plant name prefix to uniquely identify each basic event used in this study. The resulting eight-character name is listed with the appropriate basic event in each of the fault trees listed in Appendix Sect. 9.2. The failure rates, mean repair times, and initial unavailabilities for the basic events are contained in Tables 9.8.1 through 9.8.28.

6.1 ONSITE AC POWER SYSTEM UNDEPENDABILITY

The undependability of a system is defined as the probability that it will fail to start or fail to continue to run for the duration of a specified mission. For an onsite ac power system, the mission length is the elapsed time that offsite power is unavailable.

The quantitative analysis of onsite ac power undependability consisted of an analysis of each of the 18 fault trees in Appendix Sect. 9.2 and an analysis of ten different onsite power system design configurations using industry-average failure and repair data.

The term "industry average" connotes the use of median values for failure and repair data where the median point value for a parameter is the median of the plant-specific estimates of that parameter's value.

This study does not include an analysis of failures within service water systems and dc power systems, but ref. 5 includes information on the service water and dc power systems. The service water failure and repair data used in this study are based on those results.

The detailed experience with diesel generators and their dedicated support systems was analyzed. The experience data for the years 1976 through 1980 are described in Sect. 4, and Sects. 9.4 and 9.5 provide supporting documentation for the data analysis. These data are the basis for estimating diesel generator reliability parameters required for the analysis described in this report.

The SUPERPOCUS computer program[12] determines point estimates of system undependability using minimal cut sets (see Tables 9.8.29 through 9.8.55 for important cut sets) and the following data for each basic event:

(1) component initial unavailability (probability of failure to start),
(2) the component failure rate (parameter in exponential failure distribution), and
(3) the component mean repair time (parameter in exponential repair distribution).

Table 6.1. Description of basic events

Basic event	Description
SWCCF	Service water system CCF resulting in loss of cooling to all emergency generators.
DGCCF	Hardware CCF of a sufficient number of diesels to cause insufficient onsite ac power.
BACCF	CCF of the station batteries resulting in a loss of control power to the emergency generators or to the emergency ac power distribution system.
DGHEC	Human-error-induced CCF of a sufficient number of emergency diesel generators to cause insufficient onsite ac power.
DG*UD	An emergency diesel fails (independently) to start or run for the required mission. (The mission length depends on the duration of the loss of offsite power.)
SW#UD	A service-water train fails (independently) to start or continue to supply cooling water for the required mission.
DC#UD	A dc power division fails (independently) to supply emergency generator and ac division control power for the required mission.
DB*UD	An emergency diesel battery fails (independently) to supply control and loading power for the required mission.
DG*TM	An emergency diesel is out of service for testing and maintenance.
SW#TM	A service-water train is out of service for testing and maintenance.
GT1UD	An emergency gas-turbine generator fails (independently) to start or run for the required mission.

Table 6.1. (Continued)

Basic event	Description
EGCCF	Hardware CCF of a sufficient number of emergency diesel or gas turbine generators to cause insufficient onsite ac power. (See Millstone 1 fault tree.)
EGHEC	Human-error-induced CCF of a sufficient number of emergency diesel or gas turbine generators to cause insufficient onsite ac power. (See Millstone 1 fault tree.)
GTBUD	An emergency gas-turbine generator battery fails (independently) to supply control and loading power for the required mission.
GT1TM	An emergency gas-turbine generator is out of service for testing and maintenance.
DC1IE	A dc power division is deenergized during normal plant operation.

* = 1, 2, 3, 4, or 5.
# = 1 or 2.

SUPERPOCUS assumes that all basic events are statistically independent; however, common-cause events can be added to the list of minimal cut sets, as they were in this study.

The events discussed in this section are independent diesel generator failures, diesel generator testing and maintenance contributions, and diesel generator CCFs.

6.1.1 Independent Diesel Generator Failures

In all cases, the probability a diesel generator will fail to start is based on an appropriate standby failure rate and an assumption that it is as good as new after a test, but if it fails during standby it will not be repaired over the test interval required by the technical specifications. The required test interval is 30 days for all of the plants analyzed except the following: 1) those that conform to Regulatory Guide 1.108, which specifies a number of failures for specified numbers of tests; and 2) Calvert Cliffs and Peach Bottom, whose test intervals are 2 weeks.

Other models for the probability of failure to start can be applied, but they do not conservatively predict a lower probability. For example, the number of failures divided by the number of diesel generator start attempts yields a lower estimate of the probability of failure on demand in many cases, but since the start attempts are not evenly spaced, this estimate is nonconservative. Similarly, a model based on the standby failure rate, but using a shorter test interval based on the number of trials observed, predicts a lower failure probability; again, because the start attempts are not evenly spaced, this estimate is not always conservative. Section 4 discusses these failure models in detail.

The standby failure rate for the diesel generators at a given plant is based on the primary and secondary failures to start and run and the autostart failures. The failure to run data are included with the failure to start data because there are only a few failures to run and most occur during 1-h tests, making it probable that the root cause existed at the time of the start. Combining the two failure types has the added advantage of removing the need to treat the first hour of running as a special case during the mission since the failure rate during this hour is higher than average. To obtain the standby failure rate, the autostart failure rate is multiplied by 0.2 and added to the rate for the primary and secondary failures. The factor 0.2 is believed to be conservative since, in practice, almost all autostart failures are diagnosed quickly. We believe the factor 0.2 to be conservative because for each event categorized as autostart failures, the diesel generator was returned to service immediately or there was evidence that it could have been restored immediately.

The probability that a diesel generator will fail to start is the integrated average unavailability of the diesel generator over the

30-day test interval (see Sect. 4). Equation (6.1) gives the average unavailability if it is assumed that the diesel generator unavailability is zero immediately following the test, and that the mean-time-to-failure is long compared to the test interval.

$$\bar{A}_{av} = \lambda_{SB} \frac{T}{2} , \qquad (6.1)$$

where λ_{SB} is the total standby failure rate, and T is the test interval. Tables 9.5.14 and 9.5.15 tabulate standby failure rates for each plant.

The operating failure rate for independent diesel generator failures is based on the cumulative operating time for all planned runs of 6 h or longer and the number of failures to run experienced in these extended runs. Most tests were for 1-h runtime, but there were 314 tests scheduled for runtimes of 6 h or longer (see Table 9.5.15). These tests were used to calculate a probability of failure to run. Because of sparse data, the same operating failure rate is used for every plant. The operating failure rate is 2.4×10^{-3}/h.

6.1.2 Diesel Generator T&M Contributions

The probablity that a diesel generator at a particular plant will be out of service for T&M when offsite power is lost is the fraction of reactor operating time the plant's diesel generators were out of service for scheduled maintenance during the 5-y period from 1976 through 1980. Appendix Sect. 9.5 presents diesel generator T&M unavailabilities for each plant. The industry average value is 6×10^{-3}.

Test and maintenance does not affect an operating failure rate because an operating diesel generator will not be removed from service for T&M during a loss of offsite power. The mean-time-to-repair used for diesel generator T&M at a plant is the same as that for mean-time-to-repair used for independent diesel generator failures.

6.1.3 Diesel Generator CCF

Standby CCF rates taken from the output of the BFR computer program are used to determine standby common-cause unavailabilities for the diesel generator systems at the plants analyzed. Contributions from events caused by hardware failure and human errors are treated separately. The CCF contribution to system probability of failure to start is the average of the standby CCF unavailability over the appropriate test interval. The appropriate test interval used to calculate the CCF probability was calculated from the diesel generator success logic, and it is based on the assumption that individual diesel generator tests are evenly staggered througout a test interval. For example, the appropriate CCF test interval for a single-unit plant with two redundant diesel generators is half of the individual diesel generator test interval.

The operating failure rate applicable to a hardware CCF is the same as the applicable standby failure rate. Since hardware CCFs are caused by external events, the failure rate is independent of whether the diesel generators are running or not. The operating failure rate applicable to a human error is made negligibly small by assuming that operators do not interfere with properly operating diesel generators. The mean repair time used for each diesel generator CCF at a plant is the same as that for an independent diesel generator failure because restoration of one diesel generator repairs the system.

Tables 9.8.1 through 9.8.18 present the basic event failure and repair data input to each of the plant-specific SUPERPOCUS analyses. Tables 9.8.19 through 9.8.28 present the data used for the ten generic design configuration analyses.

Tables 9.8.29 through 9.8.55 list selected results of the SUPERPOCUS analyses. These results include the undependability of the onsite power system after 0, 10, and 30 h and the importance of the most significant basic events and cut sets at the end of each of the three specified times. The undependability of the onsite ac power system at time zero is the probability that the system will fail to start. The importance definition used by SUPERPOCUS is the Vesely-Fussell definition.[13] The importance of a minimal cut set is the probability that the cut set caused the top event, given that the top event occurred. The importance of a basic event is the probability that the basic event contributed to the occurrence of the top event, given that the top event occurred.

6.1.4 Repair Time

The diesel generator mean repair time applicable to a plant is the mean-time-to-repair for all primary and secondary diesel generator failures at the plant. Plant-specific mean repair times for plants for which data were available are in Table 9.5.17.

6.2 ONSITE AC POWER SYSTEM UNCERTAINTY ANALYSIS

Using the SAMPLE computer program,[14] we calculated the uncertainties of the probability of failure to start for each of the onsite ac power systems of the 18 design review plants and the 10 generic design configurations considered. These uncertainties reflect only the statistical uncertainty of the input data used to calculate the initial unavailabilities (probability of failure immediately after a loss of offsite power).

Table 6.2 lists the basic events and their associated error factors. These error factors determine the spread in the distribution of each basic event's unavailability. Log-normal distributions were used to model the uncertainty in the basic event unavailabilities. The point estimates and the error factors for all the basic events except DG*UD, DG*TM, DGCCF, and DGHEC are based on error factors provided by Sandia National Laboratory.[5] Error factors for DG*UD and DG*TM are based on 90% tolerance intervals for data taken at all 48 plants surveyed. The error factor for DG*UD was calculated by dividing the upper 95% plant-specific diesel generator standby failure rate tolerance bound by the median plant-specific standby failure rate. A similar method was used to calculate the error factor for DG*TM. These error factors, although developed for the generic design configuration analyses, are adequate estimates of the basic event unavailability error factors for any specific plant. Common-cause error factors for hardware failures and human errors are based on results of the BFR computer program runs, which include descriptions of distributions for each of the CCF rates.

Table 6.2. Basic event error factors

Basic event	Error factor
SWCCF	10
DGCCF	10
BACCF	10
DGHEC	10
DG*UD	3
SW#UD	10
DC#UD	10
DG*TM	6
SW#TM	20

* = 1, 2, 3, 4 or 5.
\# = 1 or 2.

Table 6.3 lists the onsite system uncertainty analysis results. The upper and lower confidence bounds shown in the table are resolved to within 1%.

6.3 ONSITE AC POWER SYSTEM SENSITIVITY ANALYSIS

Median values were used for most of the fault tree event reliability parameters to calculate the probability of the loss of onsite power for the ten generic designs. The median value of a parameter is the value such that half of the estimates of the parameter's values are

Table 6.3. Onsite power system uncertainty analysis results

Plant or design	Median initial unavailability	Lower confidence bound (5%)	Upper confidence bound (95%)
Arkansas Nuclear One 1	2.2×10^{-3}	1.2×10^{-3}	1.5×10^{-2}
Brunswick 1 and 2	1.7×10^{-3}	1.4×10^{-3}	1.5×10^{-2}
Calvert Cliffs 1 and 2	5.2×10^{-3}	3.8×10^{-3}	8.2×10^{-2}
Donald C. Cook 2	6.8×10^{-3}	3.4×10^{-3}	3.4×10^{-2}
Crystal River 3	4.2×10^{-3}	1.5×10^{-3}	2.0×10^{-2}
Davis-Besse	7.9×10^{-3}	3.7×10^{-3}	4.0×10^{-2}
Dresden 2 and 3	4.8×10^{-2}	3.0×10^{-2}	2.3×10^{-1}
Joseph M. Farley 1	2.4×10^{-4}	1.3×10^{-4}	1.9×10^{-3}
James A. FitzPatrick	2.2×10^{-4}	1.2×10^{-4}	1.9×10^{-3}
Edwin I. Hatch 1 and 2	2.5×10^{-3}	1.2×10^{-3}	1.3×10^{-2}
Millstone 1	1.1×10^{-3}	5.2×10^{-4}	7.6×10^{-3}
Nine Mile Point	1.5×10^{-3}	8.0×10^{-4}	1.2×10^{-2}
Peach Bottom 2 and 3	9.8×10^{-4}	2.0×10^{-4}	8.3×10^{-3}
St. Lucie	5.5×10^{-3}	2.1×10^{-3}	2.6×10^{-2}
San Onofre	1.3×10^{-3}	6.0×10^{-4}	7.7×10^{-3}
Turkey Point 3 and 4	2.6×10^{-3}	1.3×10^{-3}	1.4×10^{-2}
Yankee (Rowe, Mass.)	7.2×10^{-4}	1.6×10^{-4}	6.9×10^{-3}
1 of 2: service-water cooled	1.9×10^{-3}	1.3×10^{-3}	1.2×10^{-2}
1 of 2: air-cooled	1.5×10^{-3}	7.1×10^{-4}	8.6×10^{-3}
1 of 3: service-water cooled	3.0×10^{-4}	1.6×10^{-4}	2.4×10^{-3}
1 of 3: air-cooled	1.8×10^{-4}	6.5×10^{-5}	1.5×10^{-3}
2 of 3: service-water cooled	5.0×10^{-3}	3.6×10^{-3}	2.7×10^{-2}
2 of 3: air-cooled	4.2×10^{-3}	2.4×10^{-3}	2.3×10^{-2}
2 of 4: service-water cooled	1.0×10^{-3}	8.3×10^{-4}	9.5×10^{-3}
2 of 4: air-cooled	3.7×10^{-4}	1.9×10^{-4}	2.7×10^{-3}
2 of 5: service-water cooled	5.3×10^{-4}	3.6×10^{-4}	5.4×10^{-3}
2 of 5: air-cooled	1.4×10^{-4}	5.9×10^{-5}	1.2×10^{-3}

below the median and half are above. The probability of the diesel generator hardware CCF is not a median; the value used for each generic calculation is that which does not include any of the specific hardware common-cause susceptibility groups identified in Sect. 5. (The diesel generators cooled by service water are, of course, in the service water blockage susceptibility group.)

Sensitivities of the onsite system reliability for ten generic designs are calculated for the following changes:

(1) add a diesel generator,
(2) make a service-water, system-dependent design independent of service water,
(3) increase or decrease the probability of failure to start,
(4) remove diesels from hardware common-cause susceptibility groups,
(5) improve the worst T&M procedures, and
(6) reduce the diesel generator T&M contributions.

Methods for accomplishing such changes and the associated costs are discussed in Sect. 7.

The median probabilities of system failure to start in Tables 6.3 and 6.4 are the base case failure probabilities for the sensitivity studies. The reliability improvement associated with making a water-cooled diesel independent of service water is seen by comparing the failure probabilities for water-cooled and air-cooled designs with the same configurations (Table 6.4). The effect of adding a diesel generator to a system that has a "1-of-2," "2-of-3," or "2-of-4" success logic configuration is seen by comparing the failure probabilities of different configurations (Table 6.4).

Table 6.5 shows the sensitivity of the system failure probability of each design configuration to variation of the diesel generator failure-to-start probability. The failure to start probabilities in Table 6.5 are the following: Case 1 (base case), 0.025; Case 2, 0.013; Case 3, 0.05.

Sensitivity for each design to variation of the diesel generator CCF probability is shown in Table 6.6. Case 1 is the base case. Case 2 is for a plant in the susceptibility group that is unable to remove water from fuel; Case 3 is for a plant in the susceptibility group that has cross-connections between diesel generator air-start systems; Case 4 is for a plant in the susceptibility group that does not use a jacket-water, corrosion inhibitor. The differences between the results for Cases 2, 3, and 4 and the base case, Case 1, are additive for plants that are in more than one hardware common-cause susceptibility group.

Sensitivity of the generic failure probabilities to variation of the diesel generator human error, common-cause probability is shown in Table 6.7. Case 1, the base case, is for plants with test and maintenance procedures ranked 1 and 2 (best procedures); Case 2 is for plants with procedures ranked 3 (worst procedures). The differences

Table 6.4. Base case system failure probabilities

Design configuration	Probability of failure to start
1 of 2: service-water cooled	1.9×10^{-3}
1 of 2: air-cooled	1.5×10^{-3}
1 of 3: service-water cooled	3.0×10^{-4}
1 of 3: air-cooled	1.8×10^{-4}
2 of 3: service-water cooled	5.0×10^{-3}
2 of 3: air-cooled	4.2×10^{-3}
2 of 4: service-water cooled	1.0×10^{-3}
2 of 4: air-cooled	3.8×10^{-4}
2 of 5: service-water cooled	5.3×10^{-4}
2 of 5: air-cooled	1.4×10^{-4}

Table 6.5. Sensitivity of system failure probability to diesel generator failure probability

Design configuration	Case 1	Case 2	Case 3
1 of 2: service-water cooled	1.9×10^{-3}	1.2×10^{-3}	4.3×10^{-3}
1 of 2: air-cooled	1.5×10^{-3}	9.1×10^{-4}	3.7×10^{-3}
1 of 3: service-water cooled	3.0×10^{-4}	2.8×10^{-4}	4.6×10^{-4}
1 of 3: air-cooled	1.8×10^{-4}	1.6×10^{-4}	3.2×10^{-4}
2 of 3: service-water cooled	5.0×10^{-3}	3.0×10^{-3}	1.2×10^{-2}
2 of 3: air-cooled	4.2×10^{-3}	2.4×10^{-3}	1.1×10^{-2}
2 of 4: service-water cooled	1.0×10^{-3}	7.4×10^{-4}	2.0×10^{-3}
2 of 4: air-cooled	3.8×10^{-4}	2.8×10^{-4}	9.6×10^{-4}
2 of 5: service-water cooled	5.3×10^{-4}	4.2×10^{-4}	8.0×10^{-4}
2 of 5: air-cooled	1.4×10^{-4}	1.4×10^{-4}	1.9×10^{-4}

Table 6.6. Sensitivity of system failure probability to diesel generator hardware CCF probability

Design configuration	Case			
	1	2	3	4
1 of 2: service-water cooled	1.9×10^{-3}	2.1×10^{-3}	2.3×10^{-3}	3.0×10^{-3}
1 of 2: air-cooled	1.5×10^{-3}	1.7×10^{-3}	1.9×10^{-3}	2.6×10^{-3}
1 of 3: service-water cooled	3.0×10^{-4}	3.8×10^{-4}	4.2×10^{-4}	7.8×10^{-4}
1 of 3: air-cooled	1.8×10^{-4}	2.6×10^{-4}	3.0×10^{-4}	6.6×10^{-4}
2 of 3: service-water cooled	5.0×10^{-3}	5.6×10^{-3}	5.8×10^{-3}	7.5×10^{-3}
2 of 3: air-cooled	4.2×10^{-3}	4.8×10^{-3}	5.0×10^{-3}	6.7×10^{-3}
2 of 4: service-water cooled	1.0×10^{-3}	1.4×10^{-3}	1.5×10^{-3}	3.3×10^{-3}
2 of 4: air-cooled	3.8×10^{-4}	7.3×10^{-4}	8.4×10^{-4}	2.7×10^{-3}
2 of 5 service-water cooled	5.3×10^{-4}	6.5×10^{-4}	7.5×10^{-4}	2.2×10^{-3}
2 of 5: air-cooled	1.4×10^{-4}	2.6×10^{-4}	3.6×10^{-4}	1.8×10^{-3}

Table 6.7. Sensitivity of system failure probability to diesel generator human error CCF probability

Design configuration	Case 1	Case 2
1 of 2: service-water cooled	1.9×10^{-3}	2.3×10^{-3}
1 of 2: air-cooled	1.5×10^{-3}	1.9×10^{-3}
1 of 3: service-water cooled	3.0×10^{-4}	4.6×10^{-4}
1 of 3: air-cooled	1.8×10^{-4}	3.4×10^{-4}
2 of 3: service-water cooled	5.0×10^{-3}	7.5×10^{-3}
2 of 3: air-cooled	4.2×10^{-3}	6.7×10^{-3}
2 of 4: service-water cooled	1.0×10^{-3}	1.5×10^{-3}
2 of 4: air-cooled	3.8×10^{-4}	9.0×10^{-4}
2 of 5: service-water cooled	5.3×10^{-4}	6.4×10^{-4}
2 of 5: air-cooled	1.4×10^{-4}	2.5×10^{-4}

between plants with procedures in category 1 and those in Category 2 are negligible.

Sensitivity of the system failure probabilities to variation of the diesel generator T&M probabilities is shown in Table 6.8. The unavailability is as follows: Case 1 (base case), 6×10^{-3}; Case 2, zero; and Case 3, 1×10^{-2}.

6.4 STATION BLACKOUT FREQUENCY

Estimated frequencies of station blackouts lasting longer than 0, 0.5, and 8 h for 18 plants and 10 generic designs are presented in Table 6.9. These three times were selected when this program began, based on the assumptions that core damage would not result for blackouts lasting less than 0.5 h, that ac independent systems could function up to 8 h, and that blackouts lasting longer than 8 h would result in core damage. Equations (6.2) through (6.4) were used to calculate a frequency of station blackout for three time periods. The three equations are mutually exclusive. Therefore, the sum of the three equations is the total frequency of station blackout; Eq. (6.3) plus Eq. (6.4) is the frequency of station blackout lasting longer than 0.5 h; and Eq. (6.4) is the frequency of station blackout lasting longer than 8 h.

The frequency (expected number per year) of station blackout with a duration of less than 0.5 h is estimated by Eq. (6.2):

$$\begin{aligned} \text{ENY}\ [\text{SB}\ (0,0.5)] = {} & F(0,0.5)[Q + R(0,0.5)] + F(0.5,1)R(.25,.75) \\ & + F(1,2)R(1,1.5) + F(2,3)R(2,2.5) \\ & + F(3,5)R(3.5,4) + F(5,8)R(6,6.5) \\ & + F(8,24)R(15.5,16) \end{aligned} \tag{6.2}$$

where F(w,x) is the frequency of the loss of offsite power lasting greater than w hours and less than x hours; Q is the initial unavailability of the onsite power system (see Table 6.3); and R(y,z) is the probability that the onsite system will start, run for y hours and fail to run for some time between y and z hours.

The frequencies of station blackouts lasting between 0.5 and 8 h were calculated as follows:

Table 6.8. Sensitivity of system failure probability to diesel generator test and maintenance contribution

Design configuration	Case 1	Case 2	Case 3
1 of 2: service-water cooled	1.9×10^{-3}	1.6×10^{-3}	2.1×10^{-3}
1 of 2: air-cooled	1.5×10^{-3}	1.2×10^{-3}	1.7×10^{-3}
1 of 3: service-water cooled	3.0×10^{-4}	2.9×10^{-4}	3.1×10^{-4}
1 of 3: air-cooled	1.8×10^{-4}	1.7×10^{-4}	1.9×10^{-4}
2 of 3: service-water cooled	5.0×10^{-3}	4.1×10^{-3}	5.6×10^{-3}
2 of 3: air-cooled	4.2×10^{-3}	3.4×10^{-3}	4.7×10^{-3}
2 of 4: service-water cooled	1.0×10^{-3}	9.3×10^{-4}	1.1×10^{-3}
2 of 4: air-cooled	3.8×10^{-4}	3.3×10^{-4}	4.1×10^{-4}
2 of 5: service-water cooled	5.3×10^{-4}	5.0×10^{-4}	5.5×10^{-4}
2 of 5: air-cooled	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}

$$ENY\ [(SB(0.5,8)] = F(0.5,1)[Q + R(0,.25)] + F(1,2)[Q + R(0,1)] \quad (6.3)$$

$$+ F(2,3)[Q + R(0,2)] + F(3,5)[Q + R(0,3.5)]$$

$$+ F(5,8)[Q + R(0,6)]$$

$$+ F(8,24)[Q\ P_R(8|FTS) + R(0,8)\ P_R(8|FTR) + R(8,15.5)]$$

where F(w,x), Q, and R(y,z) are defined above, $P_R(8|E)$ is the probability that the onsite system will be repaired within 8 h given a failure for reason E, FTS is the event the onsite system fails to start, and FTR is failure to run for the onsite system. $P_R(8|FTS)$ is equal to $P_R(8|FTR)$ for all practical purposes, since the equipment expected to require repair is the same in both cases.

The frequency of station blackout lasting 8 h or longer is given by Eq. (6.4):

$$ENY\ [SB(8,24)] = F(8,24)[Q\ P_{NR}(8|FTS) + R(0,8)\ P_{NR}(8|FTR)] \quad (6.4)$$

where F(w,x), Q and R(y,z) are defined above, and where $P_{NR}(8|E)$ is the probability the onsite power system is not repaired within 8 h, given a failure for reason E. The frequency of loss of offsite power lasting longer than 8 h is negligible.

Reference 1 reports frequencies of the loss of offsite power as a function of duration for plant-centered events, area blackout or voltage reduction, and severe storms. Generic or plant-specific frequencies of the loss of offsite power for all three causes are combined for use in Eqs. (6.2) through (6.4). The estimated generic frequency and repair times for loss of offsite power are presented in ref. 1 for plant-centered and area-wide events. Area wide events include area blackout or voltage reduction and severe storms. However, these data are not in the proper form to be used in Eqs. (6.2) through (6.4). The form needed is the frequency of losses of offsite power for all causes lasting between w and x hours for the seven time intervals used in the three Eqs. (6.2) - (6.4). The data were put in the proper form as follows: For plant-centered estimates the fraction of losses of offsite power that were restored within each time interval was calculated, and the frequency for each time interval was this repair fraction times the overall frequency for plant-centered losses. The same calculation was done for area-wide losses. The respective frequencies for each time interval were added to get estimates of frequencies of loss of offsite power for all causes. (See Table 9.5.23 for estimated duration and frequency of loss of offsite power.) The value of Q applicable to a particular plant or generic design configuration is the undependability of the onsite system at time zero. Q is the mean initial unavailability in Table 6.3. These values are taken directly from the SUPERPOCUS results for the different plants or generic design configurations. SUPERPOCUS calculates failure rates as a function of time for the onsite systems. These are integrated between limits y and z to obtain the R(y,z) values for Eqs. (6.2) through (6.4).

The value used for the probability of repair in 8 h is 0.5. In almost all cases of onsite system failure, repair of a single diesel generator will restore the system to an operable state. In a few cases, repair of a service water train is also required. The probability of repairing either a diesel generator or a service water train in 8 h is ~0.5.

6.5 STATION BLACKOUT FREQUENCY UNCERTAINTY ANALYSIS

By using the SAMPLE computer program, we calculated the uncertainty of the station blackout frequency results using log-normal distributions for all parameters. Error factors for offsite power frequencies were based on the ratio of the 95% upper bounds to the median values presented in ref. 1. These error factors for the frequencies of loss of offsite power for the three different causes were weighted according to the fraction of the total frequency contributed by each cause to each duration interval. Each duration interval had its own frequency and error factor.

Table 6.9 presents the results of the station blackout frequency uncertainty analysis.

Table 6.9. Station blackout frequency uncertainty analysis results

Plant or design	Blackout lasting longer than (h)	Median point frequency	Lower confidence bound (5%)	Upper confidence bound (95%)
Arkansas Nuclear One 1	0	9.7×10^{-4}	3.7×10^{-4}	6.4×10^{-3}
	0.5	7.5×10^{-4}	3.0×10^{-4}	5.1×10^{-3}
	8	8.6×10^{-5}	1.6×10^{-5}	7.0×10^{-4}
Brunswick 1 and 2	0	2.4×10^{-4}	8.0×10^{-5}	2.0×10^{-3}
	0.5	1.5×10^{-4}	5.5×10^{-5}	1.3×10^{-3}
	8	9.6×10^{-6}	1.5×10^{-6}	9.7×10^{-5}
Calvert Cliffs 1 and 2	0	7.7×10^{-4}	2.8×10^{-4}	4.5×10^{-3}
	0.5	4.9×10^{-4}	1.9×10^{-4}	2.8×10^{-3}
	8	3.7×10^{-5}	8.0×10^{-5}	2.8×10^{-4}
Donald C. Cook 2	0	9.0×10^{-4}	2.9×10^{-4}	4.7×10^{-3}
	0.5	5.5×10^{-4}	2.0×10^{-4}	3.0×10^{-3}
	8	3.4×10^{-5}	6.8×10^{-6}	2.2×10^{-4}
Crystal River 3	0	5.7×10^{-4}	1.9×10^{-4}	2.6×10^{-3}
	0.5	3.5×10^{-4}	1.3×10^{-4}	1.7×10^{-3}
	8	2.3×10^{-5}	4.9×10^{-6}	1.4×10^{-4}
Davis-Besse	0	2.5×10^{-3}	8.0×10^{-4}	1.2×10^{-2}
	0.5	1.5×10^{-3}	5.4×10^{-4}	7.0×10^{-3}
	8	7.1×10^{-5}	1.7×10^{-5}	4.5×10^{-4}
Dresden 2 and 3	0	9.0×10^{-3}	2.5×10^{-3}	5.8×10^{-2}
	0.5	6.1×10^{-3}	1.8×10^{-3}	4.1×10^{-2}
	8	4.8×10^{-4}	4.9×10^{-5}	4.4×10^{-3}
Joseph M. Farley 1 and 2	0	3.0×10^{-5}	5.3×10^{-6}	2.4×10^{-4}
	0.5	1.8×10^{-5}	3.4×10^{-6}	1.4×10^{-4}
	8	9.5×10^{-7}	1.2×10^{-7}	9.7×10^{-6}
James A. FitzPatrick	0	3.0×10^{-5}	9.3×10^{-6}	2.7×10^{-4}
	0.5	1.9×10^{-5}	6.6×10^{-6}	1.7×10^{-4}
	8	1.3×10^{-6}	2.1×10^{-7}	1.3×10^{-5}
Edwin I. Hatch 1 and 2	0	3.2×10^{-4}	9.9×10^{-5}	1.9×10^{-3}
	0.5	2.0×10^{-4}	6.7×10^{-5}	1.2×10^{-3}
	8	1.2×10^{-5}	2.7×10^{-6}	8.5×10^{-5}
Millstone 1	0	8.1×10^{-4}	4.0×10^{-4}	5.0×10^{-3}
	0.5	6.3×10^{-4}	3.2×10^{-4}	4.0×10^{-3}
	8	7.5×10^{-5}	1.8×10^{-5}	5.3×10^{-4}
Millstone 2	0	9.9×10^{-3}	5.3×10^{-3}	5.9×10^{-2}
	0.5	7.6×10^{-3}	4.6×10^{-3}	4.7×10^{-2}
	8	6.7×10^{-4}	1.4×10^{-4}	4.6×10^{-3}
Nine Mile Point	0	2.3×10^{-4}	8.0×10^{-5}	1.8×10^{-3}
	0.5	1.5×10^{-4}	5.9×10^{-5}	1.1×10^{-3}
	8	1.1×10^{-5}	2.1×10^{-6}	1.1×10^{-4}
Peach Bottom 2 and 3	0	1.1×10^{-4}	4.4×10^{-5}	1.7×10^{-3}
	0.5	1.0×10^{-4}	3.2×10^{-5}	1.1×10^{-3}
	8	6.8×10^{-6}	1.1×10^{-6}	8.1×10^{-5}

Table 6.9. (continued)

Plant or design	Blackout lasting longer than (h)	Median point frequency	Lower confidence bound (5%)	Upper confidence bound (95%)
St. Lucie	0	2.0×10^{-3}	7.4×10^{-4}	8.9×10^{-3}
	0.5	1.7×10^{-3}	6.4×10^{-4}	7.7×10^{-3}
	8	1.8×10^{-4}	4.5×10^{-5}	9.1×10^{-4}
San Onofre	0	3.8×10^{-4}	9.7×10^{-5}	2.4×10^{-3}
	0.5	2.1×10^{-4}	5.3×10^{-5}	1.3×10^{-3}
	8	8.0×10^{-6}	1.3×10^{-6}	6.1×10^{-5}
Turkey Point 3 and 4	0	1.1×10^{-3}	4.6×10^{-4}	5.1×10^{-3}
	0.5	9.1×10^{-4}	4.0×10^{-4}	4.5×10^{-3}
	8	1.2×10^{-4}	3.0×10^{-5}	6.7×10^{-4}
Yankee (Rowe, Mass.)	0	8.6×10^{-5}	1.2×10^{-5}	9.2×10^{-4}
	0.5	5.1×10^{-5}	7.8×10^{-6}	5.6×10^{-4}
	8	2.7×10^{-6}	2.2×10^{-7}	4.1×10^{-5}
1 of 2: service-water cooled	0	2.9×10^{-4}	1.2×10^{-4}	1.7×10^{-3}
	0.5	1.9×10^{-4}	8.5×10^{-5}	1.1×10^{-3}
	8	1.4×10^{-5}	2.7×10^{-6}	1.2×10^{-4}
1 of 2: air-cooled	0	2.3×10^{-4}	8.9×10^{-5}	1.3×10^{-3}
	0.5	1.5×10^{-4}	6.4×10^{-5}	8.0×10^{-4}
	8	1.1×10^{-5}	2.4×10^{-6}	8.3×10^{-5}
1 of 3: service-water cooled	0	4.3×10^{-5}	1.4×10^{-5}	3.4×10^{-4}
	0.5	2.7×10^{-5}	9.9×10^{-6}	2.2×10^{-4}
	8	1.8×10^{-6}	3.1×10^{-7}	1.8×10^{-5}
1 of 3: air-cooled	0	2.4×10^{-5}	6.8×10^{-6}	2.0×10^{-4}
	0.5	1.5×10^{-5}	4.8×10^{-6}	1.3×10^{-4}
	8	9.7×10^{-7}	1.8×10^{-7}	1.1×10^{-5}
2 of 3: service-water cooled	0	7.7×10^{-4}	2.9×10^{-4}	4.1×10^{-3}
	0.5	4.5×10^{-4}	2.1×10^{-4}	2.6×10^{-3}
	8	3.7×10^{-5}	8.0×10^{-6}	2.7×10^{-4}
2 of 3: air-cooled	0	6.3×10^{-4}	2.6×10^{-4}	3.4×10^{-2}
	0.5	4.3×10^{-4}	1.9×10^{-4}	2.3×10^{-3}
	8	3.4×10^{-5}	7.2×10^{-6}	2.5×10^{-4}
2 of 4: service-water cooled	0	1.6×10^{-4}	4.3×10^{-5}	1.4×10^{-3}
	0.5	1.0×10^{-4}	4.1×10^{-5}	8.9×10^{-4}
	8	7.4×10^{-6}	1.3×10^{-6}	1.0×10^{-4}
2 of 4: air-cooled	0	5.6×10^{-5}	2.0×10^{-5}	4.0×10^{-4}
	0.5	3.6×10^{-5}	1.5×10^{-5}	2.6×10^{-4}
	8	2.6×10^{-6}	5.1×10^{-7}	2.4×10^{-5}
2 of 5: service-water cooled	0	7.9×10^{-5}	2.8×10^{-5}	7.8×10^{-4}
	0.5	5.0×10^{-5}	2.1×10^{-5}	5.1×10^{-4}
	8	3.5×10^{-6}	5.6×10^{-7}	4.3×10^{-5}
2 of 5: air-cooled	0	4.0×10^{-5}	3.4×10^{-6}	1.7×10^{-4}
	0.5	3.3×10^{-5}	2.3×10^{-6}	1.1×10^{-4}
	8	6.0×10^{-7}	7.8×10^{-8}	5.8×10^{-6}

7. DISCUSSION OF RESULTS

7.1 MAJOR CONTRIBUTORS TO ONSITE AC POWER SYSTEM FAILURE PROBABILITY

Tables 9.8.29 through 9.8.55 show the largest contributors to onsite ac power system undependability for three different mission lengths: 0, 10 and 30 h. The 0-h mission length represents the probability that the onsite power system fails to start. These tables show results for each of the generic designs and for each of the 18 plants analyzed except Millstone 2. Millstone 2 is not included because the offsite and onsite power systems are not independent. Therefore, the frequency of station blackout was estimated by considering both onsite and offsite together.

The largest contributors to onsite ac power system failure probability depend, to a large extent, on the amount of system redundancy. The systems with the least redundant diesel generator success logic (1-of-2, 2-of-3, and 2-of-4) are most likely to fail because of independent diesel generator failures. Systems with more redundant diesel generator success logic (1-of-3 and 2-of-5) are most likely to fail because of CCFs with human error the major contributor. FitzPatrick, the only plant analyzed that has one-of-four diesel generator success logic, is completely dominated by CCF. Service water system failures also become more important to the more redundant design configurations that employ water-cooled diesels because there are generally only two service water trains for all of the diesels.

The failure probabilities of onsite ac power systems that use service-water-cooled diesels are generally not dominated by service water system failures. Like the CCFs, service water system failures contribute a larger fraction of the system failure probability to systems with more redundant diesel generators. Service water system redundancy does not generally increase as the number of diesel generators are increased. One exception is at Farley, where there are four separate service water trains with sufficient cross-connect capabilities that service water system failures make a negligible contribution to the system failure probability. Service water system failures are not even modeled in the final fault tree for Farley; it is treated the same as a plant that uses air-cooled diesel generators.

For some plants the system undependabilities increase significantly with increasing mission lengths. This is primarily attributed to the probability that the diesel will fail to continue to run. The unavailability of a diesel generator approaches an asymptote that is approximately equal to the product of its operating failure rate and its mean repair time. In most cases, this asymptote is larger than the probability the diesel generator fails to start. The operating failure rate used in these analyses is the same for all diesel generators, and is based on a limited amount of data. The mean repair times used are relatively long. The station blackout questionnaire sought information to calculate more accurately the mean repair times based on the increased urgency of repairing a failed diesel generator when offsite power is unavailable. Most licensees were unable to elaborate on diesel generator repair times to allow this to be done.

Because of the probability that a diesel generator will fail to continue to run, as the mission length increases independent diesel generator failures become more important to the system undependability than other events.

7.2 POTENTIAL ONSITE AC POWER SYSTEM RELIABILITY IMPROVEMENTS

Potential ac power system modifications, estimates of the costs for modification, and the expected reliability improvement associated with each modification were estimated. The costs will vary depending upon many factors at a plant and should be considered as rough approximations. Reactor downtime required to make modifications is an indirect cost that was not estimated. This cost depends upon the size of the reactor and the cost of replacement power, which could be $700,000/d for a 1000-MW unit. Estimates of reliability improvements were based on the probability of failure to start for the ten generic design configuration analyses. The reliability improvement associated with a particular modification depends upon the design. Cost estimates are based on information collected verbally from utility and vendor personnel.

<u>Independent Diesel Generator Failure Proability Reduction</u>. Cost estimates for the following modifications were done because implementing them should decrease diesel failure probability at some plants. The modifications are as follows:

(1) install air driers on air-start system compressors,
(2) install dust seals on relays and relay cabinets,
(3) have the governor periodically overhauled by the factory, and
(4) review recurring failures to determine fixes.

For a single diesel with two compressors and two air reservoirs, it will cost approximately $50,000 to buy the air driers and about $50,000 to install them. The total cost for a single diesel woula be approximately $100,000. The estimated cost of installing gaskets on the diesel generator relay cabinets is approximately $10,000 per diesel generator. A governor can be overhauled for less than $6,000 (depending on the extent of repair), or a new one can be purchased for $6,000 to $10,000.

The applicability of these modifications and the amount of reliability improvement that would be attained is very plant specific. Some plants could reduce the probability of an independent diesel generator failure by nearly a factor of two. Table 6.5 shows the effects on the failure probabilities of the ten generic design configurations for three diesel generator failure probabilities. A plant whose diesel failure probability is twice as high as the industry median can make as much as a factor of two improvement in onsite ac power system reliability by reducing the diesel failure probability to the industry median. The system reliability improvement is greater for the plants with the least redundant diesel generator success logic.

A study of diesel generator failures was reported in NUREG/CR-0660.[6] In this report, several diesel generator failure modes were identified and recommendations were made to reduce the number of failures. These recommendations are useful, but there may be some plants with problems that will not be fixed by implementing these recommendations. For example, a few plants have specific problems with breaker failure or service water corrosion that probably would not be reduced significantly by implementing the recommendations of NUREG/CR-0660. There are no dominant failure modes throughout the industry. Reduction of independent failure probability depends upon subsystem improvements done plant by plant, and each nuclear plant licensee should consider the recommendations in NUREG/CR-0660.

Diesel Generator Hardware CCF Probability Reduction. The following modifications should reduce the diesel generator hardware CCF probability applicable to a plant:

(1) remove connections between independent diesel air-start systems,
(2) install water and sediment drains on fuel storage tanks, and
(3) use a corrosion inhibitor in the jacket water coolant.

Some plants already have some or all of these features.

Cost estimates to modify the three hardware features that contribute to hardware CCF are as follows:

(1) remove connections between independent diesel air-start systems, $5,000/diesel.
(2) install drain on the bottom of the diesel fuel day tank, $10,000/diesel,
(3) add corrosion inhibitor to diesel jacket-water, $500/diesel/y.

The expected reliability improvement associated with each of these modifications can be determined by inspection of Table 6.6. Use of a corrosion inhibitor has the largest effect on reliability of the three modifications; however, only a few plants do not presently use a corrosion inhibitor. Either of the other two modifications can reduce the system failure probability by a factor of two for the most redundant diesel generator success logic. Recommendations to reduce dc system CCFs are in NUREG-0666 (ref. 9).

The differences in reliabilities between Cases 2, 3 and 4, and Case 1 in Table 6.6 are additive for plants with more than one of the undesirable design features.

Diesel Generator Human Error CCF Probability Reduction. Some plants may reduce the estimated probability of diesel generator CCF caused from human errors by upgrading procedures that may contribute to CCF.

The direct cost of writing a procedure is approximately $5,000 per procedure. However, costs that were not estimated are the additional cost of filing and maintaining additional documentation, and the additional staff that may be required to perform and review maintenance.

The difference in system reliability for plants with the worst test and maintenance procedures and those with the best procedures for each of the ten generic designs is shown in Table 6.7. The importance of human-error CCF can be seen in Tables 9.8.29 through 9.8.55.

Diesel Generator T&M Contribution Reduction. Plants that schedule diesel generator overhaul while the reactor is operating can reduce their diesel generator T&M contribution to the probability of station blackout by rescheduling overhauls for times when the reactor is shut down. Rescheduling diesel generator overhaul and other extensive preventive maintenance from times of reactor operation to times of reactor shutdown will have very little direct cost. There could be some indirect costs for additional maintenance staff, and there may be a very large indirect cost for additional reactor downtime. Usually an extensive diesel generator overhaul cannot be performed in less than 72 h, which is a typical technical specification limiting condition for operation of the reactor with one diesel generator out of service. However, plants that are permitted by the technical specifications to have a diesel down longer than 72 continuous hours may be contributing significantly to the diesel T&M unavailability through scheduled maintenance.

System Design Configuration Modifications. The following modifications would improve onsite ac power system reliability by changing the system's design.

(1) install an additional diesel generator;
(2) make a diesel independent of service water.

The cost of adding a diesel generator to an existing plant has been separated into equipment, building, and installation costs. The estimated costs are: engine and auxiliary systems, $1,000/kW; building, $15-$20 million; installation, $7 million.

The estimated total cost to add a 3000-kW diesel generator is $20-$30 million. Factors such as the standards a new diesel would be required to meet, available space, and how much the service water and dc systems would have to be modified will also affect the total cost of an additional diesel.

The system reliability improvement associated with a change in onsite ac power system design configuration (e.g., 2-of-3 changed to 2-of-4) can be determined by inspection of Table 6.4. A factor of 5 to

10 in reliability improvement is expected to result from changing from a 1-of-2 to a 1-of-3 success logic. About the same amount of improvement is expected if a 2-of-3 is changed to a 2-of-4 configuration.

The largest reliability improvement achievable by making a service water-dependent system independent of service water is a factor of 4, and this applies to the 2-of-5 diesel generator success logic. However, improvements in service water system reliability are not within the scope of this project.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 SYSTEM MODIFICATIONS

Section 7 contains estimated costs and benefits for some modifications, but it is not within the scope of this project to recommend any of these changes. Any modifications to an onsite ac power system must be justified on a plant-specific basis. Eleven of the seventeen plants listed in Tables 9.8.29 through 9.8.45 have independent diesel failure as an important contributor to onsite ac system undependability. (Millstone 2 is the eighteenth unit analyzed, but it is not included in these tables because its onsite and offsite ac power systems are not independent.) Reducing independent diesel generator failure probability is a method to improve onsite ac power system reliability for many plants. However, based on the failure data we have analyzed, there was not one subsystem that dominated independent failure probability. (Section 9.5.2.1 contains a discussion of subsystem failure contributions.) Nuclear plant licensees should evaluate the performance of their diesels and compare the results to the comments in Sect. 9.5.2.1 and in NUREG/CR-0660[6] to determine if some of the suggested modifications would apply to their diesels. The probability of diesel generator failure to start used in the fault trees in this report was based on a standby failure rate rather than a failure on demand.

8.2 RELIABILITY ANALYSIS METHODOLOGY EXTENSIONS

Section 4.5.1 contains a description of the method used to calculate failure to start. Additional evaluation to determine the effects of demand and standby time on the probability of failure to start could improve the failure estimates for a reliability analysis, and it could provide insights into failure modes of diesel generators.

Mean repair times were calculated from the data reported in response to our station blackout questionnaire. The repair times reported in response to this questionnaire were for failures that occurred in non-emergency situations. It may be that the mean repair time would be different for emergencies, but we do not have data to justify changing the mean repair time. A more detailed study of repair times to determine if repairs during emergencies would be different than during normal operations would be useful to a study such as this.

A problem encountered in this study because of a lack of available methods was the quantification of the diesel generator common-cause events. The BFR method proved to be a good method for this study, except that the present version of the BFR computer program does not calculate CCF rates for all of the diesel generator configurations analyzed in this study. The BFR program should be modified to include configurations other than failure of all components in a population.

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9. APPENDIX

9.1 DESIGN DESCRIPTION OF AC POWER SYSTEMS

9.1.1 Introduction

Engineering design plans of the ac distribution and diesel generator systems of 18 nuclear power plants were reviewed, and the information and results from the review are presented in this appendix. First, design features typical of power distribution systems from the switchyard to the batteries are described, but since there are many variations of these systems the descriptions are not very detailed. Section 9.2 contains information applicable to the plants analyzed in this report.

9.1.2 General Features of Plant Distribution Systems

9.1.2.1. Switchyards

A switchyard is the interface between the nuclear plant and the bulk power transmission system. A switchyard transmits power from the main generator to the transmission grid and from the grid to the nuclear plant loads.

Equipment in a switchyard requires auxiliary equipment to perform properly. For example, compressed air for operation of high-voltage circuit breakers is stored in receivers with sufficient capacity for several circuit breaker operations. Transformers are cooled by forced circulation of oil or air or by natural circulation of air. A switchyard may also contain carrier-current or microwave-relay equipment, but such equipment is part of the transmission grid protection system. Switchyard circuit breakers require dc power to operate associated trip relays, obtaining such power from one or two dedicated switchyard batteries or the station batteries. There are usually two trip circuits, but they are not always powered by two battery sources.

9.1.2.2. 4160-V Distribution System

The diesel generator output is connected to the Class 1E buses, which are usually 4160-V (480-V at some older plants and 6900-V at some newer plants). These buses are fed by the normal auxiliary or reserve auxiliary transformers. There must be at least two physically independent sources of offsite power to the Class 1E fuses.[1] At least one of these power sources must be available in a few seconds by automatic transfer; the other offsite power source may be connected by manual or automatic transfer.

Usually the circuit breakers can be controlled locally at the breaker or remotely from the control room. The closing mechanism is usually a spring that is cocked by a dc-driven motor; the spring that opens the breaker is cocked by the closing of the breaker. Control power is required to trip the circuit breakers for other than local, manual operation; but, in most cases, control power is required to satisfy logic permissives to close the breakers. Station batteries are the source of dc control power for the circuit breakers. In some plants, Division I or II redundant plant batteries can be selected by "break-before-make" switches in the dc distribution cabinets. There may also be a way to supply power to the Division I dc bus by the Division II battery (interlocks prevent connecting more than one source to a bus).

In most operating plants, the 4-kV, Division I and Division II buses are independent, but in some plants the 4-kV Division buses can be interconnected. Interconnections in the operating plants may be between divisions in one reactor or between divisions of different reactors. The interconnections are interlocked either electrically, mechanically, or both, such that two emergency ac power sources cannot be paralleled. The purpose of the interconnections is to provide the flexibility to supply the load on one bus by the power source on another while interlocks prevent two ac power sources from being paralleled. Some reactors also have a third division with a few but not a full complement of emergency loads on it. This third redundant set of loads can be supplied by either ac power source through interlocked breakers. In plants with construction permits issued later than June 1973, Division I and II buses must be independent of each other.

9.1.2.3 480-V Distribution System

The 480-V distribution load centers and motor control centers are fed from the 4160-V buses. The 480-V breakers are not usually remotely controlled. Breaker control power is supplied, in most cases, by a 480/120-V ac transformer. We assumed that all 480-V breakers are independent of dc power for tripping. Some plants have interconnected and interlocked 480-V buses. The interlocks, which may be electrical, mechanical, or both, prevent the interconnection of two engineered safety feature (ESF) ac power supplies. For many plants, the 480-V ESF buses are not shed from their associated 4160-V buses when offsite power is lost. These buses are immediately energized by the diesel generator once it starts and its output breaker closes.

9.1.2.4. 120-V Vital AC System

The 120-V ac vital instrument power is the next level of distribution. These buses usually receive power from an inverter supplied by a dc ESF bus. These buses also have alternative power sources which may be a 480-V ESF bus, a non-ESF regulated ac, a second 480-V ESF bus, a motor-generator set, or a turbine battery and inverter.

No one plant will have all of these alternative sources. The transfer from the primary source to the alternative source may be automatic with no interruption in power or manual.

9.1.2.5. DC System

The dc system design varies considerably from plant to plant. The number of 125-V dc station batteries (batteries that supply ESF loads throughout the plant) varies from two to four. In addition to these station batteries there may be one or two 125-V switchyard batteries (nonclass IE); batteries dedicated to each diesel generator for engine and generator control (Class IE); one or two batteries to service the turbine generator system (nonclass IE); batteries for the service water system (Class IE); and a battery for the cooling tower equipment (nonclass IE). Frequently, the centerpoint of a 250-V dc battery is tapped to provide ±125 V. There is usually at least one full-capacity or two half-capacity chargers for each 125-V battery, and in some cases there are spare chargers. A full-capacity charger can charge a battery from its nominally discharged state to full charge while supplying the operating load.

In some cases, the batteries can be charged from either ac division. Some dc loads can be switched from one battery division to the other through interlocked interconnections. The operator usually can view displays of battery voltage and current and charger current. Bus undervoltage and charger failure (ac input or dc output) actuate an alarm. The batteries are usually ungrounded with a ground detector alarm. A single fault to ground will not cause battery failure in an ungrounded system.

9.1.3 Emergency Diesel Generator System

The number of generators for emergency service varies from one to five, with capacities from 200 to >4000 kW (Table 9.1.1). Final Safety Analysis Reports (FSARs) frequently state the number of diesels required for a design basis accident (DBA), and in some cases there is more than one diesel generator per reactor required to maintain adequate cooling. In this study we assumed that such a DBA has not occurred and that one diesel generator per reactor would provide sufficient power for cooling the reactor. Diesel generator configuration is shown in Table 9.1.1. Some generators are dedicated to a division, and others are interconnected between divisions or between units through interlocked breakers. The generator speed and voltage are regulated from the control room or from a local panel, either of which may display frequency, voltage, and real and reactive power. Each generator usually has both a local and a remote annunciator panel. The generator is usually wye wound, with the neutral grounded through a transformer. A resistor in the secondary limits ground fault current so that the generator will not trip on fault current, but could supply the limited fault current. However, the generator may be grounded directly so that it trips on fault current.

Table 9.1.1. Nuclear plant diesel generator configuration

Diesel generator configuration	Plant name	Diesel generator manufacturer	Continuous rating (kW)
1. One diesel, dedicated	Big Rock Point	Caterpillar	200
	Millstone 1	Fairbanks Morse	3000
2. Two diesels, dedicated	Arkansas Nuclear One 1	General Motors	2750
	Arkansas Nuclear One 2	Fairbanks Morse	2850
	Duane Arnold	Fairbanks Morse	2850
	Beaver Valley	General Motors	2600
	Connecticut Yankee	General Motors	2850
	Donald C. Cook 1	Worthington	3500
	Donald C. Cook 2	Worthington	3500
	Cooper	Cooper Bessemer	4000
	Crystal River 3	Fairbanks Morse	2750
	Davis-Besse	General Motors	2600
	Fort Calhoun	General Motors	2500
	Robert E. Ginna	Alco	1950
	Kewaunee	General Motors	2850
	La Crosse	Allis-Chalmers	A-250, B-400
	Maine Yankee	General Motors	2500
	Millstone 2	Fairbanks Morse	2750
	Monticello	General Motors	2500
	Nine Mile Point	General Motors	2560
	North Anna 1	Fairbanks Morse	2750
	North Anna 2	Fairbanks Morse	2750
	Oyster Creek	General Motors	2500
	Palisades	Alco	2500
	Pilgrim	Alco	2600
	Rancho Seco	General Motors	2750
	H. B. Robinson 2	Fairbanks Morse	2500
	San Onofre	DeLaval	6000
	Three Mile Island	Fairbanks Morse	3000
	Vermont Yankee	General Motors	3000
3. Two diesels, shared, one diesel can supply emergency load in one unit and shutdown load in the other	Prairie Island 1, 2	General Motors	2850
	Point Beach 1, 2	General Motors	2850
	Turkey Point 3, 4	Schoonmaker GM	2500

Table 9.1.1. (continued)

Diesel generator configuration	Plant name	Diesel generator manufacturer	Continuous rating (kW)
4. Three diesels, dedicated	Indian Point 2	Alco	1750
	Indian Point 3	Alco	1750
	Salem 1	Alco	2600
	Salem 2	Alco	2600
	Yankee (Rowe, Mass.)	General Motors	400
5. Three diesels, one dedicated to each unit, one shared	Dresden 2, 3	General Motors	2850
	Quad-Cities 1, 2	General Motors	2850
	Surry 1, 2	General Motors	2850
6. Three diesels, two shared, one shared and swing	Calvert Cliffs 1, 2	Fairbanks Morse	2500
7. Four diesels, generators paralleled in sets of two	James A. FitzPatrick	Bruce GM	2600
8. Four diesels, two generators (tandem), dedicated	St. Lucie	General Motors	3500 (generator)
	Trojan	General Motors	4418 (generator)
9. Four diesels, shared	Brunswick 1, 2	Nordberg	3500
10. Five diesels, two dedicated, three shared	Joseph M. Farley 1, 2	Fairbanks Morse	4075 (dedicated) 2600 (shared)
11. Five diesels, four dedicated, one shared	Edwin I. Hatch 1, 2	Fairbanks Morse	2850
	Zion 1, 2	Cooper Bessemer	4000

Table 9.1.1. (continued)

Diesel generator configuration	Plant name	Diesel generator manufacturer	Continuous rating (kW)
12. Eight diesels, four generators (tandem), shared	Sequoyah 1, 2	Bruce GM	3600 (generator)
13. Eight diesels, shared	Browns Ferry 1, 2	General Motors	2600

When the generator is not operating, the lubrication oil and jacket cooling water are kept warm by electric heaters. During operation, the lubrication oil is circulated by an engine-driven pump (some engines have an ac-driven backup pump). During shutdown, the lubrication oil is circulated through the engine by an ac-driven pump. In some engines, the oil is not continuously circulated but is circulated by manual action prior to a test start. During normal operation, the jacket cooling water is circulated by an engine-driven pump, which may have an ac-driven pump as backup. Heat is removed from the jacket water by the plant service water, which begins circulation through the diesel heat exchangers when the diesel is started. When the diesel generator is fully loaded, it can operate 1 to 3 min without being cooled.

The fuel oil system consists of bulk storage tanks, day tanks, supply pipes, and pumps. The bulk storage tanks contain enough fuel to operate at least one diesel generator for 4 to 7 days. Each diesel generator has a day tank which contains enough fuel to operate for 2 to 4 h. Usually, redundant ac pumps transfer fuel from the bulk tanks to the day tanks. An engine-driven pump or a gravity feeder supplies the diesel engine with fuel from the day tank. The engine-driven pump may have an ac, dc, or manual backup pump. The bulk tanks are frequently interconnected through pipes with normally closed valves, but since the output lines from the day tanks are usually not interconnected, each tank supplies only one diesel. There are usually one or two manually-operated block valves in the supply lines from the bulk tank to the day tanks. Alarms indicate low-low or high-high levels in the day tanks and level switches in the day tanks automatically control fuel transfer from the bulk tanks.

Most diesel engine starting systems use compressed air. Air may be injected directly into the cylinders through a distributor, or the air may drive air motors that are geared to turn the engine. Each diesel engine has at least two air receivers, each of which has sufficient capacity for several start attempts. Each receiver may be connected to supply a bank of cylinders or half the number of air motors. If the receivers are banked or split between air motors, one air channel is usually capable of starting a diesel engine, but it takes longer than if both air channels function. The receivers may be dedicated to one engine or they may be connected to a header that supplies air to all engines. If they are interconnected, the headers have normally closed, manual block valves between each diesel air supply. At most plants, moisture is removed from the compressed air by manual blowdown. The manual blowdown system may be backed up with autofloat valve action or with chillers and moisture separators. Each air-start system is connected to one or two compressors, which are usually supplied from the 480-V associated bus. Also, there may be an engine-driven or dc-driven compressor. Some of the small diesel engines are started by battery-driven motors.

The diesel generator building may be equipped with heaters and chillers or ventilation fans, but in all cases the water and lubrication oil are kept warm by immersion heaters. Combustion air is taken either directly from the room through relief dampers in the wall or from the outside through ducts. Most of the engines have turbochargers, but some of the small engines may use blowers to supply the combustion air. Some of the turbochargers are gear-driven for starting; others use blowers to assist the turbocharger during the start and load change. The engine exhaust passes through the turbocharger to the outside. Some generators have engine-driven fans to help force out exhaust gas.

The Woodward Company makes all of the governors for the diesels we examined. The governor can be electrohydraulic, hydraulic, or electrohydraulic with a hydraulic backup. If the governor fails and allows the engine to overspeed, the overspeed trip in the governor shuts off fuel to the engine. The trip mechanism is either a spring, an electric solenoid, or a hydraulic actuator.

The diesel generator is a synchronous generator that requires a dc field provided by the exciter. When a diesel generator is started, the field is energized by a battery, but after the generator is operating, the field receives its power from a rectifier connected to the generator terminals. The power requirement of a typical field is from 15 to 30 kW.

9.2 STATION BLACKOUT SYSTEMS DEFINITION AND FAULT TREES

Design information needed to construct fault trees is included in Tables 9.2.1 through 9.2.15. Fault trees for these 15 tables are in Figs. 9.2.1 through 9.2.15. Davis-Besse, Millstone 1, and Millstone 2 are described in Sects. 3.1 and 3.2.

Table 9.2.1. Arkansas Nuclear One 1 fault tree system definitions

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Diesel Generator Success Criterion

One of two emergency diesel generators is required.

Cooling Requirements

Each generator is cooled by a separate service water train. Train 1 cools generator 1, and train 2 cools generator 2.

DC Power Requirements

Each dc power division provides power to start and control its dedicated diesel generators and to control breakers within its associated ac power division distribution system. Division 1 dc power supplies generator 1, and Division 2 supplies generator 2.

ORNL-DWG. 82-20505

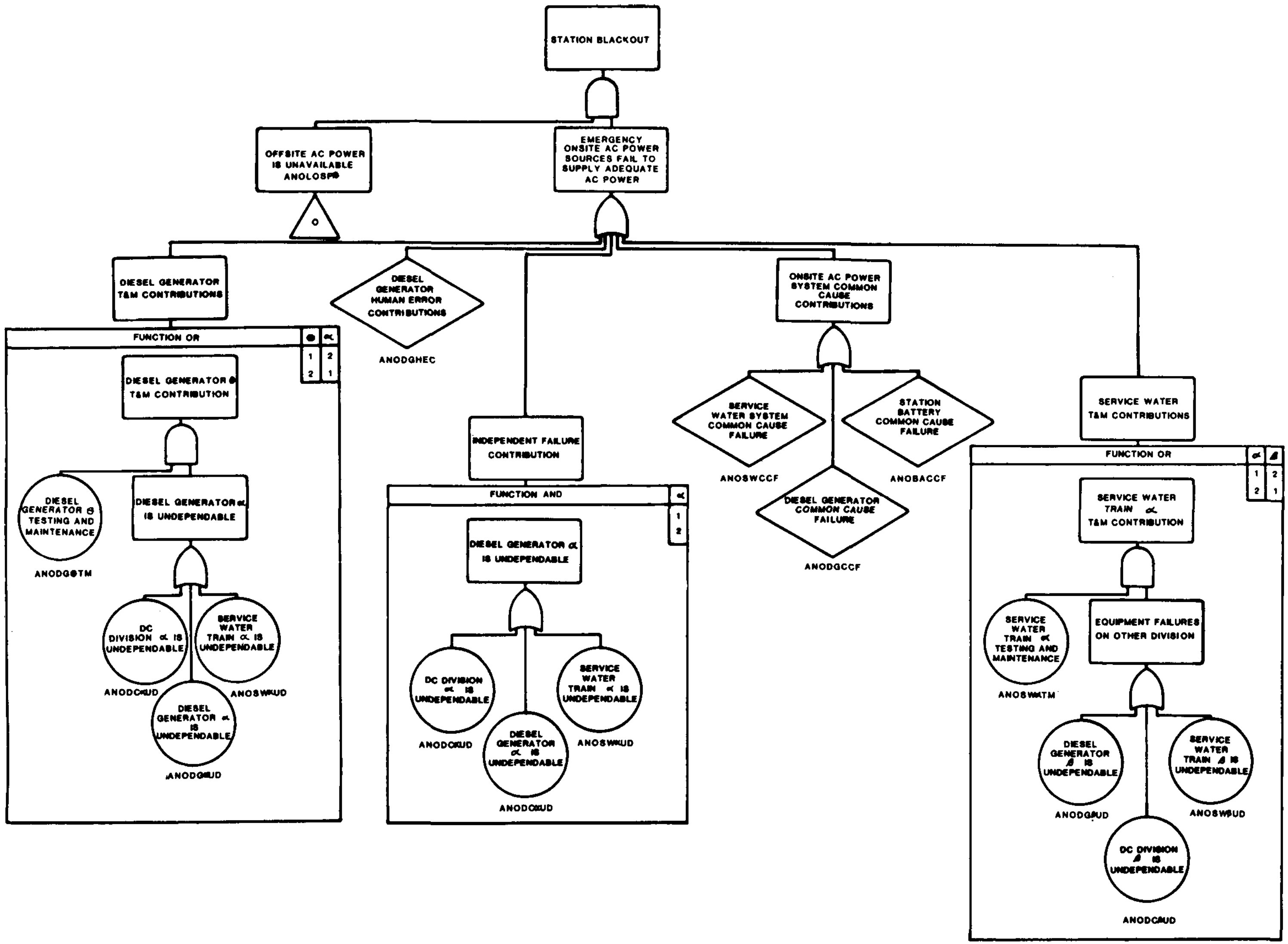


Fig. 9.2.1. Arkansas Nuclear One 1 fault tree.

Table 9.2.2. Brunswick 1 and 2 fault tree systems definitions

Diesel Generator Success Criterion

Two of four emergency diesel generators are required.

Cooling Requirements

Service water train 1 cools generators 1 and 3, and train 2 cools generators 2 and 4.

DC Power Requirements

Division 1 supplies dc power to start and control generators 1 and 3 and to control ac power division 1. Division 2 supplies dc power to start and control generators 2 and 4 and to control ac power Division 2.

Special Features

The station dc power division provides control power to the switchyard. Thus, failure of both dc divisions causes station blackout.

ORNL-DWG. 82-20506

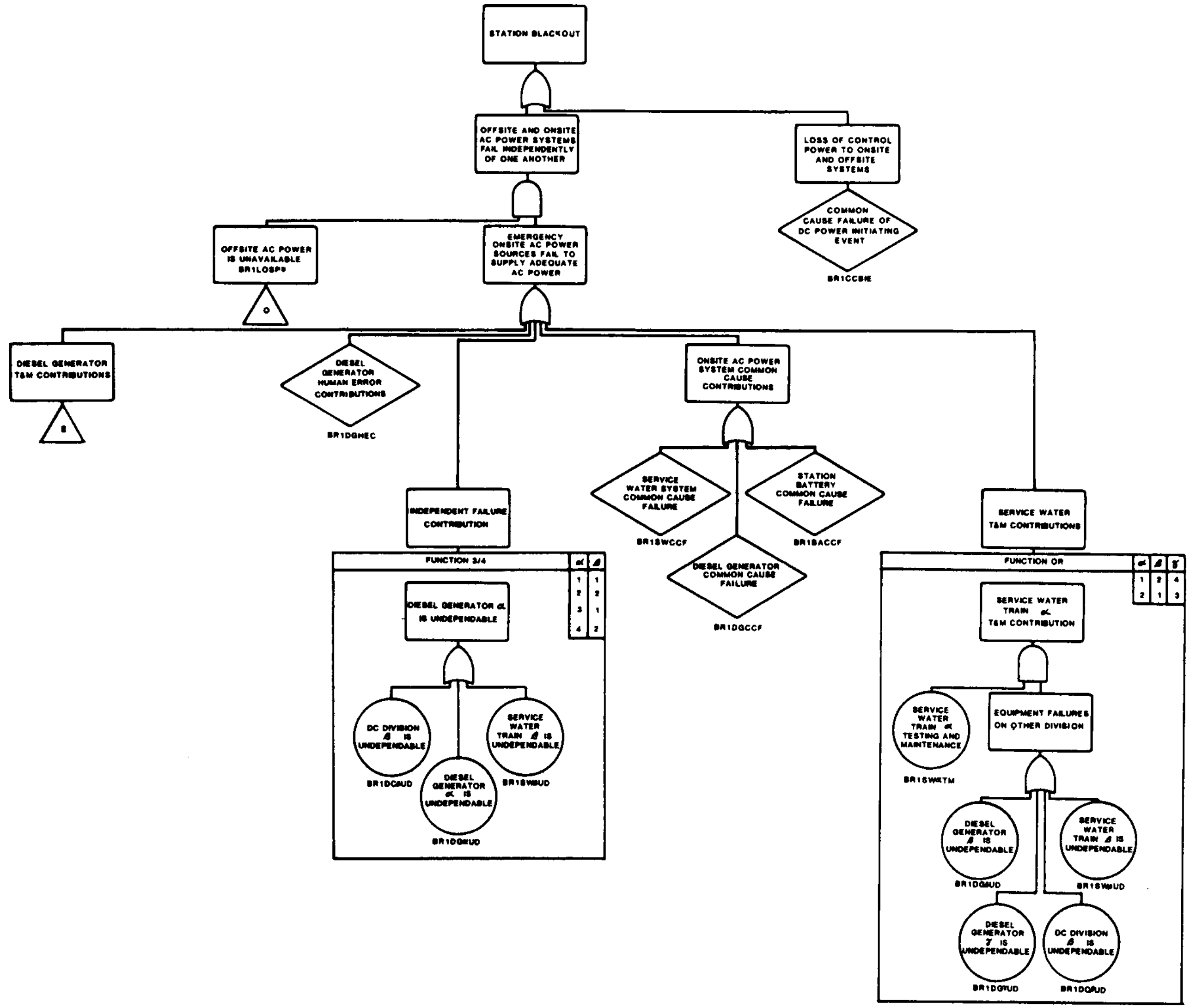


Fig. 9.2.2. Brunswick 1 and 2 fault tree.

ORNL-DWG. 82-20507

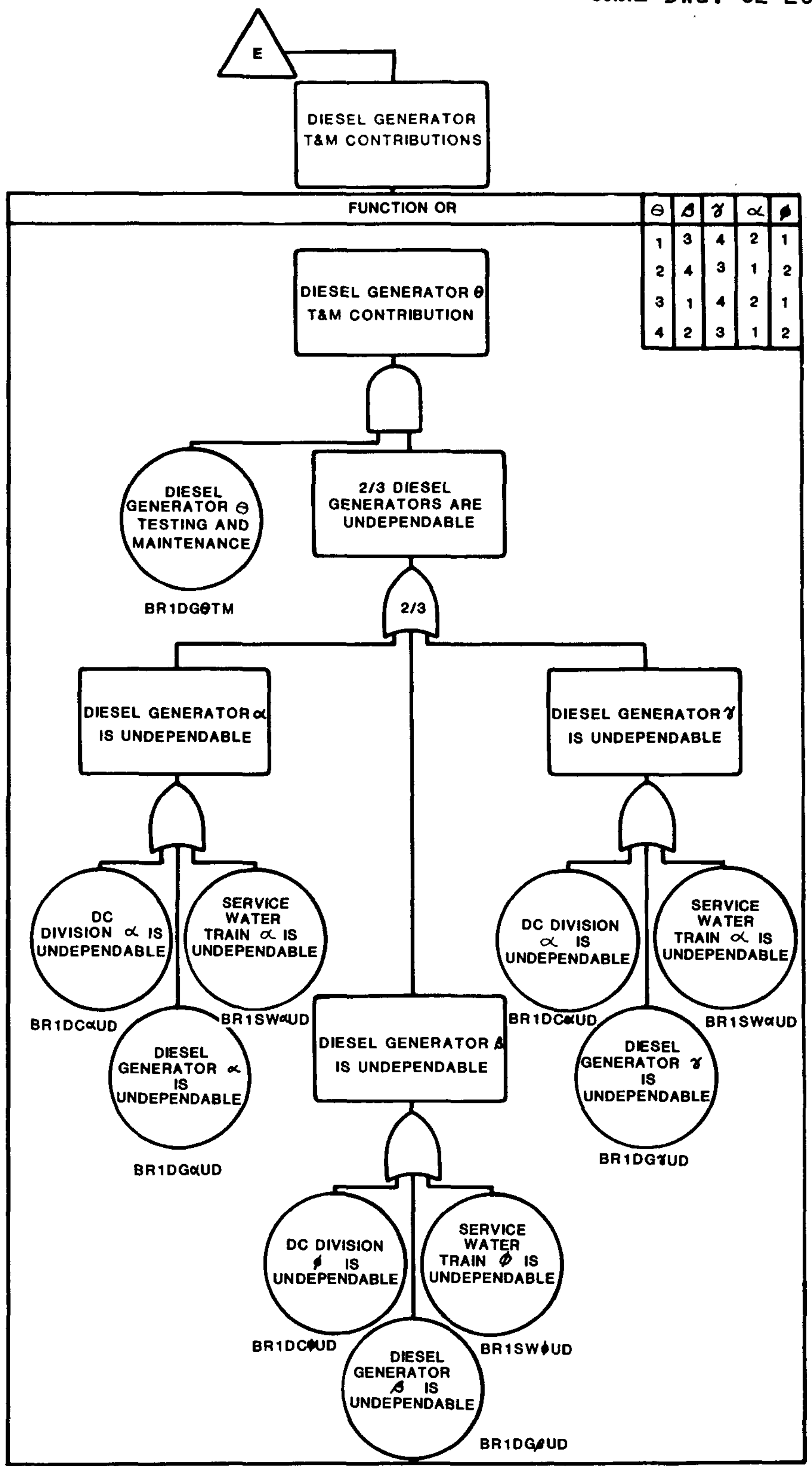


Fig. 9.2.2. Continued.

Table 9.2.3. Calvert Cliffs 1 and 2 fault tree systems definitions

---

Diesel Generator Success Criterion

Two of three emergency diesel generators are required.

Cooling Requirements

Service water train 1 cools generator 1, and train 2 cools generator 2. Generator 3 may be cooled either by train 1 or 2.

DC Power Requirements

DC division 1 provides power to start and control generator 1, and dc Division 2 provides power to start and control generator 2. Starting and control power for generator 3 may be supplied from either dc Division 1 or 2.

ORNL-DWG. 82-20509

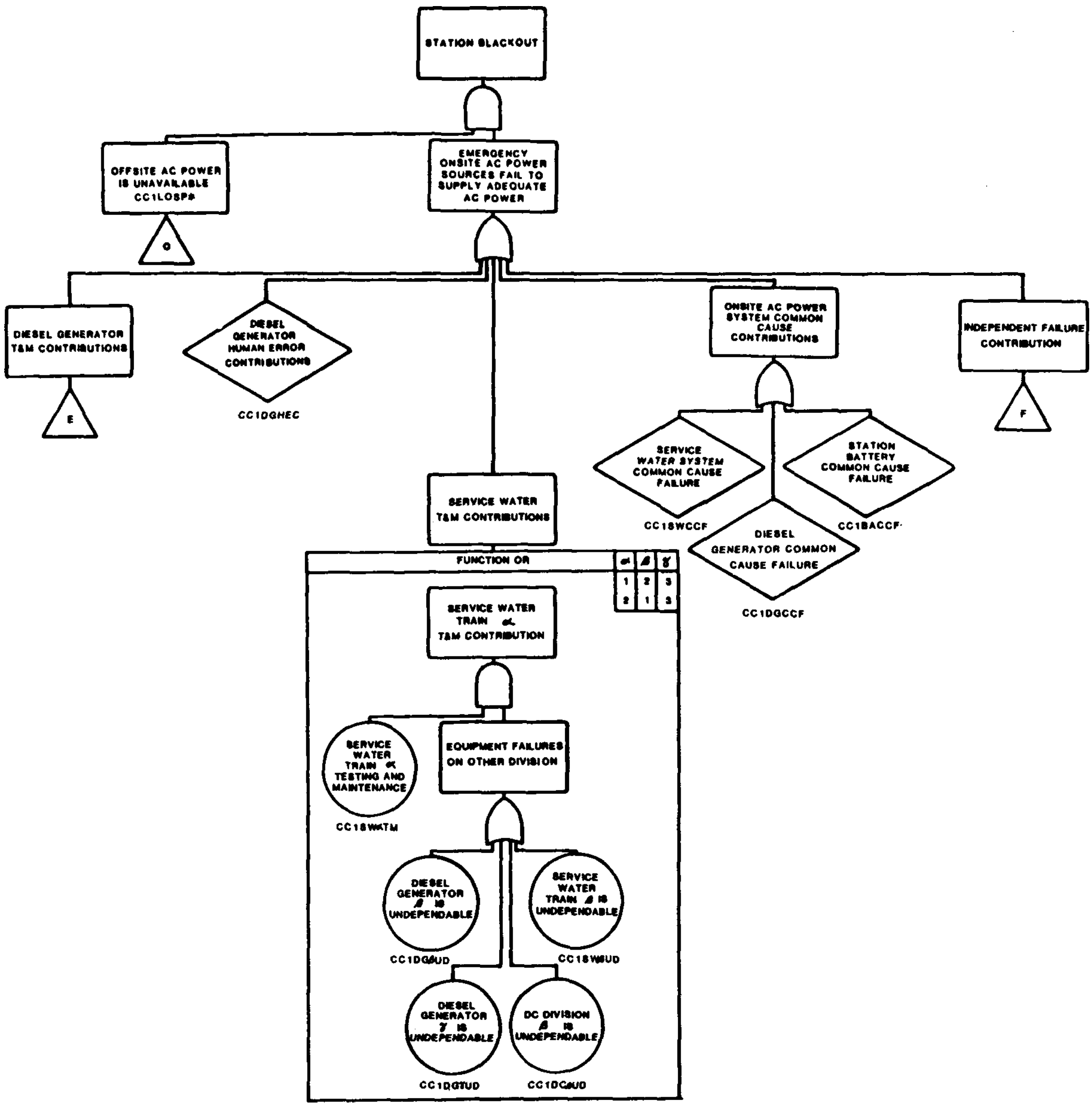


Fig. 9.2.3. Calvert Cliffs 1 and 2 fault tree.

ORNL-DWG. 82-20508

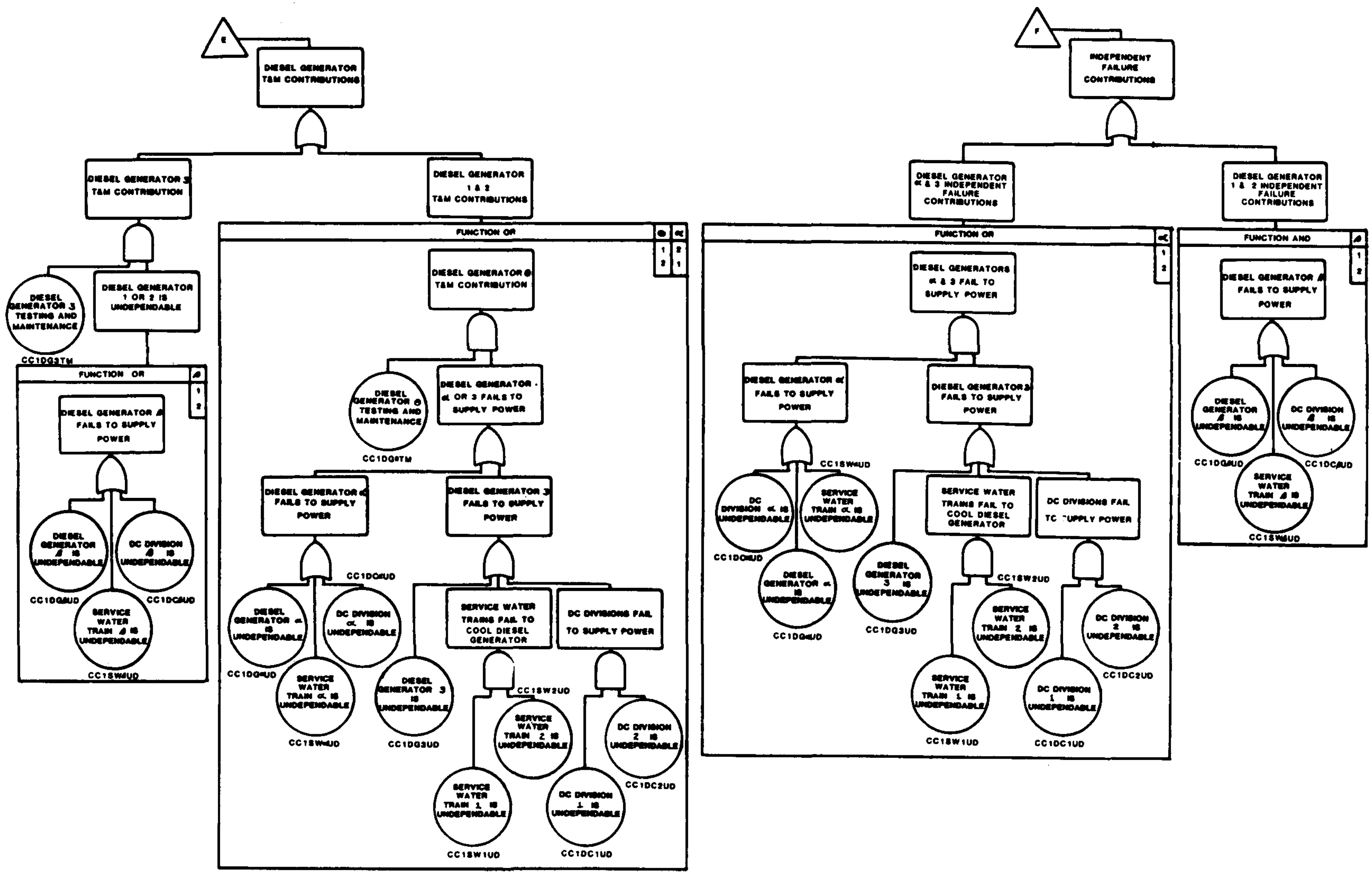


Fig. 9.2.3. Continued.

Table 9.2.4. Donald C. Cook 2 fault tree systems definitions

Diesel Generator Success Criterion

One of two emergency diesel generators is required.

Cooling Requirements

Each generator is cooled by a separate service water train. Train 1 cools generator 1, and train 2 cools generator 2.

DC Power Requirements

Each dc power division provides power to start and control its dedicated diesel generators and to control breakers within its associated ac power division distribution system. Division 1 of dc power supplies generator 1, and Division 2 supplies generator 2.

ORNL-DWG. 82-20510

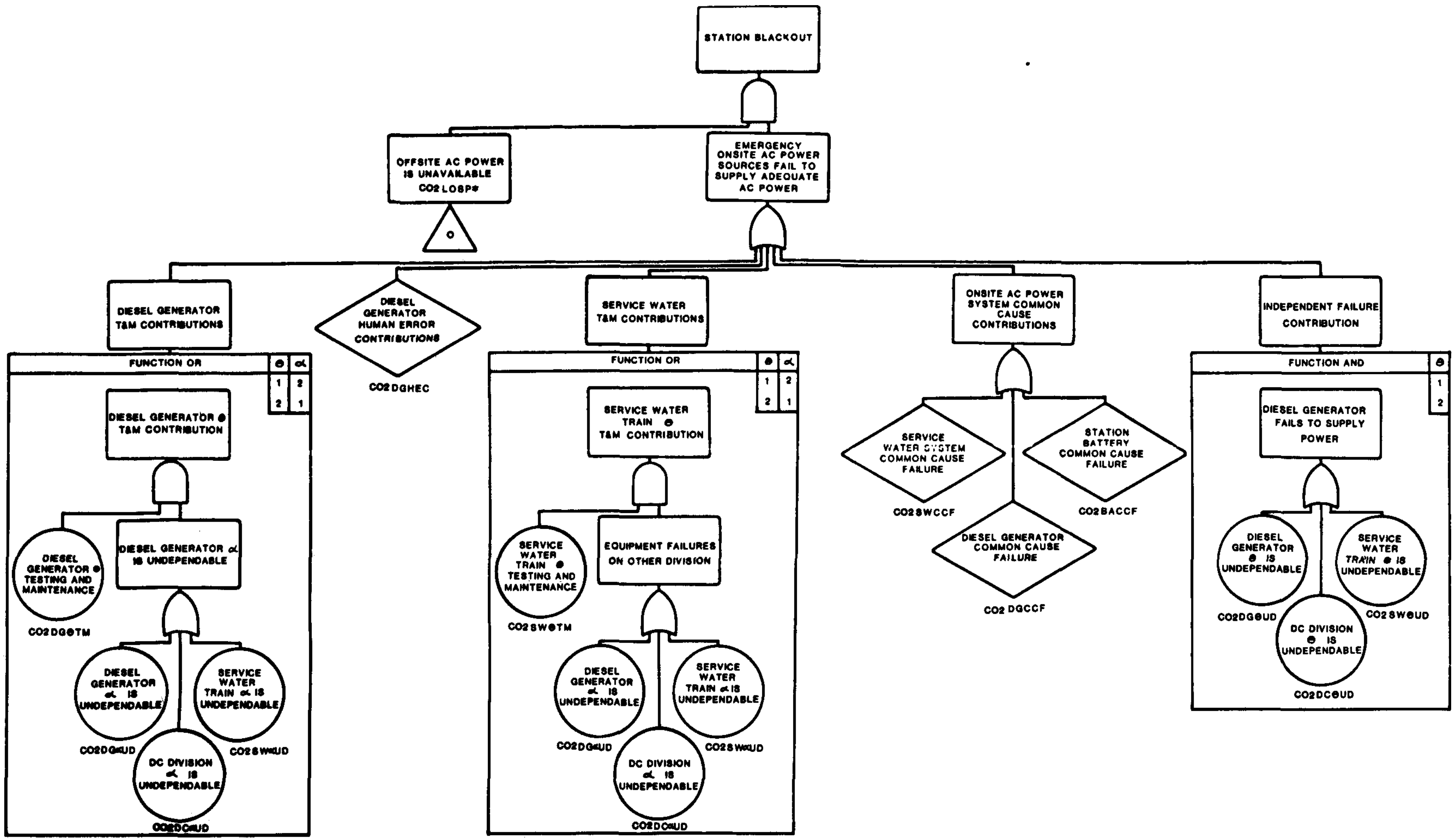


Fig. 9.2.4. Donald C. Cook 2 fault tree.

Table 9.2.5. Crystal River 3 fault tree systems definitions

Diesel Generator Success Criterion

One of two emergency diesel generators is required.

Cooling Requirements

Each emergency diesel generator is cooled by a dedicated radiator.

DC Power Requirements

Each dc division provides power to start and control its dedicated diesel generators and to control breakers within its associated ac power division distribution system. Division 1 of dc power supplies generator 1, and Division 2 supplies generator 2.

ORNL-DWG. 82-20511

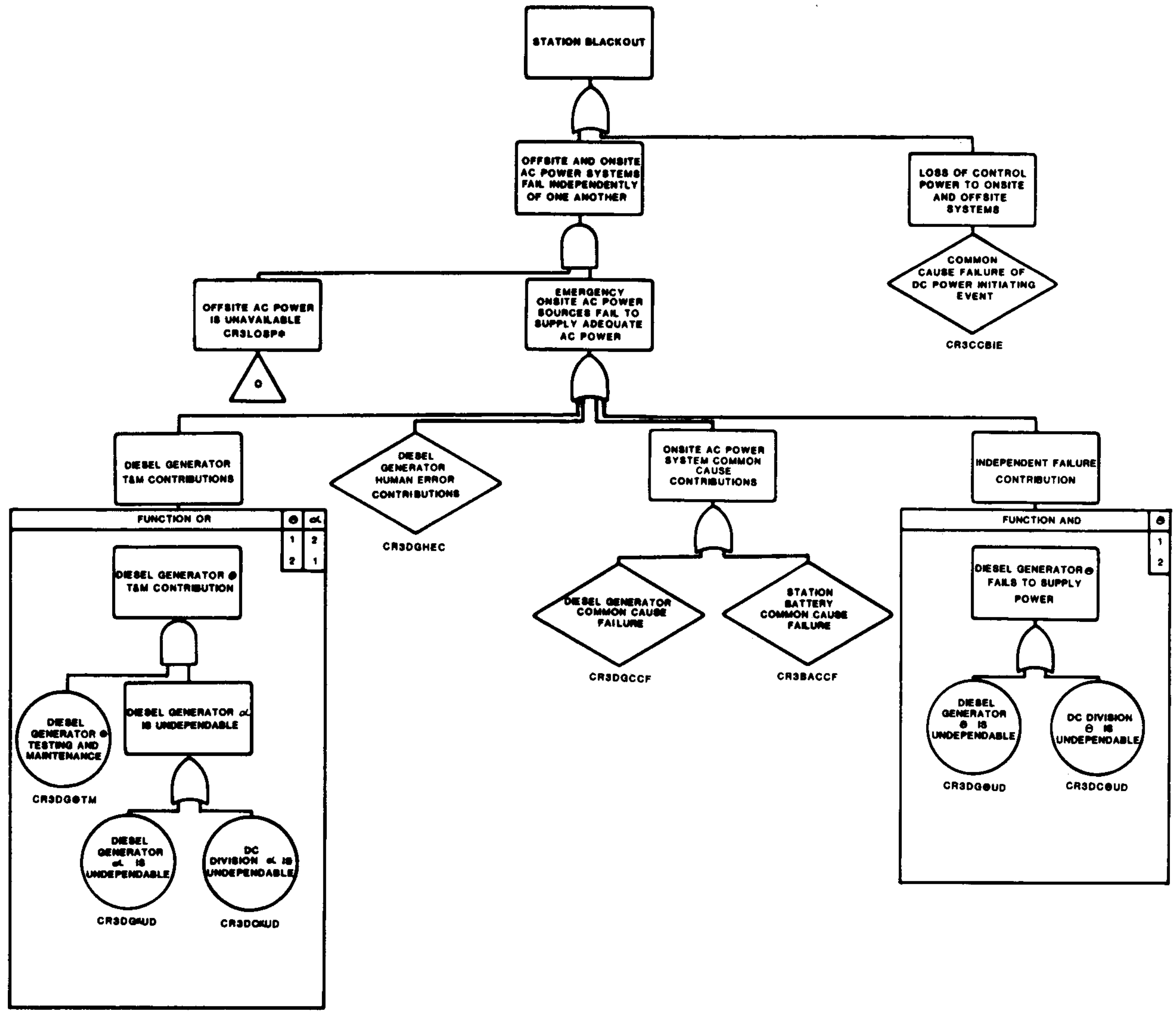


Fig. 9.2.5. Crystal River 3 fault tree.

Table 9.2.6. Dresden 2 and 3 fault tree systems definitions

Diesel Generator Success Criterion

Two of three emergency diesel generators are required.

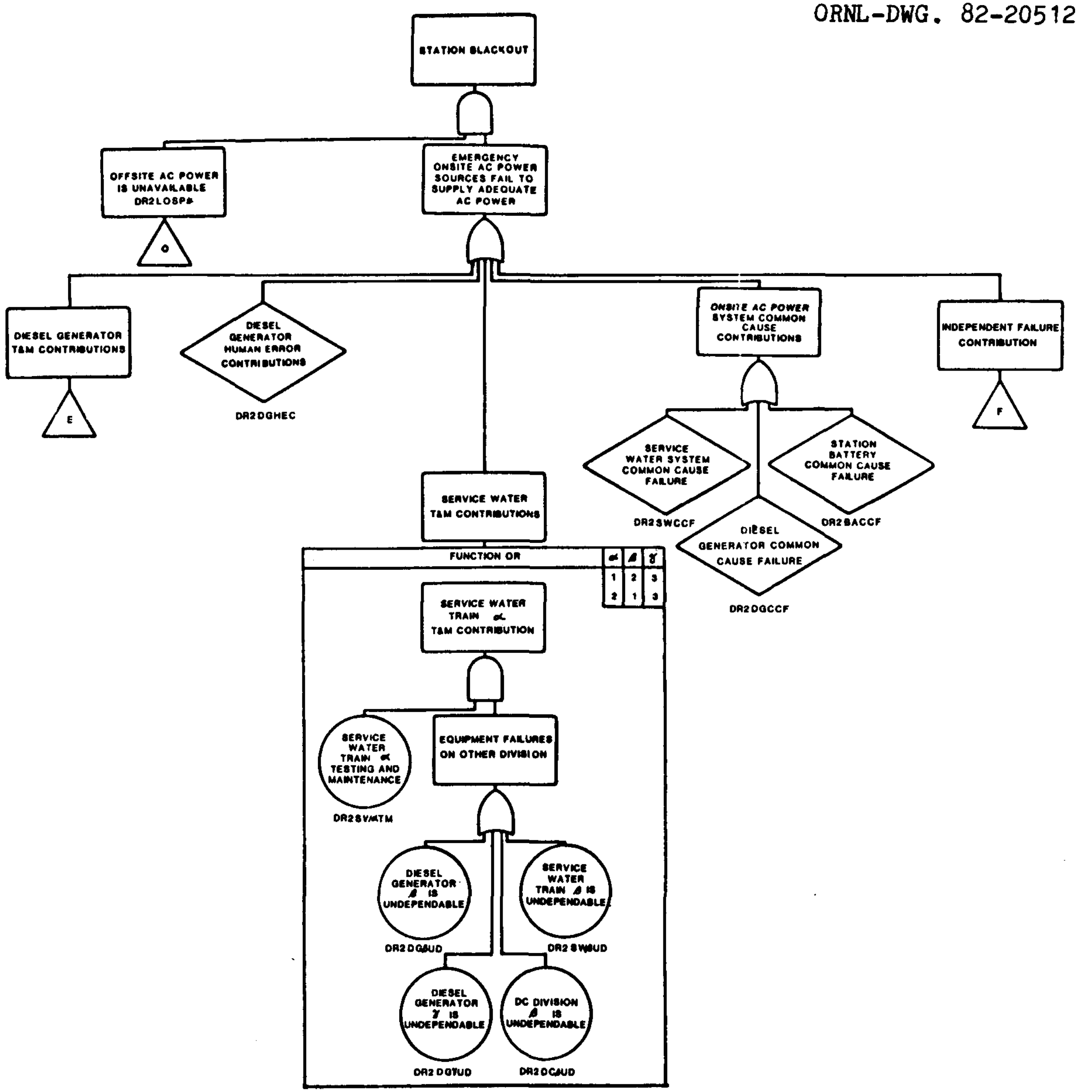
Cooling Requirements

Service water train 1 cools generator 1, and train 2 cools generator 2. Generator 3 may be cooled by either train 1 or 2.

DC Power Requirements

DC Division 1 provides power to start and control generator 1 and Division 2 provides power to start and control generator 2. Starting and control power for generator 3 may be supplied from either dc Division 1 or 2.

ORNL-DWG. 82-20512



α	β	γ
1	2	3
2	1	3

Fig. 9.2.6. Dresden 2 and 3 fault tree.

ORNL-DWG. 82-20513

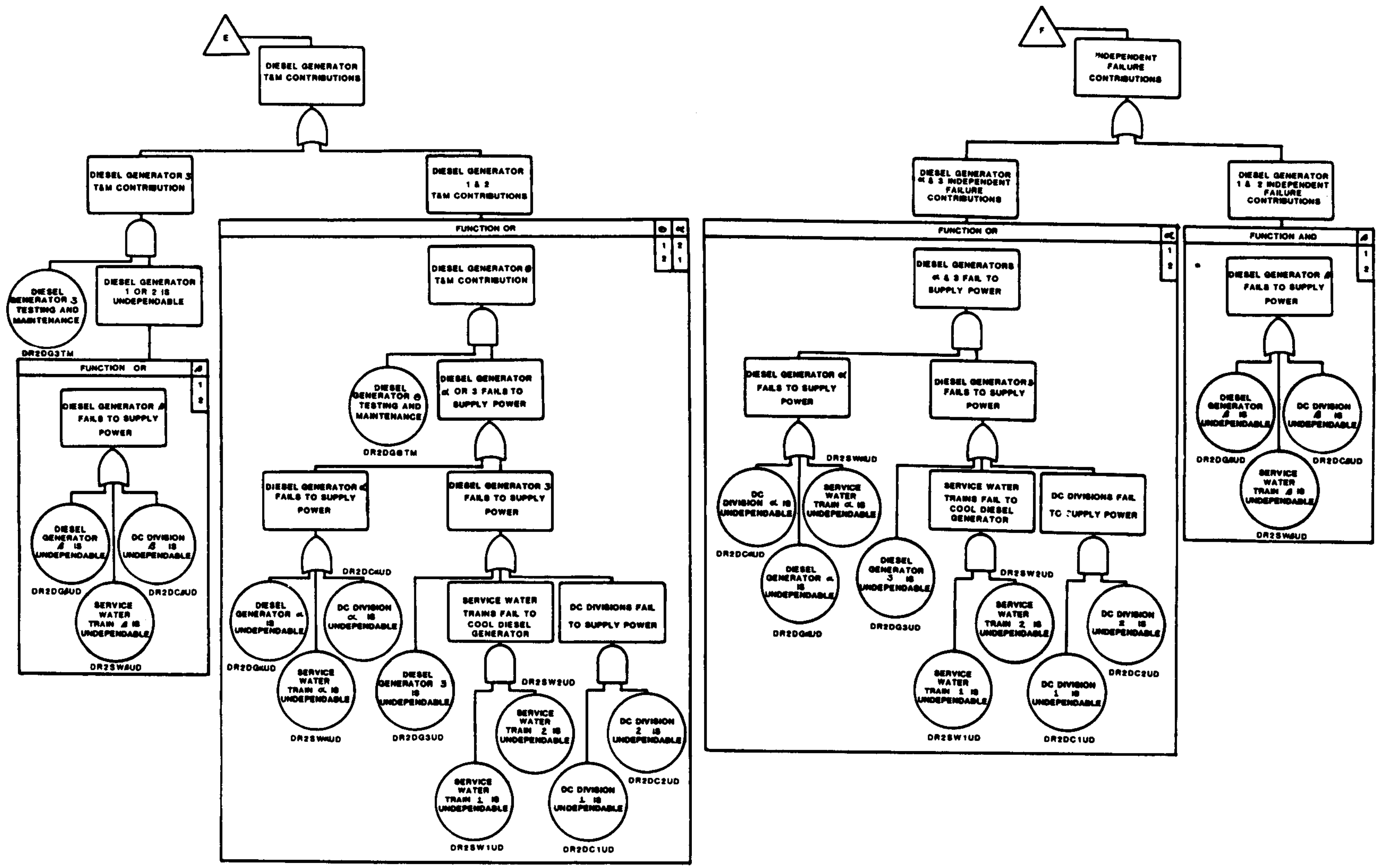


Fig. 9.2.6. Continued.

Table 9.2.7. Joseph M. Farley 1 and 2 fault tree systems definitions

Diesel Generator Success Criterion

Two of five emergency diesel generators are required.

Cooling requirements

Generators 1, 3, and 5 are cooled by train 1 of the unit 1 or unit 2 service water systems. Generators 2 and 4 are cooled by train 2 of the unit 1 or unit 2 service water systems. Because of this redundancy and the diesel success criterion, independent service water system failures are not included in the fault tree.

DC Power Requirements

DC Division 1 supplies power to start and control generators 1, 3, and 5 and to control ac Division 1. DC Division 2 supplies power to start and control generators 2 and 4 and to control ac Division 2.

ORNL-DWG. 82-20516

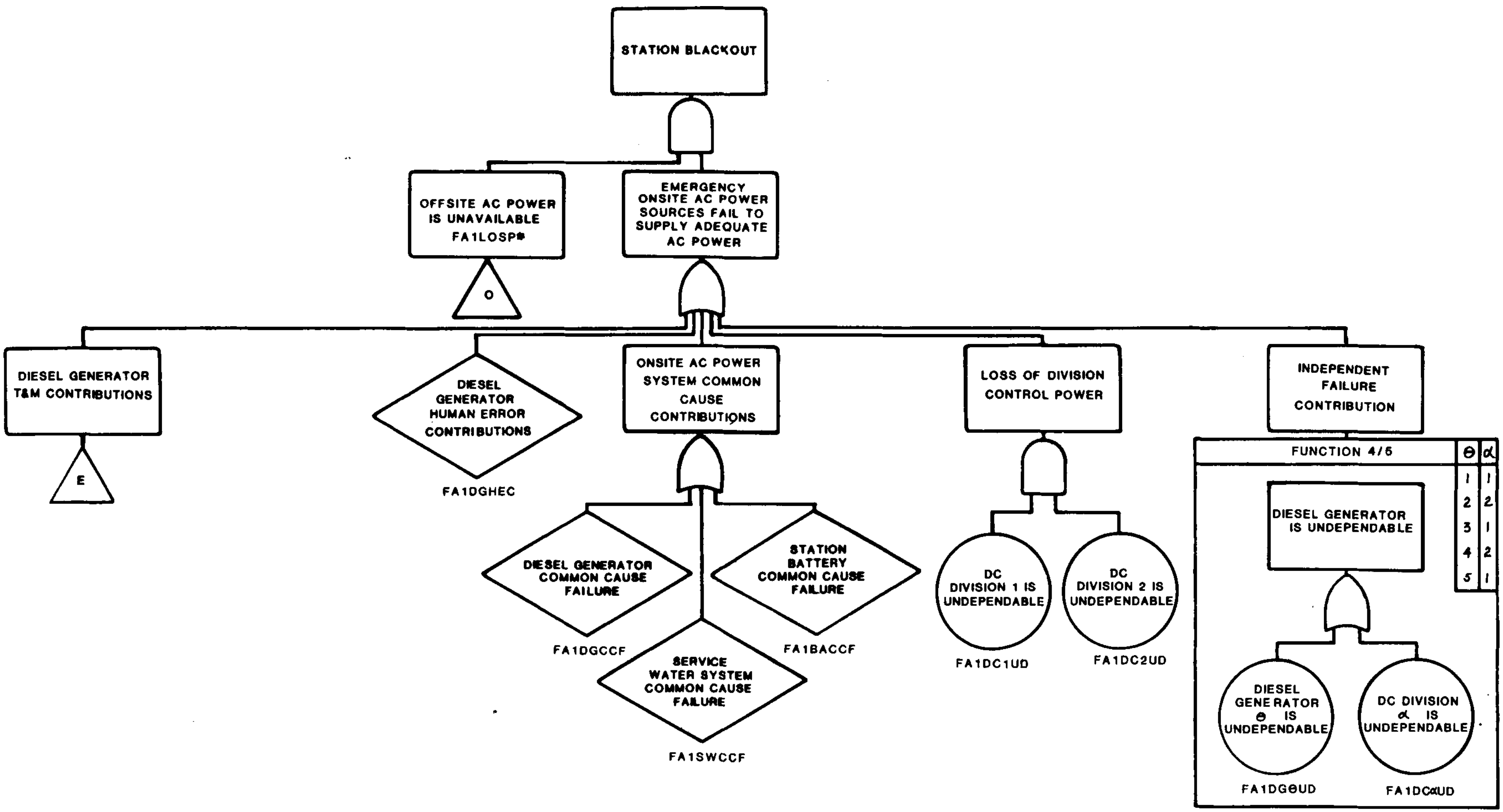


Fig. 9.2.7. Joseph M. Farley 1 and 2 fault tree.

ORNL-DWG. 82-20514

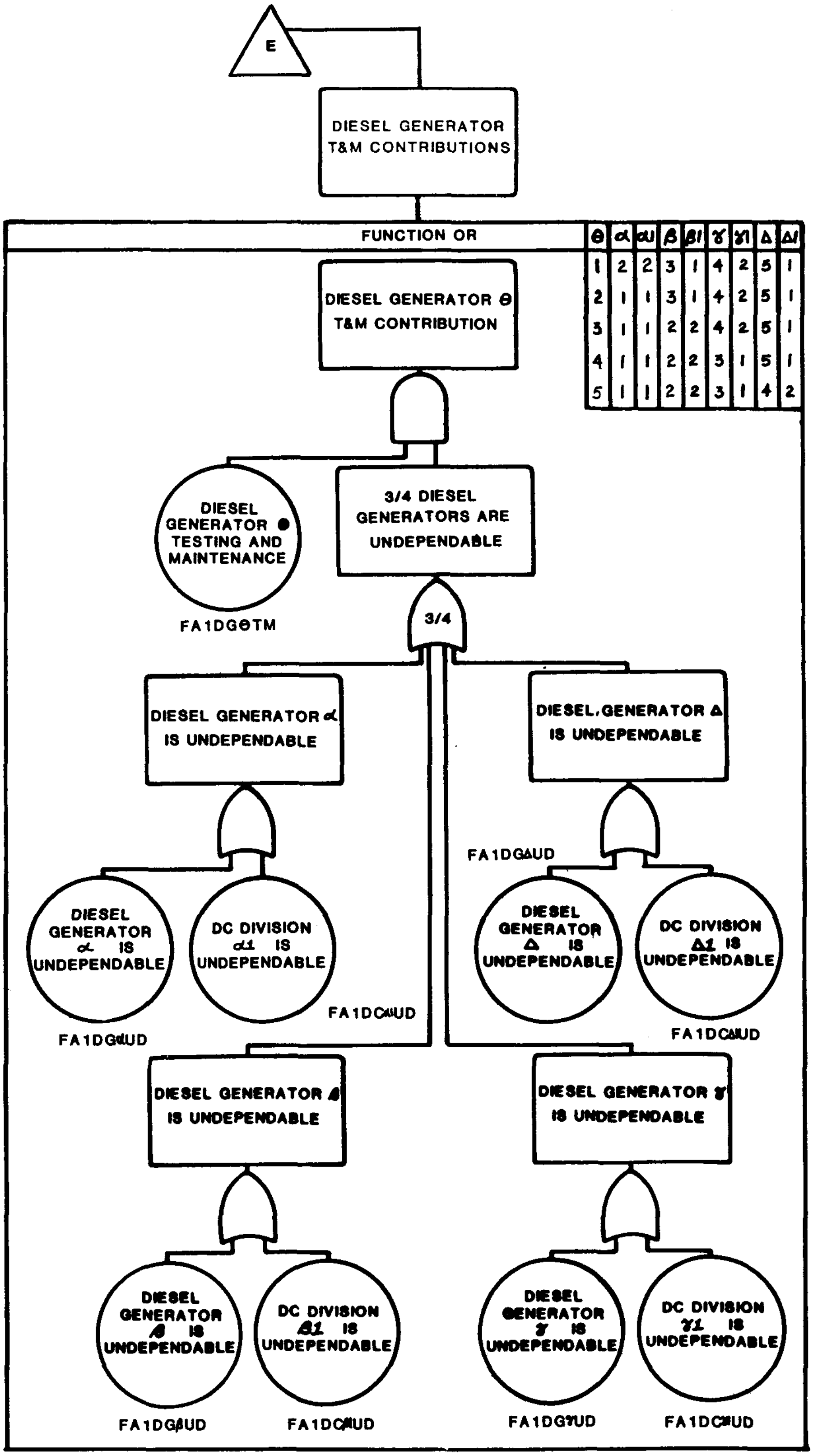


Fig. 9.2.7. Continued.

Table 9.2.8. James A. FitzPatrick fault tree systems definitions

---

Diesel Generator Success Criterion

One of four emergency diesel generators is required.

Cooling Requirements

Service water train 1 cools generators 1 and 3, and train 2 cools generators 2 and 4.

DC Power Requirements

DC Division 1 supplies power to start and control generators 1 and 3, and to control ac Division 1. DC Division 2 supplies power to start and control generators 2 and 4 and to control ac Division 2.

ORNL-DWG. 82-20517

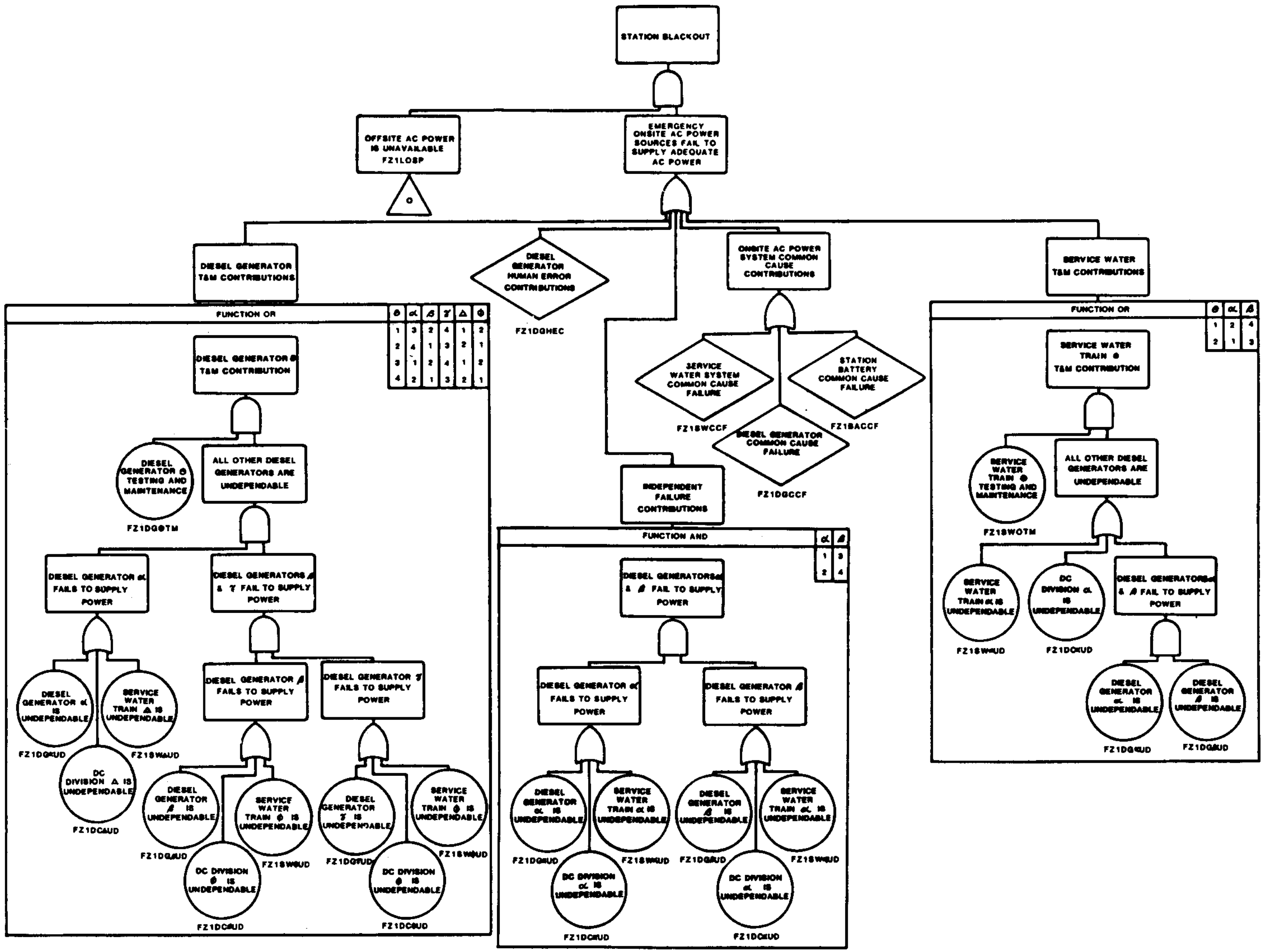


Fig. 9.2.8. James A. FitzPatrick fault tree.

Table 9.2.9. Edwin I. Hatch 1 and 2 fault tree systems definitions

---

Diesel Generator Success Criterion

Two of five emergency diesel generators are required.

Cooling Requirements

Service water train 1 cools generators 1, 3, and 5 and train 2 cools generators 2 and 4.

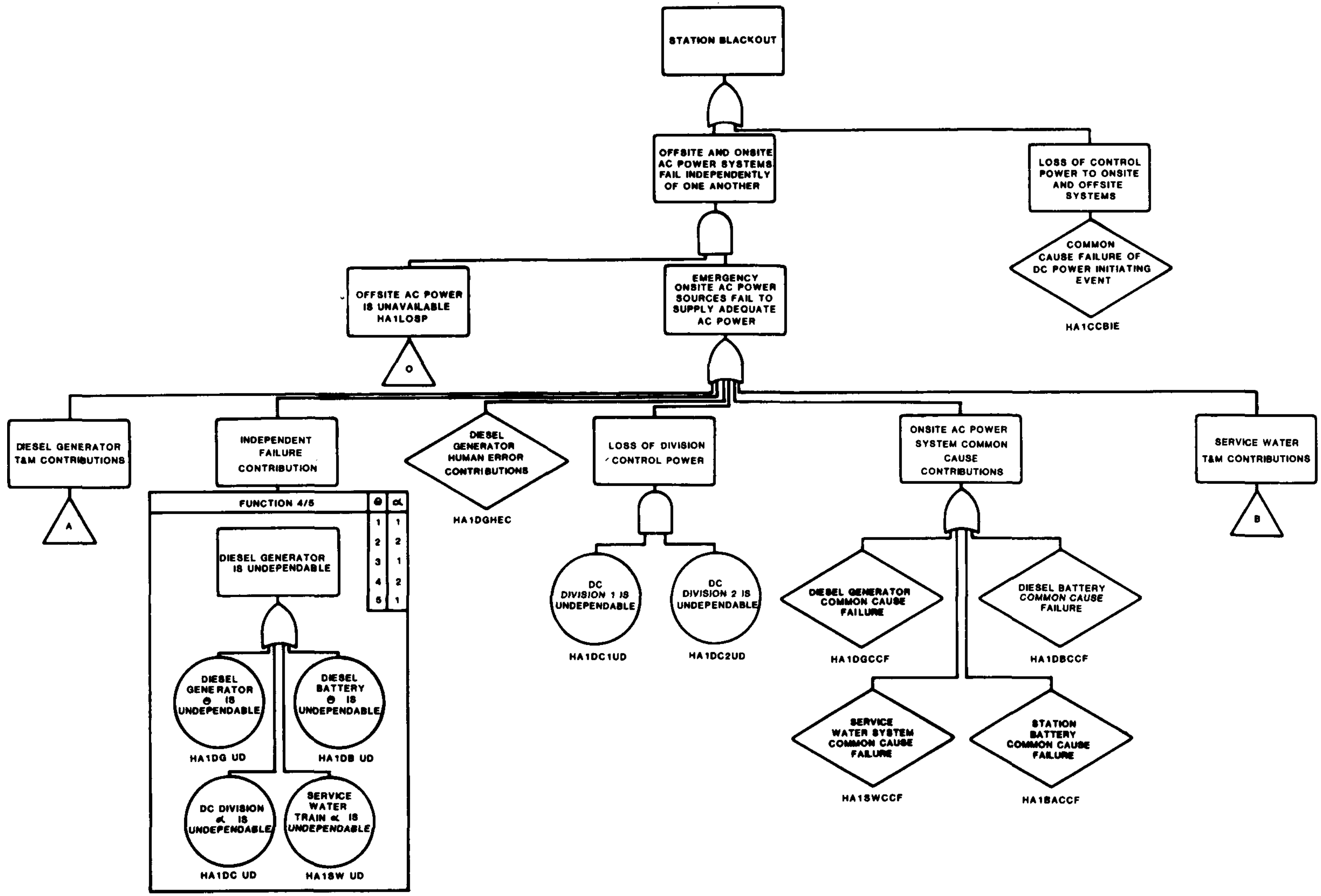
DC Power Requirements

DC Division 1 provides power to control breakers in ac Division 1. DC Division 2 provides power to control breakers in ac Division 2.

Special Features

Each generator has a dedicated battery for startup and control power. The dc divisions provide control power to the switchyard and distribution system. Thus, failure of both dc divisions will cause a station blackout because the diesel generator cannot function independently of plant dc power.

ORNL-DWG. 82-20518



⊖	α
1	1
2	2
3	1
4	2
5	1

Fig. 9.2.9. Edwin I. Hatch 1 and 2 fault tree.

ORNL-DWG. 82-20515

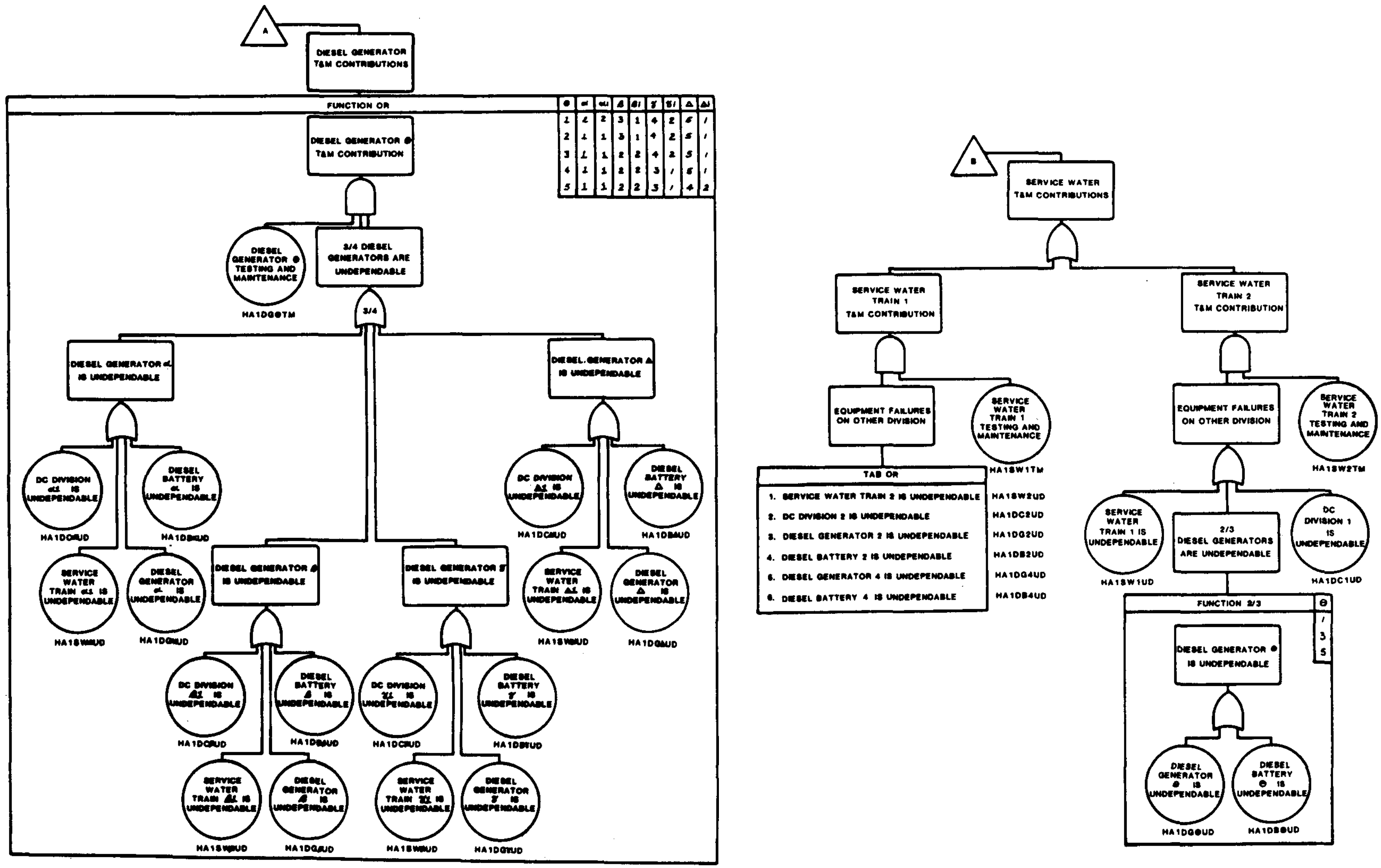


Fig. 9.2.9. Continued.

Table 9.2.10. Nine Mile Point fault tree systems definitions

Diesel Generator Success Criterion

One of two emergency diesel generators is required.

Cooling Requirements

Each generator is cooled by a separate service water train: train 1 cools generator 2, and train 2 cools generator 2.

DC Power Requirements

Each dc power division provides startup and control power for its division dedicated diesel generator and control power for the breakers within its associated ac division distribution system. DC Division 1 supplies generator 1, and Division 2 supplies generator 2.

Special Features

The dc divisions also provide control power for the switchyard. Thus, failure of both dc divisions will cause a station blackout.

ORNL-DWG. 82-20519

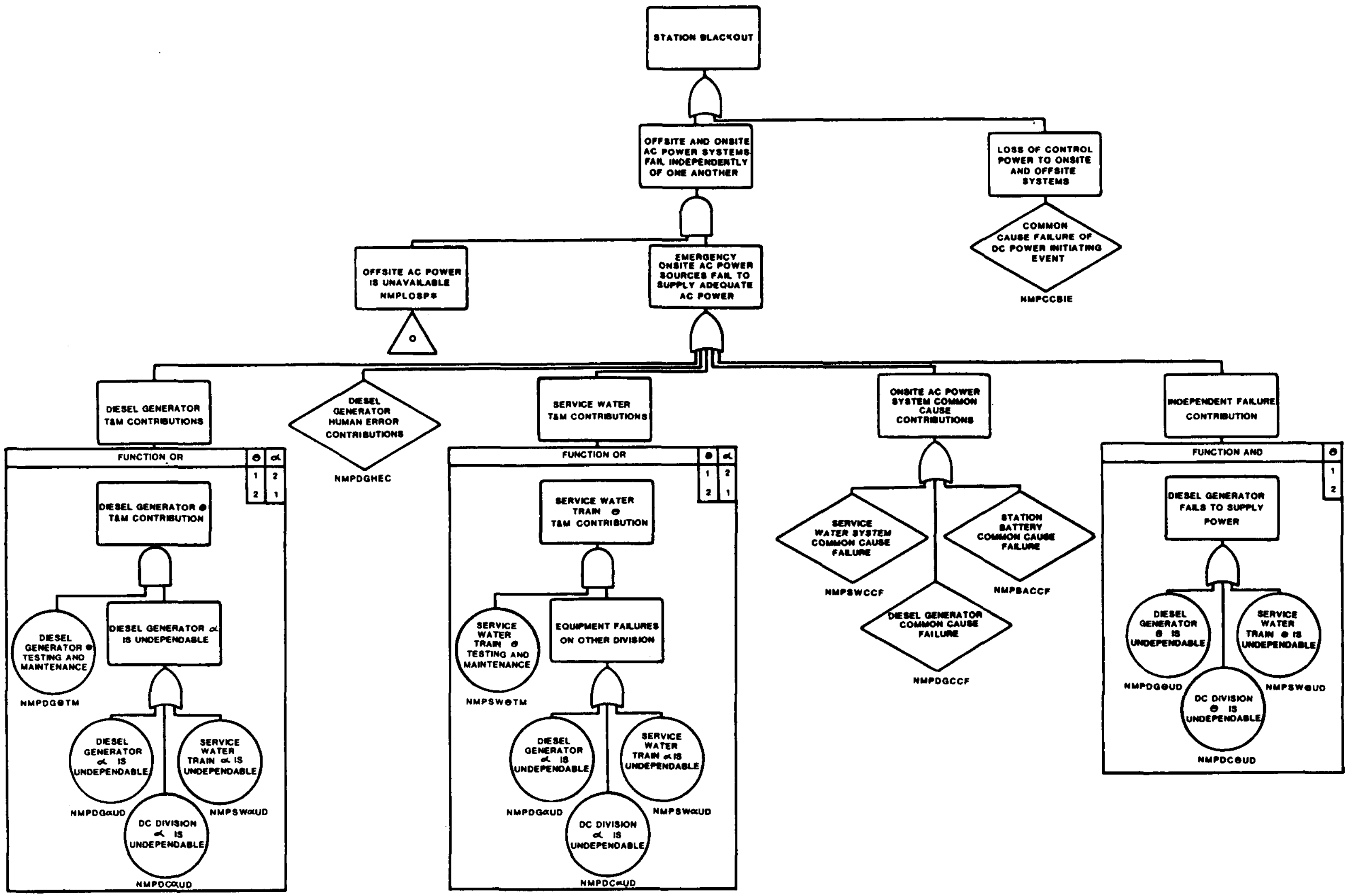


Fig. 9.2.10. Nine Mile Point fault tree.

Table 9.2.11. Peach Bottom 2 and 3 fault tree systems definitions

Diesel Generator Success Criterion

Two of four diesel generators are required.

Cooling Requirements

Service water train 1 cools generators 1 and 3, and train 2 cools generators 2 and 4.

DC Power Requirements

DC Division 1 provides startup and control power for generators 1 and 3, and control power for ac Division 1. DC Division 2 provides startup and control power for generators 2 and 4, and control power for ac Division 2.

Special Features

The station dc provides control power to the switchyard. Thus failure of both dc divisions will cause a station blackout.

ORNL-DWG. 82-20520

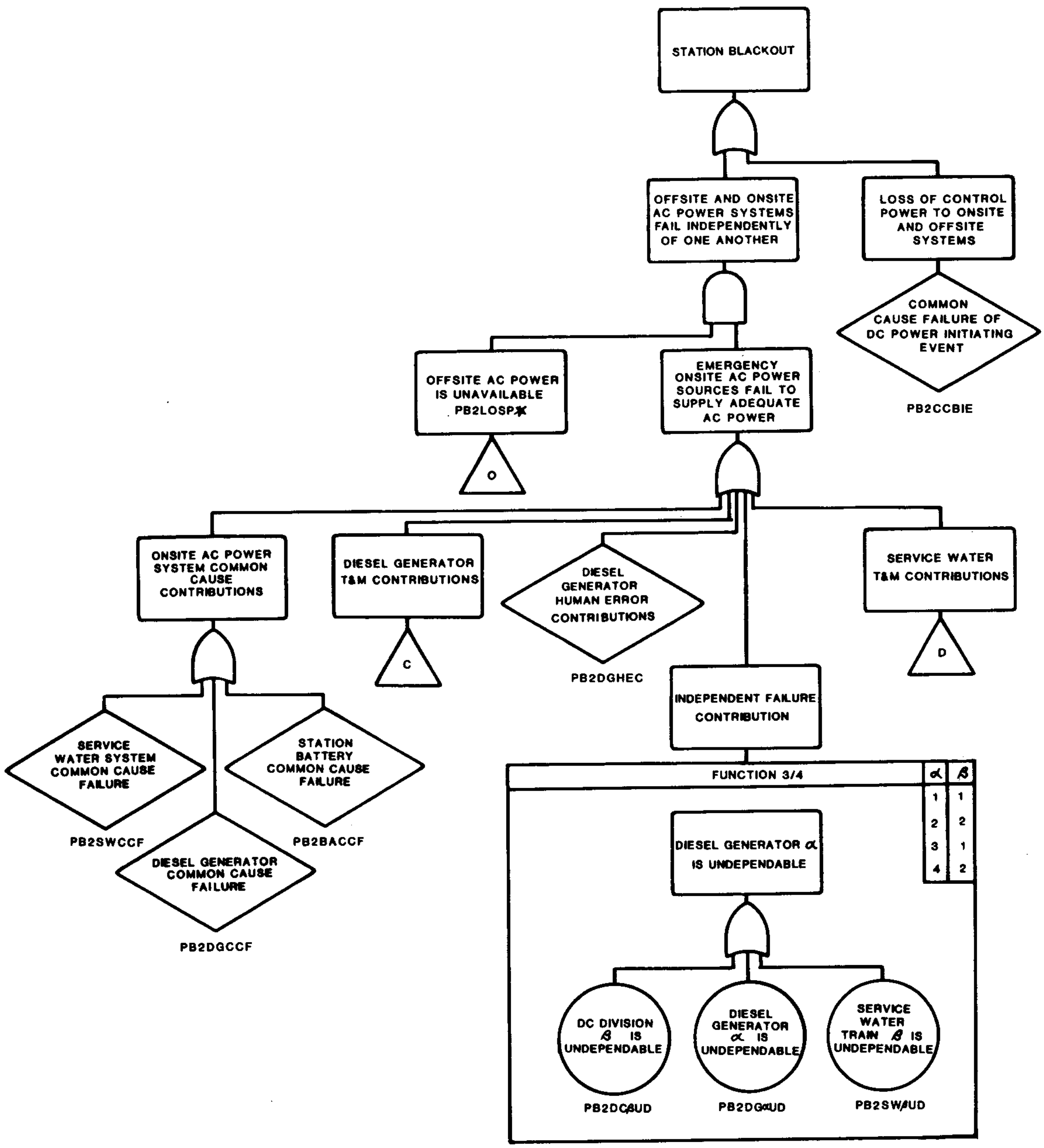


Fig. 9.2.11. Peach Bottom 2 and 3 fault tree.

ORNL-DWG. 82-20521

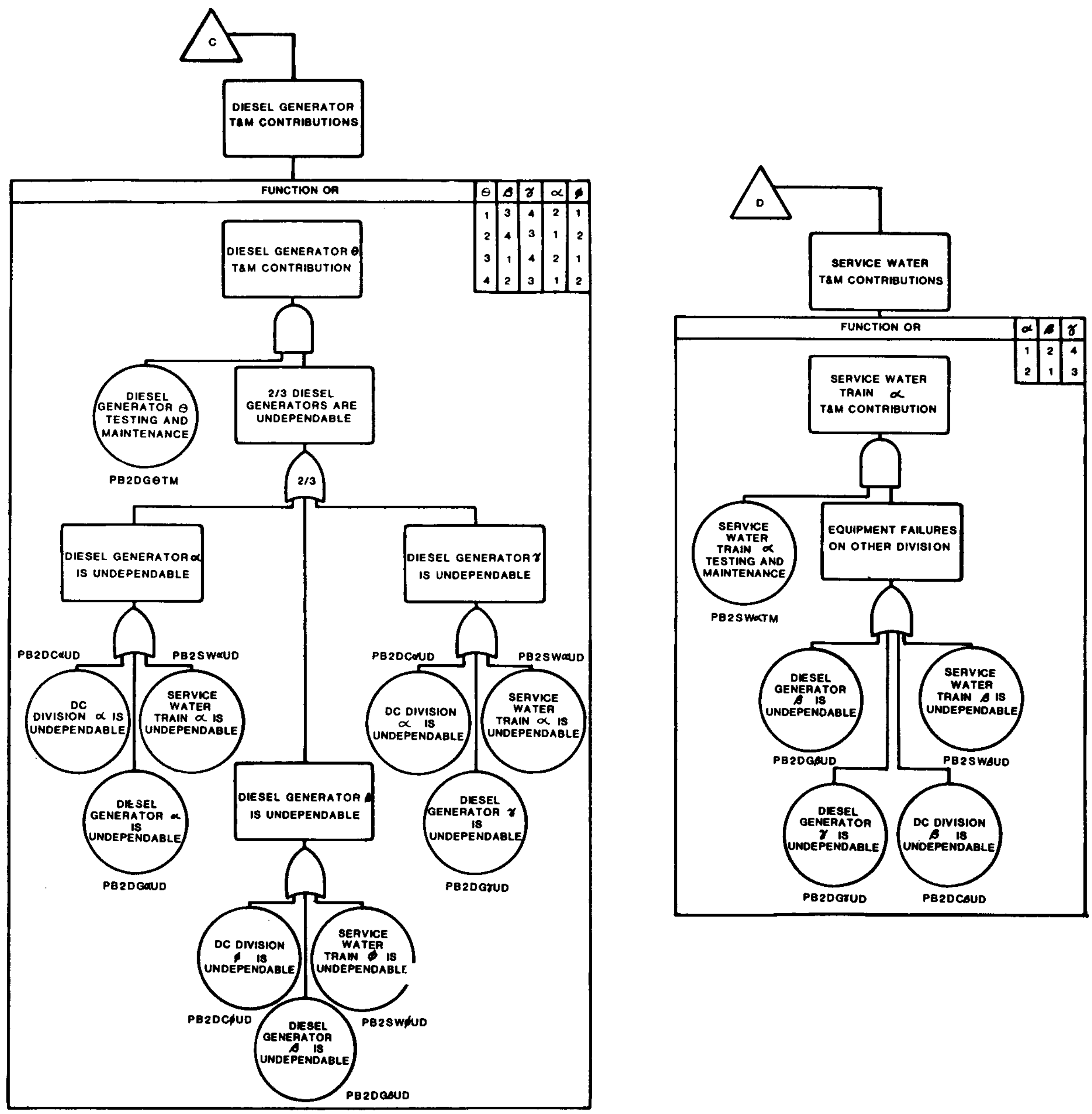


Fig. 9.2.11. Continued.

Table 9.2.12. St. Lucie fault tree systems definitions

Diesel Generator Success Criterion

One of two emergency diesel generators is required.

Cooling Requirements

Each emergency diesel generator is cooled by a dedicated air-water radiator.

DC Power Requirements

Each dc division provides startup and control power for its division dedicated diesel generator and control power for the breakers within the associated ac division. DC Division 1 supplies generator 1, and Division 2 supplies generator 2.

Special Features

Each generator unit is driven by tandem diesel engines: one eight-cylinder and one twelve-cylinder engine.

ORNL-DWG. 82-20522

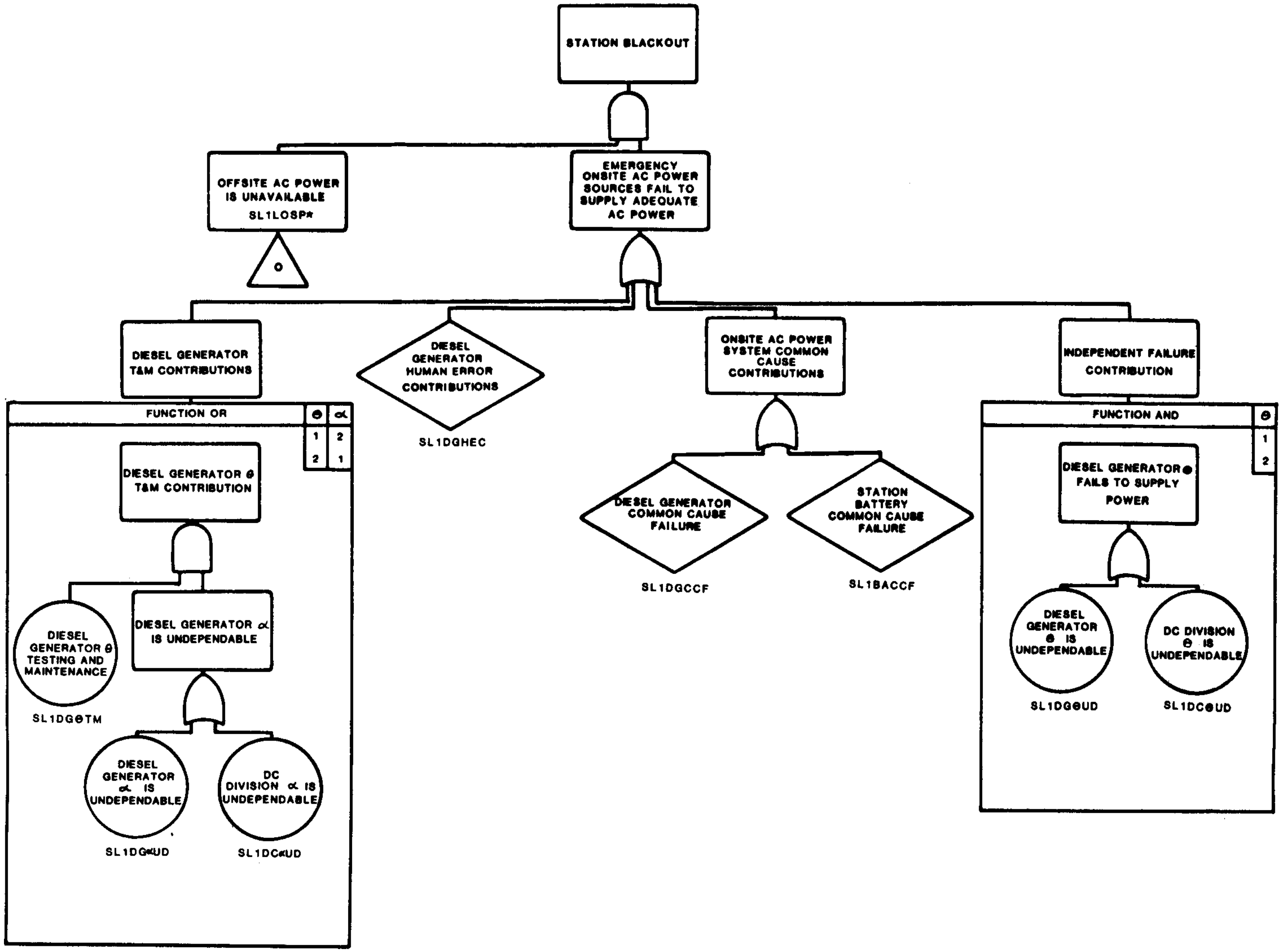


Fig. 9.2.12. St. Lucie fault tree.

Table 9.2.13. San Onofre fault tree systems definitions

Diesel Generator Success Criterion

One of two emergency diesel generators is required.

Cooling Requirements

Each generator is cooled by a dedicated radiator.

DC Power Requirements

Each dc division provides startup and control power for its division dedicated diesel generator and control power for the breaker within its associated ac division. DC Division 1 supplies generator 1, and Division 2 supplies generator 2.

ORNL-DWG. 82-20523

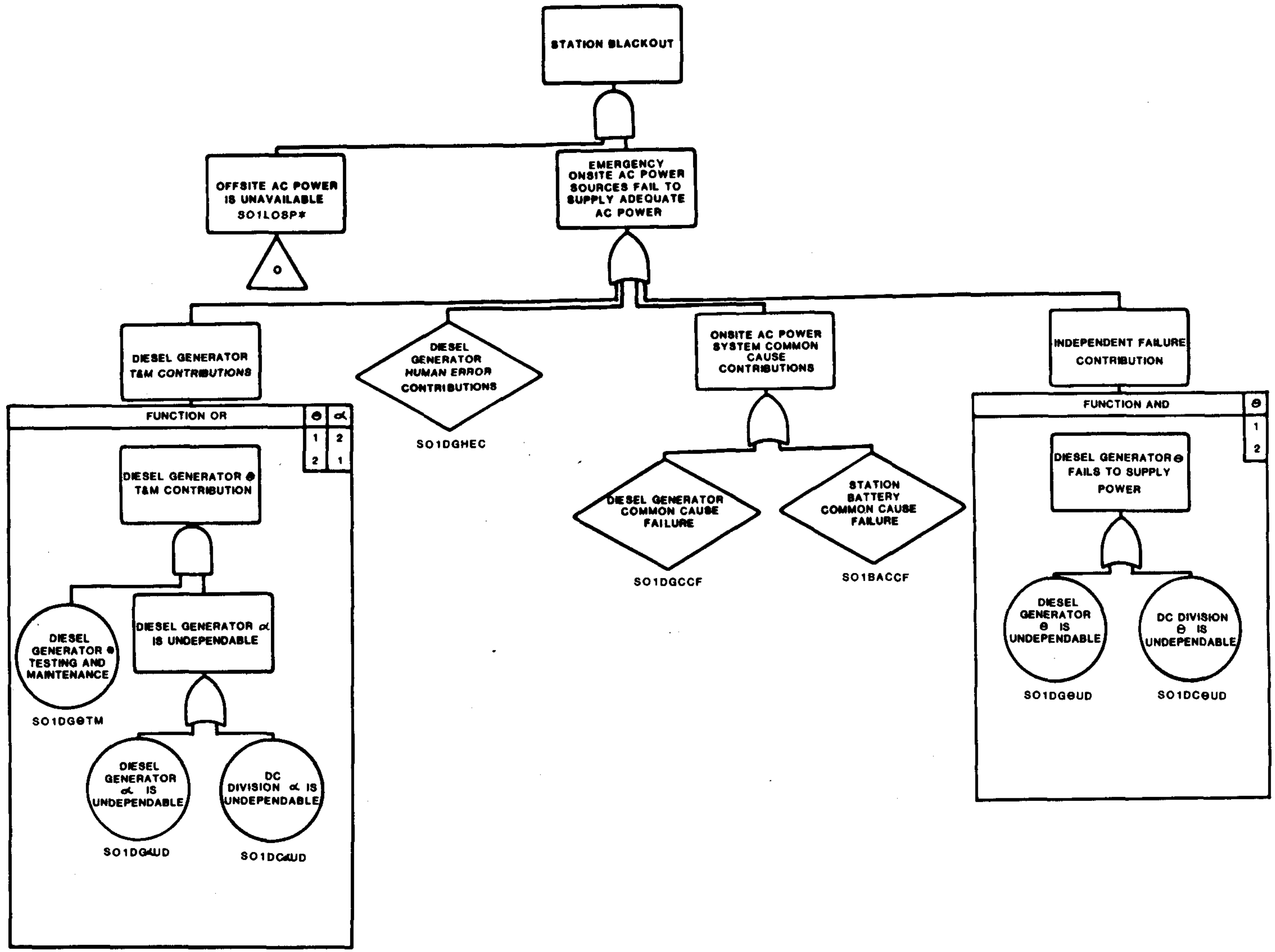


Fig. 9.2.13. San Onofre fault tree.

Table 9.2.14. Turkey Point 3 and 4 fault tree systems definitions

<u>Diesel Generator Success Criterion</u>

One of two emergency diesel generators is required.

<u>Cooling Requirements</u>

Each generator is cooled by a dedicated radiator.

<u>DC Power Requirements</u>

Each dc division provides startup and control power for its division dedicated diesel generator and control power for the breakers within its associated ac division. DC Division 1 supplies generator 1, and Division 2 supplies generator 2.

ORNL-DWG. 82-20524

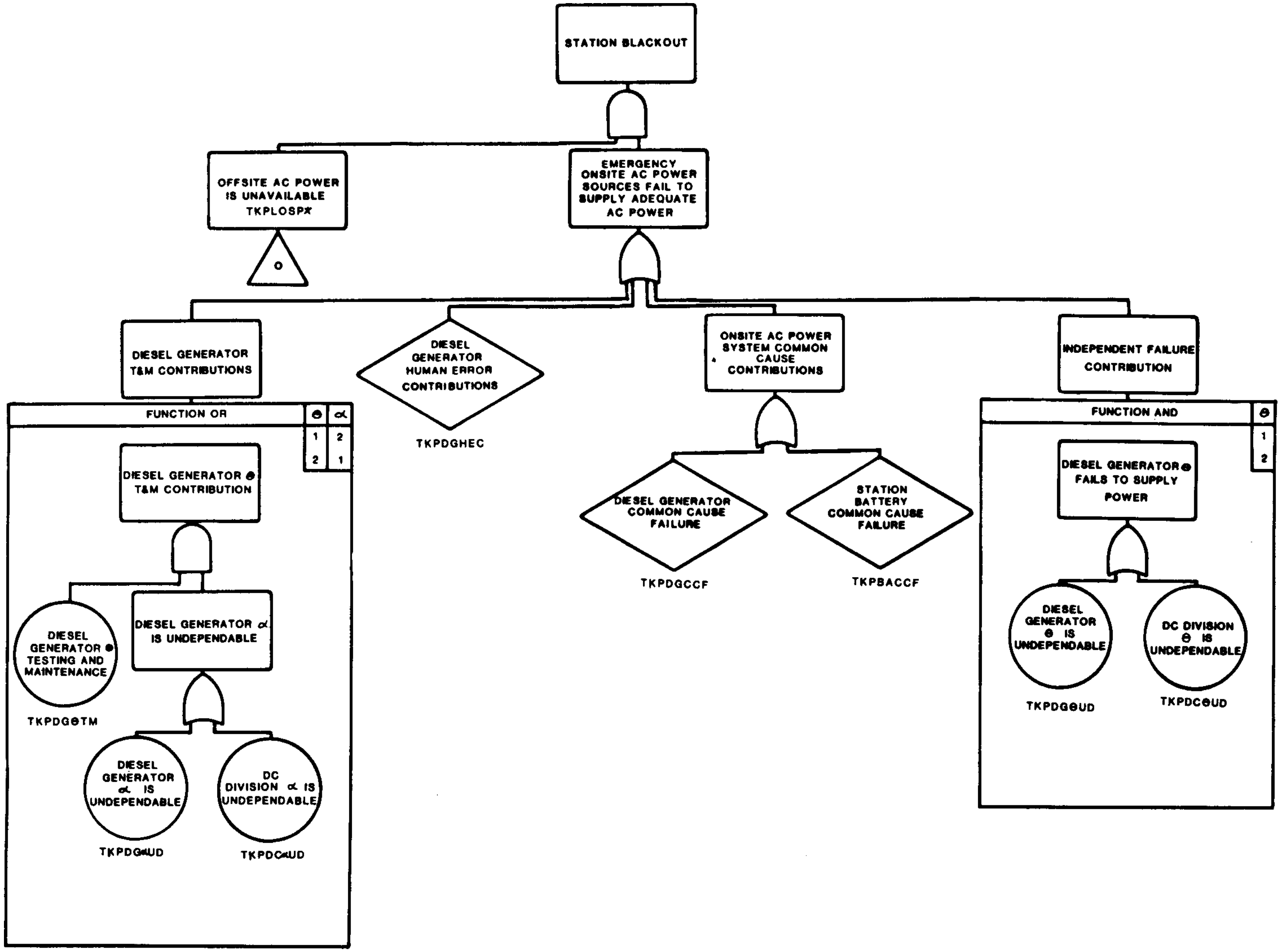


Fig. 9.2.14. Turkey Point 3 and 4 fault tree.

Table 9.2.15. Yankee (Rowe, Mass.) fault tree systems definitions

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Diesel Generator Success Criterion

One of three diesel generators is required.

Cooling Requirements

Service water train 1 cools generator 1, and train 2 cools generator 2. Generator 3 is cooled by either train 1 or 2.

DC Power Requirements

Generator 3 has a dedicated battery for starting and control power. DC Division 1 supplies startup and control power for generator 1 and control power for ac division 1. DC Division 2 supplies startup and control power for generator 2 and controls power for ac Division 2.

Special Features

The station dc provides control power to the switchyard. Thus failure of both dc divisions will cause a station blackout.

ORNL-DWG. 82-20525

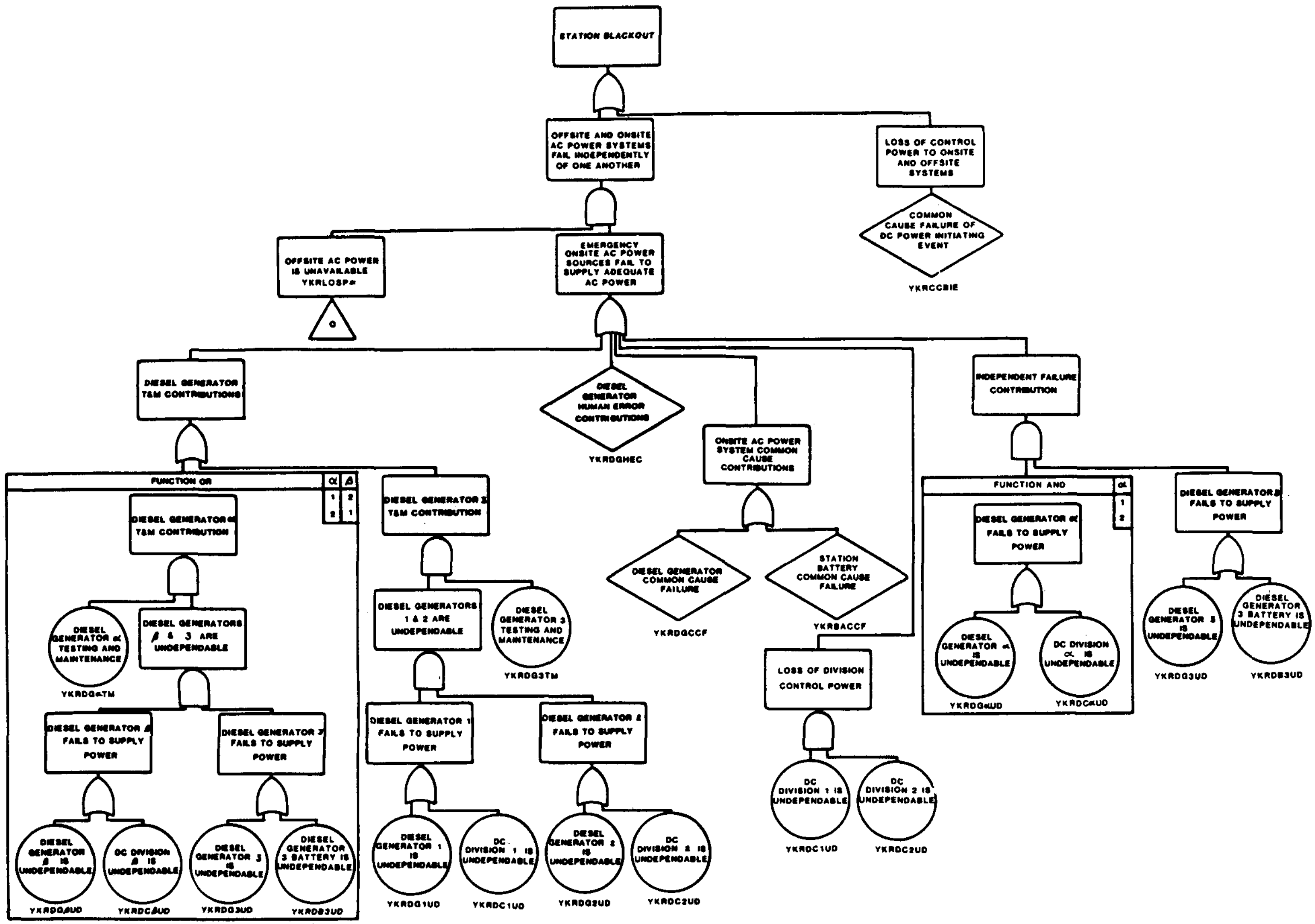

Fig. 9.2.15. Yankee (Rowe, Mass.) fault tree.

9.3 ATTACHMENT

Below is an explanation of what types of information should be entered in Tables 1 through 4. Also an example of each of the tables is attached to support the description below.

Table 1

Reason for DG Operation and Scheduled Duration of Run: This column contains the different categories of diesel generator operation. The categories are structured such that the start and run conditions are similar for all of the tests in a category. In this column, enter the scheduled run duration for each of the test categories. Also enter the number of diesel generator starts that are done for each type of test. For example, if on the monthly test there is one start from the local controls and one start from the remote controls, the number of starts per test is two. If two or more diesels are started simultaneously for any reason, please record it as a multiple start.

DG No.: Enter each diesel generator's identification number in this column as shown in the example.

Number of Starts: Enter the sum of the successful and unsuccessful start attempts for each category. If there are several starts for each test, include all of them, but be certain to record the number of starts per test in column one.

Number of Failures: Enter the sum of the failures for each category. A failure is counted if the objectives of the test are not achieved. A subsystem failure that does not cause failure of the diesel generator system is not counted as a failure. If the diesel generator did not start, run, and load as required by the test, a failure should be recorded. However, if the diesel generator would have supplied power in some capacity for an emergency, please explain in Table 3. For example, if the diesel started on the second attempt or the diesel was tripped to repair a minor oil leak that would not have been a problem in an emergency, this should be noted in Table 3.

Percent Loading of DG(KW): Enter the percentage that the diesel is loaded for each category. The continuous kilowatt rating is considered to be 100%.

Duration of Run Before Stop for each DG Failure: Record the run-time for each failure. If the diesel failed to start, the run-time would be 0 min.

Identification of Failures: Attached to this questionnaire are abstracts of the LERs related to the diesel generators. The abstracts are numbered starting with one. Refer to this number to identify the failures, but if there was a failure for which there is no abstract, assign the failure a number and include it in Table 3.

Table 2

Reason for Downtime: Enter in this column the categories of scheduled maintenance that make the diesel generator unavailable for emergency service. If the diesel generator is unavailable for emergency service during surveillance testing, report that also.

Table 2 (cont'd)

Hours of Downtime: Enter the number of hours that the diesel generator is unavailable for emergency service. Report the hours under the column reactor shutdown or reactor not shutdown as appropriate.

Comments: Comment on time to return to service after maintenance has begun, or other pertinent information.

Table 3

LER Abstract No. (Refer to attached LER Abstracts): The attached LERs are numbered starting from one. Refer to this LER number in column one. Each LER abstract should have an entry in this table. If there was a failure not included in the attached abstracts, please assign it a number and enter it in this table.

Downtime Hours: Enter the number of hours that the diesel generator is unavailable for emergency service. Subdivide these total hours into troubleshooting, parts delivery, and repair or replacement.

Comments: Use this column to comment on the downtime and the failure. If the reported failure was only a technical specification violation, but would not be a complete failure of the diesel generator to supply power or would only be a delay, please elaborate in this column.

Table 4

Equipment or procedure modified: List in this column the equipment or procedures related to the emergency onsite power system that have been modified since the reactor became critical.

Date of Mod.: Enter the date that the modification was completed.

Reason for Modification and Desired Improvement: Report the reason for the modification and the desired or observed improvement in the system.

Description of Modification: Briefly describe what modification was made.

Plant Name __________
Unit No. __________

TABLE 1 Diesel Generator Operations Data
Calendar Year 19__

Reason for DG Operation, & scheduled Duration of Run	DG No.	Number of Starts	Number of Failures	Percent Loading of DG (KW)	Duration of Run Before Stop For Each DG Failure	Identification of Failure (Refer to attached LERs or Table 3)
Tech. Spec Req'd Test						
DG Actual Demand Starts not for Testing						
Miscellaneous Tests (Specify Type)						

TABLE 2

Diesel Generator Scheduled Downtime Record
Calendar Year 19__

Plant Name__________
Unit No. __________

Reason for Downtime	Hours of Downtime										Comments
	Reactor shutdown					Reactor not shutdown					
	DG#	DG#	DG#	DG#	DG#	DG#	DG#	DG#	DG#	DG#	
Scheduled Maintenance											
Time DG is unavailable for emergency service because of required tests											

TABLE 3 Diesel Generator Unscheduled Downtime Record
Calendar Year 19__

Plant Name __________
Unit No. __________

LER Abstract No (Refer to attached LER Abstracts)	Downtime Hours				Comments - If any of the reported failures would not have been a failure under emergency conditions, please explain here. Refer to attached LERs or the failures listed in Table 1.
	Total Hours	Trouble-shooting	Parts, Delivery, etc	Repair/Replace	

TABLE 4

Onsite Emergency Diesel Generator and Auxiliary Equipment Modification Record

Plant Name ________
Unit No. ________

Equipment or procedure modified	Date of Mod.	Reason for Modification and Desired Improvement	Description of Modification

TABLE 1

Diesel Generator Operations Data
Calendar Year 1976

Plant Name xxx
Unit No. 1 & 2

Reason for DG Operation, & scheduled Duration of Run	DG No.	Number of Starts	Number of Failures	Percent Loading of DG (KW)	Duration of Run Before Stop For Each DG Failure	Identification of Failures (Refer to attached LERs or Table 3)
Tech. Spec Req'd Test Monthly Surveillance	1	12	2	100	30 min; 0 min	LER # 1 & 4
(1 hour)	2	12	0	100	—	
(1 start/test)	3	12	1	100	0 min	LER #2
Refueling Outage	1	1	0	100	--	
(12 hours)	2	1	0	100	--	
(1 start/test)	3	1	1	100	1 hour	LER # 3
Misc. Tech Spec	1	2	0	100	—	Table 3 No. 9
Req'd Tests	2	4	0	100	—	
(Start Only) (1 start/test)	3	2	0	100	—	
DG Actual Demand Starts not for Testing SIAS Signal	1	1	0	0	—	LER # 8 Multiple start of 3 DGs
(1 hour)	2	1	0	0	--	" "
	3	1	0	0	--	" "
Miscellaneous Tests (Specify Type) Verify Repairs	1	6	0	1	0 min	Table 3 # 10
(not full test)	2	4	0	0		
(Start Only)	3	4	0	0		

TABLE 2

Plant Name ________
Unit No. ________

Diesel Generator Scheduled Downtime Record
Calendar Year 19__

Reason for Downtime	Hours of Downtime: Reactor shutdown DG# 1	DG# 2	DG# 3	DG#	DG#	Reactor not shutdown DG# 1	DG# 2	DG# 3	DG#	DG#	Comments
Scheduled Maintenance											
Preventive Maintenance Semi-annual & Annual	24	16	—					16			
Equipment Modification						8	8	8			Modified lube oil on each diesel. Diesels down at different times.
Time DG is unavailable for emergency service because of required tests Down 4 hrs per test		8				48	40	48			Diesel cannot be automatically started during test or for three hours afterwards

TABLE 3 Diesel Generator Unscheduled Downtime Record
Calendar Year 19__

Plant Name XXX
Unit No. 1&2

LER Abstract No. (Refer to attached LER Abstracts)	Downtime Hours				Comments - If any of the reported failures would not have been a failure under emergency conditions, please explain here. Refer to attached LERs or the failures listed in Table 1.
	Total Hours	Trouble-shooting	Parts,Delivery,etc	Repair/Replace	
1	4	1	1	2	
2	3	0.5	1	1.5	
3	12	1	10	1	
4	0	0	0	0	Diesel started in 15 sec instead of required 10 sec
5	0	0	0	0	Secondary air pressure low. Primary air satisfactory.
6	0	0	0	0	Secondary air pressure low. Primary air satisfactory.
7	0	0	0	0	Diesel started in 20 sec instead of required 10 sec.
8 No LER	0	0	0	0	False DG start signal. DG satisfactory
9	0	0	0	0	Required DG starts after the failure of one diesel.
10	0	0	0	0	Starts to verify repairs.

TABLE 4

Onsite Emergency Diesel Generator and
Auxiliary Equipment Modification Record

Plant Name __________
Unit No. __________

Equipment or procedure modified	Date of Mod.	Reason for Modification and Desired Improvement	Description of Modification
Lube oil system	2/76	Improve turbo charger lubrication for emergency starts.	Soak-back pump was removed and replaced with a continuous lube oil pump. New pump also continuously lubricates the crankshaft.
Relay cabinets	1/78	Prevent dirt from fouling relay contacts.	Cabinet doors with gaskets were installed.
Instrument Relocation	6/79	Eliminate vibration damage to instruments	Control and monitoring instrument panel was relocated from the engine skids to a free standing panel mounted on the engine room floor.

9.4 DIESEL GENERATOR EVENT CLASSIFICATION RESULTS

Licensee Event Reports (LERs), station blackout questionnaire responses, and responses to a questionnaire for NUREG-0737 (ECCS outage data) were used to collect events reported on diesel generators. Events that have no LER number were reported in response to the NUREG-0737 questionnaire. A description of the event types is given in Table 4.1.

UNIT: Arkansas Nuclear One 1

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-31	8/27/80	2		Primary failure to run/ Ran 7 minutes	Exhaust	Loose bolts in exhaust caused insulation to burn. No damage to turbo. DG would continue to run in an emergency.
80-38	10/13/80	1		Primary failure to start/ Ran 0 minutes	Regulator	Internal mechanical wear of regulator. Regulator was replaced.
79-17	9/11/79	1	36:00	Secondary failure to start/ Corrosion. Ran 3 minutes	Lube oil	Lube oil cooler leaked water into oil. Tripped on crankcase pressure. Replaced cooler. Trip can be bypassed, but DG failure may result.
79-16	8/27/79	2	36:00	Secondary failure to start/ corrosion. Ran 3 minutes	Lube oil	Lube oil cooler leaked water into oil. Tripped on crankcase pressure. Replaced cooler. Trip can be bypassed, but DG failure may result.
79-6	6/7/79	All		Non-failure I	Turbo-charger	Vendor design error. Rapid start after shutdown, could damage turbocharger bearings.
78-17	7/15/78	2		Non-failure II	Turbo-charger	Oil leak into turbo. DG could operate with leak. Turbo was replaced.

UNIT: Arkansas Nuclear One 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-8	3/20/78	2	24:00	Primary failure to run/ Ran a few minutes	Turbo-charger	Bearing failure in turbo. Exhaust caught on fire. Turbo was replaced. DG could continue to operate in an emergency.
77-20	10/23/77	1	1:00	Primary failure to start/ Ran 0 minutes	Air-start	Starter time delay setpoint drift and diode failure. Relay timed out before DG could start. Complete repair took 4 hours, but DG was operable in 1 hour.
77-16	8/5/77			Non-failure I	N/A	DG not tested on time.
76-33	11/10/76	1	4:00	Secondary failure to start/ no start attempt	Fire protection	DG deluged by inadvertent operation of fire system.
76-23	8/17/76			Non-failure I	N/A	DG not tested on time.

UNIT: Arkansas Nuclear One 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-93	12/20/80	2	0:05	Non-failure II	Logic	Reverse power relay trip while transferring power from EDG.
80-12	2/22/80	1	600:00	Secondary failure to start/ 18-month test. Human error. Ran 20 minutes.	Generator	Generator rotor shaft broken. Shafts possibly misaligned.
80-29	5/20/80	2		Non-failure I	Fire protection	Fire system modified.
79-69	8/14/79	2		Non-failure II	Control	DG could not be stopped remotely. Stopped locally.
79-32	4/19/79	2		Primary failure to start	Engine	Engine bearings failed. The engine was replaced 10/79.
78-13	11/7/78	1		Non-failure II	Control	Design error in switch. Switch in use was not acceptable. Switch was replaced.
78-15	11/8/78	1		Non-failure II	N/A	DG was removed from service for maintenance without approval.

UNIT: Arnold

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-66	12/15/80	IG-21		Non-failure I	N/A	Core spray not tested after DG failure.
80-64	12/15/80	IG-21		Non-failure II	Air-start	Backup air-start failed. Normal air-start was functional. Dirty filter in air system.
80-51	10/14/80	IG-21	46:10	Primary failure to start	Voltage regulator	Cam switches became loose. No local control of regulator.
80-32	7/8/80	IG-21	2:15	Primary failure to start	Governor	Oxidized contacts on current transformer to governor.
80-018	5/19/80	IG-31		Secondary failure to start/ no start attempt	Governor	Governor hydraulic oil leaked out of governor. Petcock not completely closed.
80-012	3/17/80	IG-31		Non-failure II/Common cause potential	Engine	Bearing/crankshaft clearance out of spec. Vendor dipstick full-mark wrong. Oil added and crankshaft relapped.
80-011	3/17/80	IG-21		Non-failure II/Common cause see 80-12	Engine	Vendor recommended oil level was incorrect. Crankshaft relapped.
79-029	10/26/79	IG-21		Non-failure I	Fuel	Bulk fuel level went below tech spec limit. Resupplied in 4 hours.
79-034	11/21/79			Non-failure II	Load sequencer	Sequencer time delay relay set-point drift.

UNIT: Arnold (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-39	12/31/79	IG-31	16:45	Non-failure II/human error	Lube oil	Human error. Engine oil sump level exceeded. DG removed from service to remove oil from sump.
79-12	5/22/79	IG-31	46:30	Secondary failure to run/ vibration	Lube oil	Lube oil temperature alarm switch came loose and oil leaked out.
78-36	12/27/78			Non-failure I	N/A	DG 21 down for maintenance, and DG 31 was not tested.
78-20	4/5/78	IG-31		Non-failure II/human error	Lube oil	Bearing out of alignment. Low lube oil. Lube oil filter drain left open. Found during annual inspection.
77-32	4/13/77	IG-31		Non-failure II	Engine	Bearing wiped. Found during annual inspection. Reactor shut down. Generator and engine were also misaligned.
77-80	10/6/77			Non-failure I/human error	Fuel	Fuel storage tank indicator was calibrated incorrectly. Actually 2000 gallons less than indicated.
77-48	5/31/77	IG-21		Non-failure I	N/A	Test not completed in required time.

UNIT: Arnold (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-43	5/12/77	IG-31		Secondary failure to start/ human error	Governor	Governor was not reset after maintenance. It would only pick up 2500kW instead of rated 2950kW.
77-37	5/10/77	IG-21		Primary failure to start	Output breaker	Breaker auxiliary contact failed and breaker would not close. Mechanism was lubricated.
76-75	11/4/76	IG-21	18:15	Secondary failure to start/ vibration	Fuel	Crack in fuel line leaked fuel which caught on fire. Supports added for fuel lines.
76-64	10/4/76	IG-21		Secondary failure to start/ human error	Engine	Vertical drive coupling hub broke. It was made of the wrong material.
76-87	12/8/76	IG-21	144:00	Non-failure II	N/A	DG down for inspection. Parts were delivered late. Scheduled completion 9/15/76, actual completion 10/21/76. Future inspections will be during refueling.
76-43	6/23/76			Secondary failure to start/ mud	Cooling	DG tripped on high water temperature. Service water was blocked with mud.

UNIT: Arnold (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
76-21	3/30/76			Primary failure to start	Turbo-charger	Exhaust gases leaked onto engine and burned. Gasket and insulation replaced.
76-12	3/26/76			Primary failure to start	Engine	Front cover plate on engine leaked oil. Oil caught on fire but was quickly extinguished.
	2/4/76	21	120:30	Non-failure II	Air-start	Leaks in emergency air-start. Lapped drain valve.
	2/9/76	31	54:45	Non-failure II	Air-start	Air leaks. Lapped drain valve.
	4/21/76	31	58:15	Non-failure II	Air-start	Air receiver moisture level alarm failed. It was dried.
	8/16/76	21	22:20	Non-failure II	Governor	Governor oil leak. Changed fittings and replaced gasket.
	8/20/76	31	12:00	Non-failure II	Unknown	Maintenance.
	9/21/76	31	70:30	Non-failure II	Lube oil	Oil pan leaks repaired.
	10/11/76	21	75:30	Non-failure II	N/A	Annual inspection.
	10/18/76	31	34:00	Non-failure II	N/A	Annual inspection.
	10/20/76	31	9:30	Non-failure II	Lube oil	Inspect lube oil cooler.
	11/5/76	31	9:00	Non-failure II	N/A	Replace tube injector connectors.

UNIT: Arnold (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	11/11/76	31	33:30	Non-failure II	Lube oil	Repair oil leaks.
	12/9/76	21	0:30	Non-failure II	Air-start	Isolate start valve for maintenance.
	12/9/76	31	0:30	Non-failure II	Engine	Visual inspection of vertical drive.
	12/15/76	21	0:30	Non-failure II	Engine	Visual inspection of vertical drive.
	12/15/76	31	35:45	Non-failure II	Engine	Change vertical drive. Wrong material.
	12/17/76	21	11:30	Non-failure II	Engine	Change upper drive coupling.
	12/18/76	31	10:00	Non-failure II	Engine	Replace lower hub of vertical drive coupling.
	5/25/77	21	13:30	Non-failure II	Lube oil	Lube oil leaks around heater. Tightened.
	11/3/77	31	7:30	Non-failure II	Unknown	Maintenance.
	1/13/78	21	9:45	Non-failure II	Unknown	Maintenance.
	5/21/79	21	11:00	Non-failure II	N/A	Quarterly inspection.
	9/20/79	21	3:00	Non-failure II	Exciter	No remote voltage control and loss of field alarm. Cleaned contact on PT.

UNIT: Arnold (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	11/14/79	31	54:15	Non-failure II	Lube oil	Repair oil leaks.

UNIT: Beaver Valley

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-47	8/5/80	1	8:00	Secondary failure to start/ dirt	Output breaker	Manual start relay contacts were dirty. DG breaker would not close. Start mode permissives failed.
80-033	6/17/80	1	16:00	Non-failure II	Governor	Operator error. Governor failed while DG was being shut down with fast start signal still present.
79-48	12/10/79	2	96:00	Non-failure II/common cause/ 24 hour load test.	Fuel	Electric fuel pump blocked by desiccant bag. Engine-driven pump continued to operate. Bag found in DG No. 1 fuel tank.
79-043	3/1/79	All	0:00	Non-failure I	Fuel	Fuel samples not analyzed on time.
79-031	8/7/79	1	6:30	Non-failure II	Load sequencer	Sequencer connected loads out of specifications. DG can accept full load in 3.5 sec.
79-023	7/24/79	1	48:00	Non-failure II	Output breaker/ air-start	Remote manual breaker control failed. Relay repaired. Also one set of air-start motors failed. Other set started DG. Breaker would close on auto-start.

UNIT: Beaver Valley (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-009	3/20/79	1		Auto-start failure	Output breaker	Breaker did not close under remote manual control. Cause unknown. DG was down for troubleshooting 6 hours.
77-49	6/3/77	2		Auto-start failure	Output breaker	Breaker closed on second attempt. Repair took 12 hours.
78-51	9/12/78	1		Auto-start failure	Output breaker	No. 2 DG down for maintenance. Breaker did not close remotely. Closed after four attempts. Repair time 0:21.
78-50	9/5/78	2		Auto-start failure	Output breaker	Breaker did not close remotely. Closed locally. Breaker performed OK four times later same day.
78-43	7/28/78	2		Auto-start failure/LOSP	Exciter	Loss of offsite power. Field did not flash in DG 2. It was manually flashed. Manual flash was improved on 10/3/78.
78-037	6/1/78	2		Non-failure II	Lube oil	Human error. Lube oil pressure gauge installed improperly and oil leak resulted. DG was operable for emergency.
78-32	4/18/78	1		Non-failure II	Fuel	Fuel oil pump leak.

UNIT: Beaver Valley (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-004	1/11/78	2	0:45	Primary failure to start	Output breaker	Breaker would not close. Inspected but no problem found. Tested OK.
77-50	6/22/77	1		Non-failure I	Human	DG 1 down for PM and the reactor was taken to power.
77-69	7/17/77	2		Auto-start failure	Exciter	Field did not auto-flash for test. Field was manually flashed. Repair of the auto-flash circuit took 7 hours.
77-13	3/14/77	2		Auto-start failure	Output breaker	Remote manual breaker would not function. Dirty contacts on switch. Repair took 12 hours.
77-29	4/11/77	2	27:00	Secondary failure to start/ Dirt	Output breaker	"No field" relay contacts dirty. Did not permit breaker to close.
77-34	4/26/77	1	2:00	Secondary failure to start/ Dirt	Output breaker	"No field" relay contacts dirty. Did not permit breaker to close. DG 2 down for PM.
77-37	4/29/77	1	8:30	Secondary failure to start/ moisture	Air-start	Moisture in starting air-corrosion. Plan to install refrigerated air dryers.
77-39	2/24/77	2		Secondary failure to start/ human error	Logic	Loss of field trip was not removed during acceptance. Design change requested.

UNIT: Beaver Valley (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-58	4/29/77	1	<24 hrs.	Primary failure to start	Output breaker	Cleaned switch.
	10/4/77	1		Auto start failure	Output breaker	First attempt breaker did not close. Closed subsequently. Repair took 8 hours.
	10/20/77	1	<24 hrs.	Non-failure II	Load sequencer	Timer out of adjustment.
	11/7/77	1	8 hrs.	Non-failure II	Fuel	Low fuel oil press. Installed new o-ring and cleaned valve.
	12/6/78	1	10 hrs.	Primary failure to start/ no start attempt	Air start	Air motor clogged and had bad bearings. Replaced.
	8/30/79	1	21 da	Non-failure II	Cooling	Cooling water leak. Cracked pipe.
	10/20/77	2		Non-failure II	Logic	DG failed overspeed trip test. Incorrect valving.
	8/30/78	2		Non-failure II	Output breaker	Numerous breaker failures over 20-day period. No problem found. Installed trouble-shooting circuit.
78-90	-	2		Non-failure II/Common cause Both DGs inoperable	Air start	Repaired air compressor.

UNIT: Big Rock Point

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-47	12/17/80		3:00	Secondary failure to start/ vibration	Exciter	Broken socket pins on exciter. Heavier socket used as replacement.
80-37	11/18/80		432:00	Primary failure to run/ 24-hour test	Cooling	Engine cooling water pump coupling overheated. Loose set screw. Parts delivery took 17 days, 22 hours.
80-36	11/18/80		1:00	Secondary failure to start/ human error	Exciter	Diodes in exciter failed. Annual PM may have caused failure. Diode check removed from PM.
79-014	3/12/79		240:00	Primary failure to start	Unknown	No output voltage. Reason is unknown. Subsequent tests were OK.
79-8	2/22/79		0:00	Non-failure I	Fuel	Slow start. Priming pump may have introduced air. Priming under administrative control.
78-4	2/2/78		0:00	Non-failure I	N/A	Slow start.
78-7	2/9/78		24:00	Primary failure to start	Cooling	Packing leaked air and pump loss suction. DG tripped on high water temperature.
77-27	8/5/77			Secondary failure to start/ human error	Output breaker	Auto-transfer of power relay wired incorrectly. Auto-and manual-transfer failed.

UNIT: Big Rock Point (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-48	11/24/77		0:30	Non-failure I	N/A	Slow start; 33 seconds instead of 13.9. Retested OK.
77-41	10/20/77		1:30	Non-failure I	N/A	Slow start; 21.8 seconds instead of 13.9.
77-19	5/26/77		2:00	Non-failure I	N/A	Slow start; 16.5 seconds instead of 13.9. Retested OK.
77-18	5/18/77		2:30	Non-failure II	Cooling	Standby water heater failed. DG tested. Slow start. Replaced heater.
77-10	3/24/77		0:20	Non-failure I	N/A	Slow start. Exceeded requirement by 0.8 seconds.
77-5	1/10/77		7:30	Non-failure II	Governor	Oil system to governor was modified to improve reliability.
77-1	1/3/77			Auto-start failure	Unknown	DG failed auto start. Subsequent test OK. Repairtime 0:30.
76-46	12/28/76		5:30	Primary failure to start/ no start attempt	Starter (electric)	Starter spring failed. Replaced with new design.
76-45	12/27/76		0:30	Non-failure I	N/A	Slow start. Retested OK.
76-44	12/20/76		0:45	Non-failure I	N/A	Slow start. Retested OK.
76-36	11/18/76		8:00	Primary failure to start	Starter (electric)	Broken spring in starter. Starter replaced.

UNIT: Big Rock Point (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
76-38	12/2/76		1:00	Non-failure I	N/A	Slow start. Retested OK.
76-32	11/4/76		1:00	Non-failure I	N/A	Slow start. Retested OK.
76-31	10/28/76		1:00	Primary failure to start	Governor	Cause uncertain; governor to be replaced.
76-23	9/3/76		0:00	Non-failure I	N/A	DG not tested as required.
76-21	8/5/76		0:05	Non-failure I	N/A	Slow start.
76-18	8/19/76		0:00	Non-failure I	N/A	Slow start. Retested OK.
76-11	7/2/76		0:00	Non-failure II/design error	Control	Control fuse changed without approval.
76-9	6/9/76			Auto-start failure	Output breaker	Overload trip of 2A-2B breaker. Interlock did not auto-transfer to bus 2B. It was manually transferred. Cause not found.
76-8	6/9/76		9:00	Secondary failure to start/ Debris	Cooling	Cooling water shaft was scored. Inlet screen was partially plugged.
76-4	4/15/76		8:00	Secondary failure to start/ Debris	Cooling	DG tripped on high water temp. Suction screen plugged.
	8/26/76		1:30	Non-failure II	Lube Oil	Change oil.
	8/30/76		2:30	Non-failure II	Cooling	Replace jacket heater.

UNIT: Big Rock Point (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	9/3/76		0:30	Non-failure II	Control	Inspect relay panel.
	9/9/76		4:30	Non-failure II	Control	Inspect control wiring.
	9/16/76		1:00	Non-failure II	Battery	Clean battery.
	10/12/76		4:00	Non-failure II	N/A	PM.
	10/13/76		5:30	Non-failure II	N/A	PM.
	10/19/76		40:00	Non-failure II	Start (electric)	Replace start timer.
	12/10/76		8:00	Non-failure II	Governor	Replace governor.
	1/3/77			Auto-start failure	Governor	Unknown. Repair time 0:30.
	3/31/77		1:15	Non-failure II	Battery	Unknown.
	4/13/77		12:00	Non-failure II	Unknown	Troubleshooting. No problem found.
	5/27/77		0:20	Non-failure II	Control	Modify throttle.
	2/3/78		3:00	Non-failure II	Unknown	Troubleshooting. No problem found.
	2/7/78		2:00	Non-failure II		Adjust packing on pump.
	5/8/78		12:00	Non-failure II	Cooling	Install water pump seal.

UNIT: Big Rock Point (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	5/8/78		8:00	Non-failure II	Cooling	Clean water suction screen.
	5/10/78		4:30	Non-failure II	Cooling	Replace water suction line.
78-34	8/31/78		4:00	Primary failure to start	Output breaker	Output breaker failed.
	11/15/78		6:00	Non-failure II	Cooling	Change antifreeze.
	11/30/78		8:00	Non-failure II	Cooling	Repair heat exchanger; drain plug.
	3/10/79		4:00	Non-failure II	Fuel	Inspection for air in fuel line.
	12/13/79		1:00	Non-failure II	Lube oil	Oil change.
80-11	5/30/80		5:00	Primary failure to start	Breaker	Breaker inoperable.
	6/9/80		9:00	Non-failure II	Cooling	Clean water suction screen and battery.

UNIT: Browns Ferry 1 and 2

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-052	6/28/80	B		Auto-start failure/demand caused by degraded voltage on bus/human error	Human	Switch not set for parallel operation. Then on 2nd start field breaker was not reset.
79-004	2/22/79			Non-failure I	N/A	DG fuel oil samples were lost.
78-22	7/9/78	C	7:25	Secondary failure to start/ no start attempt	Exciter	Bent louvers in cabinet door stopped fans and the exciter tripped on overheat.
76-25	11/26/76	B	0:50	Primary failure to start	Logic	Broken connector on start circuit breaker.
76-23	11/3/76	D	0:30	Secondary failure to start/ dirt	Governor	Erratic speed. Dirt in governor oil. Oil changed.
76-1	1/14/76	D	17:45	Secondary failure to start/ dirt	Governor	Dirt in governor oil. Fuel pins were stored in spent fuel pool.
	11/6/78	C	216: 30	Non-failure II	Unknown	Bad relay.
	10/9/79	A	36:15	Non-failure II	N/A	Annual inspection.
	10/12/79	B	37:00	Non-failure II	N/A	Annual inspection.
	11/13/79	C	37:30	Non-failure II	N/A	Annual inspection.

UNIT: Browns Ferry 1 and 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	11/20/79	D	38:00	Non-failure II	N/A	Annual inspection.
	2/7/80	C	27:15	Non-failure II	N/A	Testing.
	2/8/80	D	23:45	Non-failure II	N/A	Testing.
	2/12/80	C	7:45	Non-failure II	N/A	Testing.
	10/2/80	A	95:00	Non-failure II	N/A	Annual inspection.
	10/6/80	B	69:30	Non-failure II	N/A	Annual inspection.
	10/29/80	C	27:15	Non-failure II	N/A	Annual inspection.

UNIT: Browns Ferry 3

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-40	10/10/80	3B	3:35	Non-failure II	Lube Oil	Lube oil pump bearings failed.
80-036	9/15/80	3A		Non-failure II	Governor	DG would not trip to idle speed. Replaced governor.
80-020	6/9/80	3B	18:30	Non-failure II	Lube Oil	Auxiliary lube oil pump bearings failed.
80-16	5/13/80	3D	2:45	Non-failure II	Cooling	Flow test revealed inadequate flow in heat exchanger, unit flushed.
80-008	4/2/80	3B	7:00	Secondary failure to start/ dirt	Governor	Dirt in governor oil. Flushed, refilled, and tested satisfactorily.
77-20	9/19/77	3D	17:10	Primary failure to start	Exciter	DG tripped on overspeed. Open fuse in exciter.
76-19	11/26/76	3D		Primary failure to start	Control	Speed sensing circuit failed. Relay failure.
80-1	1/17/80	3A		Primary failure to start	Governor	Shaft for speed pickup broke.
	4/21/77	3B	9:30	Non-failure II	Lube Oil	Lube oil pump has bad bearings.
	9/22/77	3D	14:30	Non-failure II	Lube Oil	Dirty oil.

UNIT: Browns Ferry 3 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	11/21/77	3B		Non-failure II	Air-Start	Slow start. Rust in air lines.
	7/6/78	3C	7:15	Non-failure II	Output Breaker	Charging motor shorted windings and switches damaged.
	7/6/78	3D	4:45	Non-failure II	Logic	ECR relay failed.
	11/24/78	3B		Non-failure II	Lube Oil	Failed lube oil pump.
	12/2/79	3C	64:30	Primary failure to start/ Load acceptance test	Control	Setpoint drift in frequency generator. DG connected to RHR at low speed and tripped.
	2/13/80	3A	103:00	Non-failure II	N/A	Testing.
	2/19/80	3B	42:00	Non-failure II	N/A	Testing.
	2/22/80	3D	7:45	Secondary failure to start/ no start attempt	Cooling	Clams in heat exchanger.
	3/25/80	3A	78:00	Non-failure II	N/A	Testing.
	3/28/80	3B	23:00	Non-failure II	N/A	Testing.
	3/31/80	3D	29:45	Non-failure II	N/A	Testing.

UNIT: Browns Ferry 3 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	4/2/80	3C	25:15	Non-failure II	N/A	Testing.
	4/29/80	3A	4:15	Non-failure II	N/A	Testing.
	5/1/80	3B		Primary failure to start/ SI signal	Governor	Suspect dirty oil in governor. Oil flushed and governor filled. Next test successful.
	6/3/80	3A	2:30	Non-failure II	N/A	Testing.
	6/11/80	3C	47:15	Non-failure II	Unknown	Unknown.
	6/18/80	3D	41:45	Non-failure II	Unknown	Unknown.
	7/3/80	3A	2:45	Non-failure II	N/A	Testing.
	8/5/80	3A	73:30	Non-failure II	N/A	Testing.
	9/4/80	3A	39:00	Non-failure II	Governor	Stop circuits not correct.
	10/2/80	3A	5:15	Non-failure II	N/A	Testing.
	11/5/80	3A	3:30	Non-failure II	N/A	Testing.

UNIT: Brunswick 1

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-081	10/10/80	3	11:00	Non-failure II	Air-Start	Slow start - 13.9 seconds. Air pilot valve of no. 1 cylinder stuck opening.
80-070	8/28/80	1	1:30	Non-failure II	Logic	Multiple inadvertent alarms. No cause found.
80-040	4/17/80	2	6:00	Primary failure to start	Logic	Tach pack failed. Did not open service water valve.
80-043	4/22/80	4	8:00	Secondary failure to start/ Human	Human	Operator forced lamp into socket shorting control circuit. Replaced fuse.
77-83	10/11/77	2	18:00	Secondary failure to start/ load not steady	Governor	Could not maintain constant power. Broken and shorted wires on governor.
78-074	9/11/78	1	11:00	Primary failure to run	Fuel	Cylinder 1 fuel pump failed. DG could not be fully loaded.
78-003	1/6/78	2		Auto-start failure/no start attempt	Human	Start was successful, but DG was not reset after auto-start. Repair time 0:03.
79-74	10/19/79	1	12:00	Primary failure to start/ no demand	Control	Control air was lost because of ruptured diaphigram.
77-11	-	-	30:00	Non-failure II	Control	Relay burned out.
77-115	-	-	4:00	Non-failure II	Unknown	DG started in greater than 10 sec.

UNIT: Brunswick 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-1	1/4/77	3,4	1:15	Secondary failure to start/ simulated LOSP. All four DGs started. Common cause.	Lube Oil	DGs 3 and 4 tripped on low lube oil press because lube temperature was low. Standby heater temperature setpoint raised and pressure trip time delay increased.

UNIT: Brunswick 2

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	11/14/77		3:10	Non-failure II	N/A	Test 12.5.
	12/9/77		54:00	Non-failure II	Unknown	Replace relay.
	12/9/77		9:30	Non-failure II	Unknown	Maintenance.
	1/2/78		4:00	Non-failure II	Cooling	Repair coolant leak and fuel oil.
	3/1/78		3:20	Non-failure II	Unknown	Calibrate switch.
	5/17/78	3	7:30	Non-failure II	N/A	Out for training.
	6/5/78	4	14:00	Non-failure II	Unknown	Mod. 75-412.
	6/5/78	4	0:30	Non-failure II	Unknown	Mod. 75-412.
	6/6/78	3	12:00	Non-failure II	Unknown	Mod. 75-412.
	6/7/78	4	37:00	Non-failure II	Unknown	Mod. 75-412.
	6/9/78	4	0:30	Non-failure II	Unknown	Mod. 75-412.
	6/10/78	4	8:00	Non-failure II	Unknown	Remove mod. 75-412.
	6/16/78	4	24:00	Non-failure II	Unknown	Mod. 75-412.
	6/17/78		12:45	Non-failure II	Logic	Investigate lube oil temp. alarms.
	8/31/78		4:15	Primary failure to start/ no start attempt	Cooling	Cracked water jacket line.

UNIT: Brunswick 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	3/24/77		0:20	Non-failure II	Unknown	Install modification.
	3/24/77		0:45	Non-failure II	Unknown	Install modification.
	3/24/77		0:20	Non-failure II	Unknown	Install modification.
	5/9/77		5:45	Non-failure II	Lube oil	Calibrate press switches.
	8/13/77		11:00	Non-failure II	Unknown	Maintenance.
	8/31/77		11:00	Non-failure II	Unknown	Install modification.
	9/1/77		6:00	Non-failure II	Unknown	Maintenance.
	9/2/77		8:15	Non-failure II	Unknown	Install modification.
	9/6/77		9:10	Non-failure II	Unknown	Install modification 77-64.
	9/7/77		7:00	Non-failure II	Unknown	Install modification 77-64.
	9/12/77	1	97:45	Non-failure II	Generator	Inspect generator.
	9/26/77		91:00	Non-failure II	Unknown	Maintenance.
	10/1/77		2:30	Non-failure II	Unknown	Maintenance.
	10/11/77	4	29:00	Non-failure II	N/A	Annual inspection.
	10/24/77		8:30	Non-failure II	Unknown	Maintenance.
	10/24/77		23:00	Non-failure II	Unknown	Maintenance.

UNIT: Brunswick 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
76-85	6/11/76	1	36:00	Secondary failure to start/ human	Fuel	Water in fuel. Vent line cut below ground by work crew. Rain mixed with fuel. DG stalled.
76-69	4/13/76	2	11:00	Primary failure to start	Fuel	Valve gasket had large leak.
76-5	1/23/76	1	3:00	Primary failure to start	Exciter	DG started on false under voltage signal. DG field failed because of broken wire. Stress in door.
	3/26/76		96:00	Non-failure II	Unknown	Maintenance.
	3/26/76		96:00	Non-failure II	Unknown	Maintenance.
	4/9/76		144	Non-failure II	Unknown	Maintenance.
	1/1/77		1:30	Non-failure II	N/A	Testing.
	1/4/77		1:15	Primary failure to start	Unknown	Unknown.
	1/5/77		0:25	Non-failure II	Lube oil	Oil in pressure sensing line.
	3/2/77		0:25	Non-failure II	Air	Repair instrument air line.
	3/24/77		2:30	Non-failure II	Unknown	Install modification.

UNIT: Brunswick 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-038	5/2/79	3	8:25	Primary failure to start	Control	When speed was lowered to 60 Hz, service water valve closed. Two tachometer switches had incorrect setpoints.
79-016	2/26/79	1	0:45	Non-failure II	Control	Relays tripped because of vibration caused by workers. DG was not operating.
79-002	1/15/79	3	0:45	Non-failure II	Human	DG was tested before it was returned to serivce from maintenance. Field reset failed.
78-015	2/13/78	1	10:30	Non-failure II/simultaneous start	Human	All four DGs started but did not load. No. 1 lockout would not reset after start. Loss of excitation reset. Procedure revised.
77-37	6/7/77	1	0:05	Non-failure II	Human	Reverse power trip on shutdown of DG.
76-162	12/29/76	2		Primary failure to start	Governor	Governor clutch was slipping.
76-158	12/8/76	2	9:00	Secondary failure to start/ moisture in air	Air-start	Air receiver #2 check valve failed to open. Rusted shut.
79-14	-	-	3.20	Primary failure to start	Governor	No governor speed response.

UNIT: Brunswick 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	9/8/78	4	16:15	Non-failure II	Unknown	Modification 75-412.
	9/9/78	3	38:00	Non-failure II	Unknown	Modification 75-412.
	9/22/78		1:00	Non-failure II	Regulator	Replace VR switch.
	9/26/78		12:00	Non-failure II	Unknown	Modification 75-412.
	11/3/78		5:30	Non-failure II	Cooling	Replace jacket water temperature switch.
	11/9/78	4	7:45	Non-failure II	Unknown	Modification 78-159.
	11/14/78	4	12:30	Non-failure II	Unknown	Modification 78-159.
	11/18/78		21:45	Non-failure II	Unknown	Modification 75-412.
	11/12/78		2:00	Non-failure II	Control	No speed control from local panel.
	1/15/79		2:00	Non-failure II	Unknown	Modification and maintenance.
	1/15/79		70:30	Non-failure II	Exhaust	Modification on exhaust silencer.
	1/18/79		24:00	Non-failure II	Exhaust	Modification on exhaust silencer.
	1/23/79		72:00	Non-failure II	Unknown	Modification 79-372.
	1/30/79		10:00	Non-failure II	Exhaust	Relocate silencer piping.

UNIT: Brunswick 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	1/31/79		50:30	Non-failure II	Exhaust	Relocate silencer piping.
	2/2/79		27:00	Non-failure II	Exhaust	Relocate silencer piping.
	2/6/79		10:45	Non-failure II	Exhaust	Relocate silencer piping.
	2/7/79		27:30	Non-failure II	Exhaust	Relocate silencer piping.
	2/9/79		7:45	Non-failure II	Governor	No control of governor.
	2/21/79		29:00	Non-failure II	Exhaust	Relocate silencer piping and excitation modification.
	2/21/79		3:30	Primary failure to start/ no start attempt	Governor	No speed response.
	2/22/79		32:30	Non-failure II	Exhaust	Relocation of silencer piping.
	3/21/79	1	13:00	Non-failure II	N/A	Annual inspection.
	3/29/79		9:10	Non-failure II	Cooling	Install unions on jacket water line.
	4/26/79		6:00	Non-failure II	Logic	Repair alarm.
	5/22/79		3:30	Non-failure II	Engine	Valve adjustment.
	5/25/79		3:30	Non-failure II	Exhaust	Exhaust silencer modification.

UNIT: Brunswick 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	5/30/79		2:15	Non-failure II	Lube oil	Calibrate lube oil pressure switches.
	6/15/79		8:30	Non-failure II	Unknown	Maintenance.
	6/21/79		33:30	Non-failure II	Engine noises	Investigate engine.
	6/21/79		7:00	Non-failure II	N/A	Test 12.4.
	6/23/79		12:45	Non-failure II	Engine	Replace cylinder 1 injector.
	6/25/79	1	3:10	Non-failure II	N/A	Test 12.4.
	6/26/79	2	12:15	Non-failure II	Control	Calibrate tach switches.
	6/27/79	1	6:45	Non-failure II	Control	Calibrate tach switches.
	6/28/79	2	4:45	Non-failure II	Control	Calibrate tach switches.
	6/29/79	2	4:00	Non-failure II	N/A	Test 12.4.
	7/3/79	3	14:00	Non-failure II	Control	Local control panel problems.
	7/6/79		6:45	Non-failure II	N/A	Test 12.4.
	7/10/79		5:15	Non-failure II	N/A	Test 12.4.

UNIT: Brunswick 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	7/11/79		7:00	Non-failure II	N/A	Test 12.4.
	7/12/79		10:00	Non-failure II	Logic	Annunciator tests.
	7/15/79		31:30	Non-failure II	Air-start	Replace air distributor manifold.
	7/17/79		12:00	Non-failure II	Lube oil	Repair oil leaks and modifications.
	7/21/79	2	6:30	Non-failure II	Unknown	Modification.
	7/23/79	1	8:00	Non-failure II	Unknown	Modification.
	8/13/79		1:00	Non-failure II	Control	Problem with auto mode indicator light.
	8/14/79		2:30	Non-failure II	Control	Replace auto-start lamp socket.
	8/16/79	2	17:45	Non-failure II	Control	Repair tach no. 1.
	8/17/79	2	7:15	Non-failure II	Control	Repair tach no. 1.
	8/21/79		8:15	Non-failure II	Lube oil	Repair prelube pump and crankcase vacuum pump.
	8/23/79		5:30	Non-failure II	Control	Calibrate tachometer.
	8/27/79		10:30	Non-failure II	Unknown	Maintenance.

UNIT: Brunswick 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	8/27/79		4:00	Non-failure II	Control	Check calibration of tachometer.
	8/28/79		4:00	Non-failure II	Control	Check calibration of tachometer.
	8/29/79		4:45	Non-failure II	Control	Check calibration of tachometer
	8/30/79		4:00	Non-failure II	Lube oil	Repair lube oil press switches.
	10/18/79	2	10:30	Non-failure II	Cooling	Repair jacket water leak.
	10/19/79		12:00	Primary failure to start	Unknown	Unknown.
	11/8/79		30:00	Non-failure II	Distri-bution	Fault on bus 1D.
	11/26/79		1:00	Non-failure II	Control	Investigate auto-start relay.
	11/28/79		2:30	Non-failure II	N/A	Test 12.2.d.

UNIT: Calvert Cliffs 1

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-061	10/24/80	11	3:00	Primary failure to run/ ran 15 minutes	Fuel	Fouled injector tips. DG could not carry full load for 60 min.
80-036	7/21/80	11	4:30	Secondary failure to start	Control	Water on speed and voltage control.
80-028	5/15/80	12	6:00	Non-failure I/DG ran for 13 hours	Logic	Slow start on two attempts. Failed speed switch caused slow start.
80-010	2/2/80	11, 12& 21	0:15	Non-failure II - DGs shutdown before start signal reset. SI demand.	Logic	Human error - procedures - common cause potential. SIAS started all DGs.
79-074	12/4/79	12	5:00	Non-failure II	Fuel	Leaky fittings.
79-069	11/27/79	11	7:15	Non-failure II	Fuel	Leaky fuel line.
79-068	11/27/79	12	1:20	Non-failure II	Cooling	Failed vent valve on service water return line.
79-065	11/13/79	12	2:47	Secondary failure to start/ no start attempt	Governor	Sticking due to sludge.
79-073	12/4/79	11	1:43	Non-failure II	Logic	Bound output breaker auxiliary switch.
79-061	10/24/79	11& 12	0:00	Non-failure II	Air-start	Diesels started and left running until seismic supports installed.
79-060	10/20/79	12	47:00	Secondary failure to start/ human error/ran 10 minutes	Fuel	Clogged and maladjusted injectors.

UNIT: Calvert Cliffs 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-056	10/1/79	11		Auto-start failure	Control	High reading on output voltage meter. Operator lowered voltage and DG tripped. Voltmeter was in error. Repaired in 4:35.
79-047	9/14/79	11& 12	0:00	Non-failure II	Air-start	Diesels started and left running while seismic supports installed.
79-028	7/24/79	11	5:30	Non-failure II/ran 16 minutes	Exciter	Ground in exciter potential transformer. Trip occurred during troubleshooting.
79-017	5/15/79	12	206: 00	Primary failure to run/ ran 5 minutes	Combustion air	Interference between lobes of auxiliary blower. Reactor shutdown.
78-058	12/18/78	11	0:21	Primary failure to start	Ventilation	Fan breaker B phase overload trip.
77-122	11/15/77	12	9:33	Non-failure II	Fuel, lube, cooling	Minor leaks.
77-119	11/16/77	12	4:25	Non-failure II	Fuel, lube, cooling	Minor leaks.
77-104	10/10/77	12	4:38	Secondary failure to start/ vibration	Exciter	Loose fuse holders in exciter circuit - vibration.
77-91	9/21/77	12	2:40	Non-failure II	Logic	Gasket cooling pressure switch would not reset.

UNIT: Calvert Cliffs 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-19	4/10/78	11		Auto-start failure	Cooling	Service water valve failed to open. It was opened manually.
78-19A	4/10/78	11	4:00	Maintenance after auto start failure	Cooling	Repair service water valve opener.
78-25	4/10/78	12		Auto-start failure	Governor	Diesel oversped and tripped. Repair time 0:13.
78-26	4/11/78	11		Auto-start failure/partial LOSP, demand	Output breaker	No problems found - operator closed breaker.
78-020	4/13/78	11	0:50	Primary failure to start/ LOSP	Logic	Start/failure alarm - cause unknown. DG 12 took a minute to close onto bus.
77-096	10/3/77	11	0	Auto-start failure	Cooling	Erratic operation of service water control valve - valve placed in manual mode. Repair took 2 hours.
77-101	10/4/77	12		Auto-start failure/no start attempt - possible common cause (see 77-96)	Cooling	Service water valve controller not controlling properly. Repair time 8:43.
77-64	7/11/77	11	8:10	Non-failure II/ran 10 minutes/ maintenance error	Lube oil	Improperly glued gasket caused oil leak and fire. Failed during troubleshooting.

UNIT: Calvert Cliffs 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-065	7/13/77	11	2:00	Secondary failure to start/ human error/ran 0 minutes/ SIAS	Logic	Jacket cooling pressure switch isolation valve closed - human error - DG tripped when SIAS reset. Unavailable for 46 hours, but repair took 2 hours.
77-053	6/17/77	11	2:00	Secondary failure to start/ human error/ran 5 minutes	Engine	Maintenance error - cylinder relief valve fell off.
77-051	6/1/77	11	7:00	Non-failure II	Exhaust	Replacing bolts in scavenging air blower discharge pipe.
77-052	6/3/77	12	1:45	Non-failure II	Fuel	Minor leaks in fittings due to vibration.
77-039	5/15/77	12	5:00	Secondary failure to start/ dirt/ran 5 minutes	Ventilation	Dirt on fan breaker contacts.
77-003	11/18/76	12	5:12	Primary failure to start/ Ran 5 minutes	Ventilation	Blown fan control transformer fuse.
76-047	10/25/76	12	0:21	Primary failure to start/ ran 10 minutes	Ventilation	Blown fan control fuse.
76-044	11/4/76	12		Secondary failure to start/ human error	Cooling	Operator error - both cooling water discharge valves left closed. Closed valve two instead of opening valve one.

UNIT: Calvert Cliffs 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
76-039	8/10/76	11		Auto-start failure	Logic	"At voltage" switch failure prevented automatic closing of output breaker. Repair took 4 hours.
76-036	8/1/76	12	4:45	Secondary failure to start/ partial LOSP/human error/ran 0 minutes.	Cooling	Maintenance error - cooling system air-bound.

UNIT: Calvert Cliffs 2

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-035	7/30/80	All	0:00	Nonfailure II	Air-start	Design error-tubing not seismically qualified.
80-016	3/3/80	21	44:25	Non-failure II	Governor	Slow start.
80-011	2/27/80	21	17:00	Non-failure II	Governor	Slow start.
80-003	1/10/80	21	3:35	Non-failure II	Cooling	Minor gasket leak.
79-040	10/12/79	21	1:55	Primary failure to start/ no start attempt	Voltage Regulator	Overheated resistor.
79-039	10/24/79	12 & 21	0:00	Non-failure II/see 79-61, unit 1	Air-start	Diesels left running while seismic supports installed.
79-034	9/14/79	12 & 21		Non-failure II, see 79-47, unit 1	Air-start	Diesels left running while seismic supports installed.
79-023	6/21/79	21	2:30	Secondary failure to start/ human error/ran 0 minutes	Logic	Lube oil pressure switch isolated for 15 hours.
79-017	5/20/79	21		Auto-start failure/ran 0 minutes	Logic	Operator error-The low speed relay was energized from a previous test. The DG had local control only. DG was unavailable for 24 hours.
77-080	11/1/77	21	11:00	Non-failure II	Cooling	Replace relief value O-rings.

UNIT: Calvert Cliffs 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-015	6/6/78	21	16:00	Primary failure to start/ ran 5 minutes	Logic & Cooling	High resistance in remote start relays. Cooling water valve did not open.
78-025	8/1/78	21	3:30	Primary failure to start/ ran 5 minutes	Cooling	Service water supply valve failed to open.
78-002	1/10/78	21	2:00	Non-failure II/ran 30 minutes	Logic	A bus voltage increase caused a reverse power trip. This would not occur in an emergency.
77-047	6/21/77	21	5:00	Maintenance	Fuel	Leaky fuel oil fittings vibration caused leaks.
77-028	3/22/77	21	14:00	Non-failure II	Cooling	Leak resulting in cold engine and slow start.
77-054	7/18/77	21	5:00	Non-failure II	Lube oil	Cracked sight glass.
77-048	6/1/77	NA		Non-failure I		Test interval.
77-023	3/17/77	12	5:30	Secondary failure to start/ ran 5 minutes/design error	Ventilation	Transformer breaker overload ratings too low. Design error. All DGsaffected. No start attempt on others.
77-020	2/22/77	21	2:30	Non-failure II	Unknown	Slow start.
76-018	12/15/76	21	1:15	Secondary failure to start/ ran 0 minutes/corrosion	Air-start	Air-start valves plugged from corrosion.

UNIT: Connecticut Yankee

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-01	01/03/80	All	1:10	Non-failure II	Load Sequencer	Sequencer timers out of limits. Timers replaced.
80-02	12/24/79	2A		Secondary failure to start/ no start attempt/Human error	Distribution	Transformer neutral leads were cut.
80-03	01/29/80	All		Non-failure II/Design error	Load Sequencer	DGs could become overloaded if plant tripped and loss of offsite power occurred.
79-09	08/31/79	All		Non-failure I/Design error	Turbocharger	EMD design error could cause turbo failure if DG is started within 3 hours of being shut down.
78-06	05/08/78	All		Non-failure II/Design error	Human	DG could be overloaded for LOCA. Charging pump was not included as part of the load.
76-6	2/23/76	2B	1:10	Secondary failure to start/ Human error	Human	Tool left in injector rack caused DG to overspeed.
	6/21/76		2:00	Primary failure to start/ no start attempt	Cooling	DG fresh water pump leak. Pump rebuilt.
	6/23/76		12:00	Primary failure to start	Governor	Setpoint drift. Readjusted potentiometer.
	04/02/76		7:15	Primary failure to start	Governor	Speed control failed. Replaced solenoid.

UNIT: Connecticut Yankee (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	11/15/77		12:00	Primary failure to start	Logic	Start timers faulty. Readjusted timers.
	6/17/80		8:00	Secondary failure to start/ no start attempt/Human error	Human	Jacking gear left engaged. Deburred flywheel.
	7/09/80		2:00	Auto-start failure/no start attempt	Control	Start relay crushed by worker. Repair time 2:00.
	9/05/80		1:15	Non-failure II	Air-start	Start relay leaking air. Replaced fitting.

UNIT: Cook 1

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-15	7/3/80	1 AB		Non-failure II/cross connections could be used	PM	A DG down for 18-month inspection. A train charging pump shaft broke.
79-30	4/17/79	1 AB		Primary failure to start/ no start attempt	Logic	Load conservation relay failed. Non-essential loads remained on bus. Redundancy installed.
79-10	2/3/79			Secondary failure to start/ corrosion	Cooling	Two service water check valves failed. Stainless steel used in place of cast steel.
79-9	2/23/79	Both	1:07	Non-failure II		Both DGs unavailable simultaneously twice. Once for 1 hour and once for 7 minutes.
78-62	11/7/78	1 AB		Non-failure II	Voltage Regulator	Regulator board damaged by workman. Board has been protected.
78-16	2/15/78	1 AB		Non-failure II	Output breaker	DG removed from service. Breaker alignment was not verified.
78-17	2/15/78	1 CD		Non-failure II	Governor	Cleaning water caused failure of governor inverter. Inverter switched to alternate power source and DG tested.

UNIT: Cook 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-1	12/17/77	1 CD		Auto-start failure	Logic	12/17/77, 1/2/78, and 1/7/78 DG tripped on overspeed. DG was restarted each time.
76-55	12/9/76	1 CD		Primary failure to start	Control	DG tripped on overspeed. Blown fuse in inverter. Silicon controlled rectifier was replaced.
76-36	9/17/76	1 CD		Secondary failure to start/ human error	Control	No exciter output and governor inverter failure. Valves for the start to run transfer switch were open. Valves were closed and inverter was repaired.
76-16	4/30/76	1 CD 1 AB		Non-failure II	Combustion air	Air aftercoolers leaked. First leak found in 1 CD and a few days later in 1 AB.

UNIT: Cook 2

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-54	12/26/79	-		Non-failure II	Sequencer	Setpoint drift in sequencer timer relays.
79-42	11/1/79	-	0:45	Secondary failure to start/ no start attempt/Human error	Control	One DG out of service. Contractor began to remove second DG. Blew fuse in inverter. Switched to alternate source in 45 minutes.
79-17	4/23/79	2 CD		Non-failure II	Service water	Service water valve failed. Cast iron disks replaced with stainless steel.
79-6	1/23/79	2 AB		Non-failure II	Service water	Service water valve failed to seat. Valve repaired.
78-79	10/19/78	2 AB		Primary failure to start	Fuel	Prior to removal of 2 CD from service, 2 AB failed two start attempts. It was successful on third after DG inspection. No cause found for lack of fuel.
78-46	6/17/78	2 AB		Primary failure to start/ no start attempt	Cooling	Leak in lube coil cooler head. The cooler head was replaced.
78-42	6/17/78	2 CD		Primary failure to start	Fuel	Cylinder 6 fuel injection pump failed. Widely varying temperatures in cylinder 6. The fuel injector was replaced.

UNIT: Cook 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-62	6/13/78	2 AB	13:30	Non-failure II/human error	Inverter	Inverter failed and shifted to alternate inverter supply, but the DG was not logged operable.
78-65	9/1/78	2 CD		Primary failure to start/ no start attempt	Lube oil	Fuel oil contaminated the lube oil. Four injector pumps and one injector were replaced.
78-56	7/28/78	2 AB		Primary failure to run	Governor	DG tripped on overspeed as it was unloaded. Break in governor linkage.
78-37	6/15/78	2 AB 2 CD		Auto-start failure/no start attempt/Common cause	Human	Both DGs incapable of auto-start. The wrong starting air valves were closed. Repair time 3:00.
78-25	4/15/78	2 CD		Non-failure I		DG not tested on schedule.
78-13	3/19/78	2 CD		Primary failure to start	Air-start	Air-start check valve on cylinder #5 broke. Valve and gaskets were replaced.
79-9	1/18/78	2 CD	28:00	Primary failure to start	Logic	1/18/78 tripped on overspeed. 1/21/78 tripped on overspeed. 28 hours later DG returned to service.
78-70	9/11/78	2 AB		Secondary failure to start/ vibration	Air-start	Check valve in air-start line leaking. It permitted combustion gases to enter air system.

UNIT: Cooper

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-27	5/8/80	2	454	Primary failure to run/ ran 3:00	Engine	Piston rod pins broke. Damaged parts replaced. All piston bolts were replaced.
79-33	11/9/79	1	0:00	Non-failure I		DG #2 inoperable (not reported) and DG #1 not tested.
79-34	11/7/79	2	28:00	Non-failure II	Lube oil	During annual inspection lube oil hose was found damaged by cam chain. DG operable for emergency.
79-36	11/10/79	2	231 :00	Primary failure to run	Engine	Four cylinder sleeves were damaged.
79-37	11/13/79	1	0:20	Non-failure II	Control	Silencer bypass solenoid failed because of insufficient air supply. DG could be started manually. DG #2 was inoperative.
78-39	12/6/78	1	3:20	Primary failure to start	Combustion air	Air damper failed to open, solenoid stuck in mid position. Reduced air pressure. Solenoid valves were cleaned.
78-31	9/12/78	2	88:00	Secondary failure to start/ dirt/ran 1 minute	Lube oil	Insufficient oil to bearings during engine coastdown. Bearings replaced and oil changed. No alarms.

UNIT: Cooper (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-15	3/30/78	2	28:00	Non-failure II	Fire protection	Smoke detector failed and discharged CO_2.
78-14	4/13/78	2	30:00	Non-failure II	Fire protection	Smoke detector failed and discharged CO_2.
78-6	1/17/78	1	0:06	Non-failure II	Output breaker	Breaker auxiliary switches failed to close.
77-46	9/12/77	1	3:00	Primary failure to start/ no start attempt	Control	Water leaked into DG control panel. Holes around pipes allowed rain water in. Holes were sealed.
77-47	9/12/77	1	12:00	Secondary failure to run/ ran 1:10	Fuel	Fuel line to day tank vibrated and broke. Support was improved.
76-45	11/7/76	2	5:45	Primary failure to start/ ran 2 minutes	Governor	Potential transformer fuse contacts were oxidized.
76-47	11/29/76	1	2:00	Secondary failure to start/ human error/ran 3 minutes	Output breaker	Breaker would not close. Blown fuse caused by maintenance. Failure 2 days prior to test.
76-34	8/23/76	1	2:15	Secondary failure to run/ vibration/ran 2 hours	Fuel	Fuel line to injector broke.

UNIT: Cooper (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	1/5/76	1	3:45	Non-failure II	N/A	PM.
	1/28/76	1	34:30	Non-failure II	N/A	Annual inspection.
	2/3/76	1	82:00	Non-failure II	N/A	Annual inspection.
	8/27/76	1	3:35	Non-failure II	Fuel	Replace injector line.
	12/15/76	1	0:30	Non-failure II	Output breaker	Clean breaker contacts.
	1/3/77	1	37:15	Non-failure II	N/A	Annual inspection.
	2/8/77	2	78:15	Non-failure II	N/A	Annual inspection.
	11/15/77	1	56:45	Non-failure II	N/A	Annual inspection.
	1/3/78	1	7:15	Non-failure II	N/A	PM.
	1/3/78	2	72:00	Non-failure II	N/A	Annual inspection and PM.
	5/22/78	2	5:30	Non-failure II	Breakers	Unknown.
	5/22/78	2	4:15	Non-failure II	Breakers	Unknown.
	7/20/78	1	30:45	Non-failure II	N/A	PM.
	8/9/78	2	37:15	Non-failure II	N/A	PM.
	11/7/78	1	56:00	Non-failure II	N/A	Annual inspection.
	11/14/78	2	34:45	Non-failure II	N/A	PM.

UNIT: Cooper (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	12/5/78	1	40:00	Non-failure II	N/A	Annual inspection and PM.
	12/27/78	2	6:25	Non-failure II	Unknown	Unknown.
	1/24/79	1	29:00	Non-failure II	N/A	PM.
	2/15/79	1	6:35	Non-failure II	Test equipment	Broken test connection.
	3/21/79	1	80:00	Non-failure II	N/A	PM.
	5/29/79	1	53:10	Non-failure II	N/A	PM.
	5/31/79	2	24:00	Non-failure II	N/A	PM.
	6/20/79	1	18:30	Non-failure II	N/A	PM.
	9/25/79	2	6:45	Non-failure II	N/A	Maintenance prior to 24-hour test run.
	10/9/79	1	27:15	Non-failure II	N/A	Annual inspection.
	11/20/79	2	36:05	Non-failure II	Engine	Torque head.
	12/7/79	1	12:00	Non-failure II	N/A	PM.
	10/13/80	1	72:30	Non-failure II	N/A	Annual Inspection.
	10/17/80	1	5:30	Non-failure II	Output breaker	Unknown.
	11/3/80	2	17:30	Non-failure II	N/A	Special test run.

UNIT: Cooper (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	12/1/80	1	45:00	Non-failure II	Fuel	Fuel leak - gaskets and valve.
	12/6/80	2	93:00	Non-failure II	N/A	Annual inspection.

UNIT: Crystal River 3

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-46	10/16/80	1B	14:00	Primary failure to start/ Ran 0 minutes	Unknown	Failed start. No trouble found.
80-30	7/31/80	1B	32:00	Secondary failure to start/ vibration	Turbo-charger	Turbo ductwork spearated from turbocharger. DG unavailable for 95 hours.
80-32	8/5/80	1A	20:00	Primary failure to start	Breaker logic	Overcurrent relay tripped. Relay setpoint was incorrect.
79-108	12/1/79	1B	6:30	Non-failure II	Cooling	Shutdown cooling water pump failed. Bearing failure.
79-069	7/24/79	1B	39:30	Primary failure to start/ Ran 0 minutes	Turbo-charger	Fire in exhaust. Fuel accumulated in exhaust caused by leak in turbocharger. Repaired gasket leaks.
79-57	6/6/79	1A	5:00	Non-failure II/Procedure error	Output breaker	DG A&B output breakers tripped on separate tests. Probable cause is procedural errors. Imbalance of reactive load. Would not fail in emergency.
79-57A	6/6/79	1B	6:30			
78-61	11/17/78	1B		Auto-start failure	Unknown	DG failed two starts. Started twice without maintenance being performed. Repair time 0:10.
77-146	11/28/77	-	1:00	Non-failure I	N/A	DG surveillance not performed when tunnel sump pump failed.

UNIT: Crystal River 3 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-001	1/3/78	1B	5:30	Secondary failure to start/ dirt/ran 0 minutes	Governor	Dirty oil in governor and servo-booster. Oil replaced.
77-94	7/26/77	1B		Auto-start failure/ procedure error	Human	Local control panel trips not reset. Procedure inadequacy. Trips reset and DG started. Repair time 0:30.
77-55	6/2/77	1A	2:00	Secondary failure to start/ vibration	Fuel	Fuel injectors loose. Injectors tightened.
	9/28/78		7:00	Non-failure II	Lube oil	Low lube oil pressure caused loss of start permissive.
77-158	12/27/77		11:30	Primary failure to start	Governor	Dirty oil in governor. Cleaned governor and booster and changed oil.
	1/4/79	1A		Secondary failure to start/ environment	Ventilation	Room temperature 280°F. DG would not start.
	1/4/79	1B		Secondary failure to start/ environment	Ventilation	Room temperature 280°F. DG would not start.
	10/23/79		72:00	Non-failure II	Fuel	Crack in fuel line. It was resoldered.
	12/28/80	1B		Primary failure to start/ no start attempt	Control	Fire in control panel.
	3/11/80			Auto-start failure	Fuel	Fuel transfer pump did not auto-start. Cause not found.

UNIT: Crystal River 3 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	5/29/80		504	Non-failure II	Cooling	Inspected radiator. Changed corrosion inhibitor.
	8/12/80	1A	24:30	Non-failure II	Turbo-charger	Changed gasket.
	11/25/80	1B	72:00	Secondary failure to start/ human error	Air-start	Air switch out of calibration.
	8/25/80		20:00	Non-failure II	Cooling	Change of jacket coolant.
	8/6/80		23:05	Non-failure II	Engine	Install new aftercooler.
	4/15/80	1A	361 :00	Non-failure II	N/A	Engine overhaul.
	5/5/80	1A	110 :30	Non-failure II	Unknown	Maintenance.
	6/26/80	1B	97:45	Non-failure II	Unknown	Maintenance.
	7/3/80	1A	55:00	Non-failure II	Unknown	Maintenance.

UNIT: Davis-Besse

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-53	7/9/80	All	0:00	Non-failure II/design error common cause	Load sequencer	Simultaneous loss of offsite power and SI signal could cause sequencers to overload DGs.
80-71	9/23/80	1-2	175 :00	Primary failure to run/ ran 22:35	Turbo-charger	Turbo failed and caused fire in exhaust. Turbo and aftercoolers were replaced.
80-65	8/26/80	1-1	0:15	Secondary failure to start/ no start attempt	Human	Both DGs unavailable. Service representative removed control power from essential bus without approval.
80-69	9/2/80	1-1	404 :00	Non-failure II	Turbo-charger	Bolt fragment found in crankcase during oil change. Bolt was from turbo gear assembly.
80-52	7/9/80	All	0:00	Non-failure II/design error	Exhaust	Exhaust supports received too much stress. Supports added during regueling outage.
79-126	12/9/79	1-1& 1-2	0:20	Secondary failure to start/ common cause/human error	Governor	DG 1-1 was inoperable for excessive load variation, but DG 1-2 was taken out of service instead. Governor problem in 1-1. Reactor shutdown.

UNIT: Davis Besse (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-96	10/15/79	2	0:00	Auto-start failure/loss of offsite power	Cooling Water	Component cooling water pump 2 and service water pump 2 failed to start automatically. They were started manually to cool DG2. Pump breaker failed to close. See VOR 79-17.
79-46	3/30/79	1-1	51:00	Primary failure to run	Turbo-charger	Turbo bearings failed. The turbo was replaced.
79-40	3/16/79	1-2	22:00	Secondary failure to start/ no start attempt	Generator	Water from fire sprinkler test got onto generator and regulator.
78-107	10/31/78	1-2	3:00	Primary failure to run	Ventilation	The air damper linkage was out of adjustment and would not open damper. DG room temperature rose to 110°F. DG could function for a while. Repaired and test completed.
78-96	9/14/78	1-1	0:00	Non-failure II	Human	DG 1-1 down for PMs at 10:00 on 9/13. DG not tested until 1:30 on 9/14.
78-81	7/19/78	-	0:00	Non-failure I	Procedure	The time required for the DG to reach 900 rpm was not measured.

UNIT: Davis-Besse (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-62	6/4/78	1-1	9:30	Primary failure to start/ ran 0 minutes	Control	Fuse blown in control power to regulator and governor. Fuse replaced and test completed.
78-49	5/9/78	1-1	106 :00	Primary failure to start/ 18-month test	Unknown	DG would not maintain constant load. Reactor was already shutdown.
78-18	2/8/78	1-1	50:00	Primary failure to start	Turbo-charger	Turbo failed and was replaced.
78-7	1/9/78	1-1	3:30	Secondary failure to start/ dirt/ran 3 minutes	Engine	DG tripped on high crankcase pressure. Trip was reset and test completed. Dirty oil collector.
77-101	12/1/77	1-2	0:00	Non-failure I	Human	DG 1-1 down for maintenance and DG 1-2 was not tested on time.
77-96	11/29/77	1-1	67:00	Secondary failure to start/ maintenance error/loss of offsite power/ran 0 minutes	Governor	Governor high speed limit switch setpoint was incorrect.

UNIT: Dresden 2

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-027	07/25/80	–	29:00	Primary failure to start/ no start attempt	Cooling/Lube	Heat exchanger tube leak.
80-008	01/26/80	2/3	42:00	Non-failure II	Cooling	Heat exchanger tube leak.
79-067	12/13/79	2/3	1:00	Primary failure to start	Control	Bad connection in speed sensing unit.
79-048	09/18/79	2, 2/3	0:00	Non-failure I	N/A	Operator failed to take sample.
79-052	10/01/79	2	4:00	Secondary failure to start/ no start attempt	Control	Human - Water in control cabinet.
79-047	08/16/79	2	5:00	Non-failure II	Output Breaker	Output circuit breaker trips open.
79-045	07/24/79	2	2:00	Non-failure II	Cooling/Lube	DG head cooling water flange seal leaks.
79-044	07/09/79	2/3	2:00	Non-failure II	Unknown/ Cooling	Unknown - cooling water pump alarm.
79-034	05/30/79	2/3		Primary failure to start	Air-start	Start gear failed to engage.
79-037	05/30/79	2	8:00	Non-failure II	Logic	Operator inadvertantly tripped fault relay.
79-024	04/24/79	2	3:00	Secondary failure to start/ human error	Air-start	Air line reversed.

UNIT: Dresden 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-014	03/05/79	2	11:00	Secondary failure to start/ corrosion	Air-start	Bendix or solenoid failures/air lines. Scheduled modifications should improve performance.
79-022	03/31/79	2	12:00	Secondary failure to start/ insufficient lubrication	Governor	Governor linkage was binding. There may also have been a sticking air-start solenoid.
79-013	02/23/79	2/3	3:00	Secondary failure to run	Cooling	Cooling water pump trip. Cause unknown.
78-066	12/16/78	2/3		Auto-start failure	Air-start	Air-start motors disengaged. DG started on second attempt. Repair time 5:00.
78-020	03/07/78	2/3	2:00	Primary failure to start	Air-start	Damaged power lug. Repair took 5 hours. Bad solenoid connection.
78-052	09/27/78	2/3		Auto start failure	Air-start	Air motor engaged but would not start. Started on second attempt. Repair took 4 hours.
78-050	08/24/78	2		Auto start failure	Air-start	Pinion gear did not engage. DG started on second attempt. Repair took 18 hours.
78-041	06/30/78	2/3	10:00	Secondary failure to start/ human error	Cooling	Cooling water pump trip was set too low.
78-033	05/22/78	2	6:00	Secondary failure to start/ human error	Governor	Governor speed set too high, which caused trip.

UNIT: Dresden 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-021	03/07/78	2/3	10:00	Secondary failure to start/ human error	Governor	Governor compensation out of adjustment.
78-001	10/03/78	2	2:00	Primary failure to start	Governor	Loose wire to governor.
77-065	1/22/77	2/3	0:00	Non-failure II	Cooling	Failure to follow procedures. Service water isolated.
77-070	12/02/77	2	1:00	Primary failure to start	Fuel	Unknown.
77-071	12/03/77	2/3	8:00	Primary failure to start	Air-start	Air regulator diaphram ruptured.
77-075	11/16/77	2/3		Auto-start failure	Logic	Unknown. Started 1 hour later.
77-066	11/29/77	2/3	8:00	Primary failure to run/ran 10 minutes	Cooling	Hole in stat housing - grounded.
77-055	11/03/77	2/3	0:00	Non-failure I	Logic	Test not performed.
77-051	10/30/77	2/3	16:00	Primary failure to start	Turbocharger	Clutch and shaft bearing failure. On the second start attempt the air motors were damaged.
77-025	07/12/77	2/3	2:00	Secondary failure to start/ human error	Governor	Frequency control improperly set.
77-024	06/30/77	2/3	1:00	Primary failure to start	Fuel	Injector control lever sticks.

UNIT: Dresden 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-011	03/22/77	2/3 +3	0:17 8:00	Primary failure to start	Air-start	Start motor momentarily jammed. DG 3 failed test so DG 2/3 was started but failed.
76-070	12/18/76	2	10:00	Secondary failure to run/ design error	Fuel	Water in fuel oil. Poor design.
76-064	11/26/76	2	7:00	Secondary failure to start/ maintenance procedure	Governor	Shutdown solenoid out of adjustment.
76-062	10/29/76	2/3	8:00	Primary failure to run	Generator	Short in rectifier in exciter circuit.
76-033	06/22/76	2/3		Auto-start failure	Air-start	Rust and corrosion in air-start system. Repair took 5 hours.
76-064	11/26/76	2	7:00	Secondary failure to start	Governor	Shutdown solenoid out of adjustment.
76-062	10/29/76	2/3	8:00	Primary failure to run	Generator	Short in rectifier.
76-050	08/09/76	2		Secondary failure to start/ no start attempt	Cooling	Cooling water pump breaker tripped. Over-temperature in breaker box.
76-033	06/22/76	2/3	5:00	Non-failure II	Air-start	Unknown.

UNIT: Dresden 3

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-049	12/25/80	3	5:00	Non-failure II	Air-start	Air-start regulator valve leaks.
80-017	04/04/80	3	3:00	Primary failure to start	Logic	Air-start relay did not operate.
78-057	11/30/78	3	0:00	Non-failure II	Fuel	Day tank fill valve stuck closed.
78-018	04/24/78	-	0:00	Non-failure II	Fuel	Fuel storage tank level low. Fuel tank valve open.
77-053	11/22/77	3	3:00	Primary failure to run	Control	Bad capacitor in frequency generator. DG tripped but the output breaker remained closed. It was manually closed.
77-054	11/29/77	3	2:00	Primary failure to run/ran 30 minutes	Control	Capacitor short in speed sensor. DG tripped but output breaker remained closed. It was manually opened.
77-044	10/04/77	-	0:00	Non-failure I	Fuel	Fuel storage tank low.
77-038	09/14/77	3	8:00	Primary failure to start/ no start attempt	Cooling	Outboard bearing worn on pump. Shorted meter.
77-028	07/01/77	3	2:00	Non-failure II	Fuel	Day tank low. Loose wire to pump controller.
77-029	07/12/77	3	0:00	Auto-start failure/no start attempt	Cooling	Hot environment causes cooling water pump breaker to trip.

UNIT: Dresden 3 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-007	03/22/77	3	3:00	Non-failure II	Exciter	Capacitor short in exciter circuit caused DG trip. The DG was being started for maintenance test.
76-032	12/02/76	3	0:00	Non-failure II	Control	Limit switch out of adjustment. Speed could not be increased from the control room. This would not affect emergency operation.
76-024	11/08/76	3	2:00	Non-failure II	Control/ Governor	Loose wire in DG governor control circuit. Speed could not be adjusted from control room. This would not affect emergency operation.
76-019	10/21/76	3	8:00	Primary failure to run/ ran 50 minutes	Lube oil	Strainer clogged and caused high temperature alarm.
76-013	08/11/76	3	10:00	Non-failure II	Cooling	Worn cooling water pump bearings.
76-004	03/11/76	3	2:00	Non-failure II	Control	Loose wire on governor control caused loss of remote speed control. This would not affect emergency operation.

UNIT: Farley 1

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-64	10/21/80	1B	0:10	Non-failure II	Output breaker	Breaker inadvertently racked out. Alarmed.
80-60	10/9/80	2C	7:00	Primary failure to start	Voltage regulator	Blown fuses in 125V dc regulator circuit.
80-51	8/26/80	1C	1:00	Non-failure II	Fuel	Slow start. Leaking check valve replaced.
80-43	7/17/80	1C	2:00	Non-failure I	Unknown	Slow start. Cause not found.
80-40	7/17/80	2C	3:30	Secondary failure to start/ human error/ran 0 minutes	Lube oil	Lube oil drain valve left open after yearly PM. DG tripped after receiving low pond level signal. Diesel started on second attempt.
80-44	7/23/80	1C	0:15	Non-failure I	Unknown	Slow start. DG will be started weekly during investigation.
80-33	5/16/80	1-2A	4:30	Non-failure II/human error	Control	Test equipment caused a fuse to blow. Lost speed control.
80-35	5/19/80	2C		Auto-start failure/no start attempt/human error	Cooling	Cooling pump switch left in wrong position. DG would not auto-start. Repair time 3:00.
80-34	5/19/80	1C	0:30	Non-failure II	Fuel	Slow start. Fuel oil check valve replaced.

UNIT: Farley 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-28	4/24/80	1B	1:00	Primary failure to start	Control	Regulator and main control power blew fuses.
80-25	3/31/80	1C	1:00	Non-failure II	Lube oil	Slow start. Low lube oil sump temperature was only problem found.
80-9	2/1/80	1B		Auto-start failure/LOSP test	Output breaker	Breaker did not close on LOSP test. Contacts in auto-close circuit failed. Auto-start circuit was repaired in 7 hours.
80-7	2/2/80	1B	12:00	Non-failure II/LOSP test/ human error	Cooling	Service water valve did not auto-open, and it would not manually open. Failure caused by test equipment used for LOSP test.
80-2	1/9/80	1C	0:30	Non-failure I	Fuel	Day tank fuel level low.
79-32	7/30/79	1C& 2C		Auto-start failure/no start attempt/common cause	Output breaker	DG 1C and 2C breakers left racked out for 312 hours after maintenance.
79-20	4/11/79	1C	2:00	Non-failure II	Load sequencer	1C sequencer key switch failed other sequencer inoperable for modification.

UNIT: Farley 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-13	2/22/79	1-2A		Auto-start failure/no start attempt	Load sequencer	Faulty switch put sequence in test mode 1B DG down for PM. Repair time 0:30.
79-14	3/6/79	2C	14:00	Secondary failure to start/ human error/Demand	Output breaker	Construction personnel had removed cables. Breaker would not close. Loss of 4160V to bus.
79-16	3/25/79	1-2A	6:00	Non-failure II	Load sequencer	Sequencer did not meet T. S. for loading step 6. DG 1B and 2C were down for sequencer modification. Timers were adjusted.
79-11	2/21/79	1-2A	3:15	Non-failure II/LOSP Test	Load sequencer	Timer relay drift. Timer adjusted.
78-89	12/6/78	1B		Auto-start failure	Load sequencer	Sequencer did not pick up battery charger 1B. Sequencer was repaired in 8 hours.
78-77	10/11/78	1B	21:00	Non-failure II	Air-start	Desiccant stuck in relief valve in B compressors. A compressor down for maintenance. Desiccant removed from air dryers.
78-76	10/11/78	1B	0:45	Primary failure to start	Air-start	Air solenoid stuck open.

UNIT: Farley 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-75	10/10/78	1-2A	14:00	Non-failure II	Exciter	9/17/78 DG breaker was slow in closing. 125V dc exciter fuse was blown. Generator was starting on residual magnetism which caused slow voltage buildup.
78-68	9/17/78	1B		Auto-start failure/SI & LOSP test	Governor	Loose coupling between speed pot and dc motors. Pot was moved manually. Coupling was tightened. Repair took 4:30.
78-66	9/14/78	1B	2:00	Primary failure to start/ no start attempt	Air-start	1B compressor relief valve leaked. This caused 1A and 1B reservoirs to bleed down.
78-50	7/18/78	1-2A		Auto-start failure	Load sequencer	Step 5 of sequencer failed. The relay was repaired. Repair took 5:15.
78-60	8/27/78	2C	5:15	Primary failure to start/ Low-low pond level signal	Control	125V dc control fuses blew. Lost voltage and frequency control.
78-61	9/5/78	1-2A	4:30	Non-failure II	Control	125V dc control fuses blew. Lost voltage and frequency control. Being started for maintenance.

UNIT: Farley 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-55	8/12/78	1B& 2C		Auto-start failure/ actual LOSP signal	Output breaker	1B breaker did not close. It was manually closed. 2C started. Repair time 0:06.
78-23	3/23/80	1B	10:45	Non-failure II	Air-start	Slow start. Air-start solenoid valve leaking.
78-18	3/8/78	1C	4:45	Primary failure to start	Air-start	Air-start solenoid valve failed. Corrosion improvements being studied.
78-16	3/2/78	1B	18:00	Non-failure II/tech. spec. violation	Air-start	Air-start solenoid caused the DG to fail to attain 514 rpm in less than 10 seconds.
77-37	10/2/77	1B		Auto-start failure	Load sequencer	Sequencer failed to pick up step 6 load. Repair took 2 hours.
77-26	9/13/77	1B	14:00	Primary failure to start	Air-start	Air-start solenoid stuck open.
77-27	9/16/77	1-2A	6:15	Primary failure to start	Air-start	Air-start solenoid stuck open.
77-35	10/2/77	1-2A	7:45	Primary failure to start/ LOSP test for all DGs	Air-start	DG tripped because of air valve failure. Could not be restarted because of speed switch failure.

UNIT: Farley 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-2	1/3/78	1B	5:00	Non-failure II	Air-start	1B and 1A air compressor inoperable.
77-15	8/17/77	1B	8:30	Primary failure to start	Air-start	Air-start valve did not shut.
77-23	8/28/77	1B	8:15	Primary failure to start	Air-start	Air-start valve failed open.

UNIT: Fitzpatrick

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-056	6/10/80	C		Secondary failure to start/ dirt	Regulator	Dirty contracts on VR droop switch. Reactor at 0% power for refueling. Repair took 529 hours.
80-012	1/11/80	A	48:00	Primary failure to start	Lube oil	Trip on low lube oil press. Immersion heater failed. Lube oil was cold.
79-105	11/14/79	C	12:00	Non-failure II	Lube oil	Shutdown lubricating pump failed.
79-097	10/30/79	C	9:00	Primary failure to start	Exciter	High resistance contacts prevented flashing field of DGC. Could not parallel A & C DGA started.
79-073	9/14/79	C	7:30	Secondary failure to start/ vibration	Logic	Loose wire on overspeed caused DG trip.
79-020	3/27/79	B	0:00	Non-failure II	Air-start	Air compressor failed. Spare compressor available.
78-098	12/5/78	A	3:00	Secondary failure to start/ human error	Governor	Governor misadjusted would not parallel to bus.
78-070	8/28/78	A	5:30	Primary failure to run	Lube oil	Soak back pump was noisy. Misaligned. May have operated and supplied power for a while.

UNIT: Fitzpatrick (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-054	7/31/78	-	0:00	Non-failure I	Human	Fuel oil samples not taken on time.
78-09	2/15/78	A&C	1:00	Primary failure to start	Control	Blown fuse in synchronization circuit. DG A & C could not be paralleled. First DG tripped, restarted, but could not parallel. DG was unavailable for 17 hours.
77-21	4/20/77	A	14:00	Primary failure to start	Control	Tachometer relay failed.
77-06	1/19/77	D	7:30	Non-failure II	Lube oil	Low lube oil press trip. This trip is bypassed in emergency. No problem found.
76-94	12/15/76	A	1:00	Non-failure II	Lube oil	Low lube oil pressure trip. Relief valve lifting on soak back pump. Bypassed on emergency.
76-78	11/17/76	A&C	0:00	Non-failure II	Fuel	Fuel oil pump failed. Redundant pump operational.
76-77	11/17/76	B	8:00	Primary failure to start/ ran 0 minutes	Control	Tachometer failed.
76-65	10/11/76	A	33:00	Primary failure to run/ ran 2:38	Turbo-charger	Oil leak in turbo caused fire. Turbo was replaced. DG was unavailable for 125 hours.

UNIT: Fitzpatrick (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
76-25	6/16/76	A,B, & D	11:00	Non-failure II/ran 1:30	Governor	Droop circuit failure. Not necessary for emergency.
76-25A	6/6/76	C	11:00	Primary failure to start/ ran 1:30	Output breaker	DG C output breaker failed to close. All four DGs unavailable.
76-21	5/19/76	D		Primary failure to start/ ran 0 minutes	Control	Tachometer relay failed. Relay was replaced.
79-21	3/27/79	A&C		Non-failure II/Loss of offsite power		A and C DGs down for maintenance.

UNIT: Fort Calhoun

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-30	12/11/80	1		Auto-start failure	Air-start	The secondary air start motors failed. The motors were cleaned and reinstalled. Added to annual inspection. Primary motors should function.
80-28	11/5/80	1		Primary failure to start	Logic	DG has slow start. Upon retest DG did not start. Suspect stuck relay. Also air compressor was repaired.
80-14	9/10/80	1	5:00	Non-failure II	Lube oil	Transformer to lube oil heater and to some alarms failed. It was replaced.
80-21	9/10/80	1		Non-failure II	Lube oil	Transformer to lube oil heater and to some alarms failed. It was replaced. Cause of failure was movable contactor on heater.
80-3	1/22/80	2		Primary failure to start/ 24-hour load test	Exciter	Zener diode failed in exciter.
80-3A	1/22/80	2		Primary failure to run/ 10-hour run out of 24-hour scheduled run	Cooling	Radiator tube leak. Leak was repaired and test completed.

UNIT: Fort Calhoun (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-6	3/12/79			Non-failure II/common cause	Fuel	Cracked pipe leaked water into bulk storage. Operator noticed increasing fuel level. Water was pumped out.
78-38	11/27/78	2		Auto-start failure	Output breaker	Breaker would not auto-close. Switch contacts were bad. Breaker could probably be closed manually.
78-24	8/9/78	1		Primary failure to start	Exciter	Zener diode in exciter failed.
78-22	7/12/78			Primary failure to start	Exciter	Zener diode in exciter failed.
78-17	6/19/78	1		Primary failure to start	Exciter	100 amp fuse to field failed. The fuse was replaced and the DG tested.
77-12	4/6/77	1		Non-failure II	Air-start	Slow start.
77-12A	4/14/77	2		Non-failure II	Air-start	Slow start. Both 77-12 and 77-12A were caused by deposits on the secondary air system. There is a time delay before the secondary air is actuated.

UNIT: Fort Calhoun (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-11	4/7/77	-		Non-failure I	Human	Fuel oil level readings were made incorrectly.
76-27	8/15/76	2		Primary failure to start	Air-start	Primary air motor did not disengage. Starter motor gear teeth were burned.
76-26	7/31/76	2		Primary failure to run	Governor	Governor motor failed. Caused a dc ground alarm. The motor was replaced.
76-16	4/10/76	2	4:00	Primary failure to start	Air-start	Primary air-start motor did not disengage. Tachometer to switch off air was not set correctly.
76-11	4/4/76	-	0:00	Non-failure I	Air-start	Slow start on secondary air. Primary air started within technical specification limit.

UNIT: R. E. Ginna

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-09	10/3/80	1A	3:45	Non-failure II/engine inspection required	Human	Engine barring device left engaged. Engine was inspected but no damage was found.
80-08	9/10/80	1B	4:41	Primary failure to start	Output breaker	Circuit breaker would not close.
80-001	1/18/80	1A	5:40	Secondary failure to start/ human error	Governor	Label not removed after overhaul did not have correct setpoint. DG would not accept more than 1800kW.
79-018	9/13/79	1B		Auto-start failure	Output breaker	Breaker failed to close. Trouble not found. Operated properly 10 hours later.
79-004	2/6/79	1A	2:35	Non-failure II	Fuel	Day tank fuel lowered for test. DG tested before fuel level returned and DG tripped. Human error.
77-19	9/14/77	1B	3:24	Secondary failure to start/ maintenance error/ran 0 minutes	Output breaker	Breaker would not close. Secondary contact fingers bent during maintenance.

UNIT: R. E. Ginna (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-007	8/16/78	1B	3:30	Non-failure II	Output breaker	Breaker would not trip upon completion of the test. Fuses inserted and breaker would not close. Bad contact with fuses.
76-20	6/16/76	1A	4:00	Non-failure II	Output breaker	Upon shutdown of the DG a false breaker trip signal was received. The breaker was reset manually and the reset spring was adjusted.
	8/21/76	1B		Auto-start failure/ no start attempt	Output breaker	Bus 16 breaker. Replaced the secondary contacts. Reactor in cold shutdown. Repair time 18:30.
	3/27/78	1B	109 :00	Non-failure II/reactor in cold shutdown	N/A	Inspection.
	1/8/79	1A	3:30	Non-failure II/reactor operating	Lube oil	Lube oil cooler had high oil pressure.
	9/24/79	1B	126 :30	Non-failure II/reactor operating	Lube oil	Clean lube oil cooler.
	10/16/79	1B	3:30	Non-failure II/reactor operating	Unknown	Clean inlet cooler.
80-11	12/11/80	1B	0:00	Auto start failure	Output breaker	Breaker to bus 17 failed to close, but breaker to bus 16 closed. Bus 17 breaker closed on second attempt.

UNIT: Hatch 1

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-066	06/15/80	1C	7.10	Non-failure II	Air-start	Air compressor unloader valves failed. Air pressure dropped to 150 psi.
80-067	06/28/80	1B	8:40	Non-failure II	Logic	Suspect spurious alarm on crank-case pressure. Bypassed for emergency.
80-029	03/22/80	1C	5:02	Primary failure to start/ ran 0 minutes	Governor	Governor booster and shutdown solenoid failed.
80-024	02/29/80	1C	5:40	Non-failure II	Voltage Regulator	Manual voltage regulator failed.
79-101	12/12/79	1C	1:45	Primary failure to start/ ran 0 minutes	Governor	Booster servo was replaced after 3 failures 12/12, 13, & 16.
79-104	12/16/79	1B	169 :00	Secondary failure to start/ electrolysis corrosion	Cooling	Service water pump failed. Bolts deteriorated causing shaft misalignment.
79-041	06/24/79	1B	0:00	Auto-start failure/ran 15 minutes	Unknown	DG tripped after 15 minutes but was restarted.
79-035	05/21/79	1A	14:00	Secondary failure to start/ human error	Control	Governor cams to monitor speed were misaligned. DG could supply 50% load. Modification was not sufficiently tested prior to test.

UNIT: Hatch 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-018	03/10/79	1B		Auto-start failure/no start attempt/Human error	Cooling	Service water left valved out after maintenance. Repair time 6:00.
78-18	03/30/78	1B	0:00	Non-failure II	Load Sequencer	Design error. Overload DG for LOCA and LOSP.
78-77	09/20/78	All	0:00	Non-failure II	Logic	Loss of remote start if a LOCA, LOSP, and DG trip occur.
78-93	11/09/78	1A	0:00	Non-failure I		Holes drilled through fire wall for conduit. Conduit was run and holes patched.
78-53	06/27/78	1C	0:00	Non-failure I	Battery	DG battery not inspected on schedule.
78-39	06/02/78	1A, 1B,& 1C	0:00	Non-failure I	Logic	Vibration could cause tie breaker to close prematurely.
78-19	03/30/78	2A & 2C	0:00	Non-failure I/Common cause potential	Logic	Design error on DG battery could cause loss of both DGs.
77-86	11/25/77	1A	11:30	Secondary failure to start/ corrosion	Governor	Water in air caused corrosion and caused booster servo failure. Air orifice was enlarged.
77-91	11/19/77	1B	7:45	Secondary failure to start/ maintenance error	Voltage Regulator	Regulator voltage set too high. The control pot was moved from outside to inside the cabinet.

UNIT: Hatch 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-62	08/18/77	1B	102 :00	Primary failure to run/ran less than 1 hour	Generator	Generator bearing failed. Bearing failure also occurred on 6/28/75.
77-59	08/12/77	1A	11:30	Non-failure II	Voltage Regulator	Manual voltage regulator failed. Manual control is not used for auto-start.
77-44	06/13/77	1C	0:00	Non-failure II	Cooling	Low jacket coolant pressure. Installing additional local gauge.
77-46	06/18/77	1C	0:00	Non-failure II	Cooling	Low jacket coolant pressure.
77-48	06/25/77	1C	0:00	Non-failure II	Cooling	Low jacket coolant pressure. Gauge indicated pressure was not low. Actual cause is unknown.
77-40	05/28/77	1A	0:00	Non-failure I	N/A	Slow start - 16 seconds. Second start - 9 seconds.
76-96	12/25/76	1C	0:01	Primary failure to run/ ran 45 minutes	Unknown	DG ran 45 minutes, tripped, checked, and retested satisfactorily.
76-99	12/31/76	1A	0:00	Auto-start failure	Unknown	DG did not start. It was inspected and then started satisfactorily.
76-83	11/06/76	1C	8:15	Primary failure to start	Logic	Shutdown relay was chattering. Caused output breaker to open.

UNIT: Hatch 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
76-81	10/29/76	1C	0:00	Auto-start failure	Governor	Did not reach 250 rpm in 7 seconds. Restarted immediately.
76-74	8/27/76	1A	16:00	Non-failure II	Logic	Reverse power relay trip. Would not occur in emergency. Human error.
76-77	9/11/76	1A	0:00	Non-failure II	Unknown	Added oil. Retested satisfactorily.
76-70	8/14/76	1C	0:00	Non-failure II	Control	When start switch is not held long enough, relay will not seal.
76-66	8/5/76	1A	12:45	Non-failure II	Human Error	DG connected to bus out of synch. caused loss of excitation. Tested 3 times OK.
76-51	6/16/76	-	0:00	Non-failure I	Logic	DGs could not be tested with transformer unavailable.
76-53	6/26/76	1C	17:00	Non-failure II/maintenance error	Lube oil	Temperature switch miscalibrated. Tripped DG below desired temperature setpoint. Would not trip in auto-start.
76-41	5/15/76	1B	0:00	Auto-start failure	Unknown	Started on second attempt.

UNIT: Hatch 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
76-35	5/1/76	1C	3:45	Secondary failure to run/ vibration/ran 37 minutes	Unknown	Cause of trip unknown. Loose wire caused blown fuse and loss of annunciators except for shutdown alarm.
76-24	5/15/76	1A	2:40	Primary failure to start/ ran 0 minutes	Air-start	Solenoid air valve stuck closed.
	3/5/76		16:45	Non-failure II	Cooling	Mod to coolant jacket system.
	6/4/76	1B	7:30	Maintenance	Battery	Run Pre-op on batteries.
	6/7/76		4:00	Maintenance	Fuel	Repair fuel injectors.
	6/26/76	1C	2:00	Primary failure to start	Unknown	Tripped on emergency engine shutdown.
	6/27/76	1C	6:00	Primary failure to start	Lube oil	Trip switch on high lube oil
	8/5/76	-	12:30	Primary failure to start	Output breaker	Supply breaker tripped.
	8/26/76	-	12:00	Maintenance	Lube oil	Maintenance - change oil.
	8/27/76	-	16:00	Maintenance	Lube oil	Maintenance - change oil.
	8/29/76	1C	12:30	Maintenance	Battery	Batteries-pilot cell low specific gravity.
	10/5/76	1C	5:45	Maintenance	Fuel	Fix fuel line.

UNIT: Hatch 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	11/6/76	1C	8:15	Maintenance	Unknown	Maintenance.
	11/25/76	-	6:30	Maintenance	Lube oil	Maintenance on lube oil pump.
	12/6/76	-	14:10	Maintenance	Blower	Inspect air blower.
	12/6/76	-	18:15	Maintenance	Blower	Inspect air blower.
	12/7/76	1C	13:15	Maintenance	Blower	Inspect air blower.
	12/8/76	1B	13:00	Maintenance	Unknown	Inspection.
	12/18/76	1A	3:45	Maintenance	Unknown	Maintenance.
		1C	3:30	Maintenance	Lube oil	Repair oil leak.
	5/23/77	1A	3:15	Maintenance	Unknown	DG inoperative. Surveillance test.
	5/24/77	1B	6:45	Maintenance	Engine	Cam inspection.
	5/24/77	1C	3:45	Maintenance	Engine	Cam inspection.
	6/7/77	1A	48:30	Maintenance	Engine	Cam-shaft inspection.
	6/10/77	1C	33:00	Maintenance	Engine	Inspect cam.
	6/13/77	1C	60:15	Maintenance	Engine	Inspect cam.
	6/13/77	1B	55:00	Maintenance	Engine	Cam inspection.

UNIT: Hatch 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	7/16/77	1C	16:00	Maintenance	Unknown	PM and calibration.
	7/23/77	1A	10:30	Maintenance	Lube oil	PM and change oil.
	7/30/77	1B	13:15	Maintenance	Lube oil	Change oil.
	8/6/77	1A	4:30	Maintenance	Control	Broken timer.
	8/18/77	1B	101:00	Maintenance	Engine	Bad bearing.
	9/1/77	-	3:15	Maintenance	Unknown	DG out.
	9/2/77	1A	18:15	Maintenance	Unknown	Rebuilding pump.
	10/4/77	1A	2:30	Maintenance	Unknown	INOP for tests.
	10/5/77	-	9:30	Unknown	Unknown	DG out.
	11/20/77	-	7:45	Unknown	Unknown	DG out.
	12/6/77	1B	77:15	Maintenance	Unknown	Pre-op for Unit II.
	12/17/77	1B	9:30	Maintenance	Unknown	Servomotor replacement.
	1/16/78	1B	78:30	Maintenance	Engine	Inspect generator bearings.
	3/17/78	1B	3:15	Maintenance	Battery	Replace DG battery chargers.
	3/25/78	1B	4:00	Maintenance	Unknown	Tagged for pre-op test.
	6/9/78	1B	112:00	Maintenance	Governor	Repacking governor.

UNIT: Hatch 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	6/13/78	1B	0:30	Maintenance	Output breaker	Maintenance.
	6/14/78	1A	3:30	Maintenance	Output breaker	Maintenance.
	8/5/78	1B	13:00	Maintenance	Lube oil	PM & investigate pre-lube problem.
	8/14/78	1B	36:30	Maintenance	Unknown.	PM.
	9/2/78	1C	8:00	Maintenance	Unknown.	DG inoperative.
	9/27/78	1C	16:45	Maintenance	Air-start	Air compressor leaking relief valve.
	10/28/78	1C	5:30	Maintenance	Lube oil	Blown oil pressure gauge.
	11/12/78	1B	10:30	Maintenance	Unknown	Maintenance.
	2/4/78	1B	4:30	Maintenance	Service water	Calibrate SW flow.
	2/24/78	1B	8:45	Maintenance	Service water	Pre-op for SW pump.
	3/26/78	1C	4:30	Maintenance	Unknown	Testing.
	4/1/78	1B	23:45	Unknown	Unknown	DG inoperative.
	4/28/78	1C	4:45	Maintenance	Unknown	Maintenance.

UNIT: Hatch 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	5/18/78	1B	1:45	Unknown	Unknown	DG inoperative.
	5/22/78	1B	7:45	Maintenance	Unknown	DG inoperative to perform PM.
	5/24/78	1B	11:00	Maintenance	Unknown	Maintenance.
	5/29/78	1B	16:15	Maintenance	Unknown	PM.
	6/4/78	1B	20:00	Maintenance	Unknown	Maintenance.
	6/4/78	1A	20:00	Maintenance	Unknown	DG inoperative.
	7/2/78	1B	10:45	Maintenance	Unknown	Temp switch broke.
	7/28/78	1C	8:00	Unknown	Unknown	DG inoperative.
	9/28/78	1A	39:15	Unknown	Unknown	DG inoperative.
	10/30/78	1B	5:30	Unknown	Unknown	DG inoperative.
	1/6/79	1A	2:00	Maintenance	Unknown	Repair relief valve.
	1/16/79	1B		Maintenance	Unknown	Repair pump.
	8/9/79	1B	13:45	Maintenance	Unknown	Maintenance.
	9/18/79	1A	20:00	Maintenance	Unknown	PM.
	4/5/80	1C	15:00	Maintenance	Control	Work on stop.

UNIT: Hatch 2

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-159	11/26/80	2C	1444:00	Primary failure to run	Engine	Thrown rod. Broken cotter pins.
80-146	10/29/80	1B	3:00	Secondary failure to start/vibration/ran less than 1 hour	Scav. Air Blower	Blower failure. Vibrating. Test was to verify maintenance.
80-127	8/30/80	2C	0:00	Auto-start failure.	Unknown	Three start failures, then successful start. No repair.
8-115	7/27/80	2C	15:00	Non-failure II	Logic	Relay setpoint drift. Failed to synchronize. Breaker would not close.
80-046	4/4/80	2C	0:00	Non-failure II	Logic	Synch speed not set correctly. Operator error.
80-058	4/16/80	1B	0:00	Non-failure II	Output breaker	Output breaker would not trip.
80-040	3/31/80	All	0:00	Non-failure I	Human	18-month test performed late.
80-006	1/19/80	2C		Non-failure II/maintenance error	Governor	Governor speed control pot was not set properly. DG would have functioned for an auto-start.
79-139	12/28/79	2A	7:20	Non-failure II/Potential for primary failure	Fuel	Dirt in fuel line check valve allowed fuel to drain out of injectors. Slow start.

UNIT: Hatch 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	4/15/80	1B	25:45	Maintenance	Distri-bution	Maintenance on 4160v. circuits.
	4/28/80	1C	34:30	Maintenance	Unknown	PM.
	10/11/79	1C	40:45	Maintenance	Unknown	Yearly PM.
	10/16/79	1B	3:45	Maintenance	Exhaust	Paint exhaust header.
	10/17/79	1B	9:30	Maintenance	Exhaust	Paint exhaust header.
	10/22/79	1C	127:00	Maintenance	Unknown	Repair discharge check valve.
	10/26/79	1A	9:00	Maintenance	Exhaust	Paint exhaust header.
	11/2/79	1B	5:45	Primary failure to start	Service water	Unknown.
	12/13/79		11:00	Maintenance	Service water	SW out.
	4/29/80	1C	8:00	Maintenance	Unknown	Maintenance.
	6/15/80	1C	7:15	Unknown	Unknown	Inoperable.
	10/1/80	1A	9:45	Maintenance	Unknown	Maintenance.
	10/6/80	1B	14:15	Maintenance	Unknown	
	10/28/80	1B	54:15	Maintenance	Unknown	PM.

UNIT: Hatch 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-109	10/17/79	1B	0:00	Non-failure I	Human	Did not notify unit 1 operator that shared DG was down.
79-047	6/2/79	1B	0:00	Auto-start failure	Human	Service water valves left closed. Opened before trip.
79-032	5/8/79	All	0:00	Non-failure I	Design	Disagreement between FSAR and actual design. Not unsafe.
78-069	11/13/78	2C	0:00	Non-failure I	N/A	Test not performed within required time.
79-020	1/18/79	2A	0:00	Non-failure I	Procedures	Day tank level low. Incorrect procedures for calculating level.
78-37	9/20/78	All	18:00	Non-failure I/Potential primary failure	Control	No remote start after LOCA, LOSP, and DG trip. Design.
78-60	10/31/78	2C	17:45	Primary failure to start/ Common cause potential (there was a similar failure 3 days earlier - not in abstracts)	Logic	Speed switch failure. Did not recognize 250 rpm in 7 seconds.
	9/14/78	2C	5:00	Non-failure II	Air-start	Air compressor.
	9/14/78	2A	19:15	Non-failure II	Air-start	Comp. inoperable.
	9/16/78	2A	5:30	Non-failure II	Air-start	Air compressor.
	8/1/79	2A	27:00	Non-failure II	Unknown	Design change.

UNIT: Hatch 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	8/9/79		13:45	Non-failure II		Maintenance.
	10/22/79	2C	127:00	Non-failure II	Service Water	Repair discharge check valve.
	10/23/79		9:00	Non-failure II	Exhaust	Paint exhaust header.
	10/24/79	2C	13:00	Non-failure II	Exhaust	Paint exhaust header.
	10/25/79	2A	12:00	Non-failure II	Exhaust	Paint exhaust header.
	11/13/79	2C	7:15	Primary failure to start/ 11 minutes	Engine	Tripped on high crank case pressure on two start attempts.
	12/28/79	2A	7:15	Primary failure to start	Unknown	Unknown.
	1/2/80	2A	57:15	Non-failure II	Unknown	Maintenance.
	2/23/80	2C	3:00	Non-failure II	Unknown	Blown pot fuse.
	6/28/80		4:45	Primary failure to start	Unknown	Unknown.
	9/21/80		3:00	Non-failure II	Unknown	Possible errors in wiring.
	10/3/80	2A	4:00	Non-failure II	Unknown	Check coupling alignment.
	10/3/80	2C	2:45	Non-failure II	Unknown	Maintenance.

UNIT: Indian Point 2

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-9	8/10/80	23		Auto-start failure/spurious SI signal	Breaker	All three DGs started on spurious SI signal. Normal feed to 480V bus 6A actuated lockout relay. Lockout was reset and DG connected. Defective overcurrent relay replaced. Repair time 0:10
80-2	4/9/80	22		Primary failure to start	Engine	Temperature of cylinders 7 and 8 was above normal. Timing out of specified limits.
78-37	12/19/78	21		Primary failure to start/ no start attempt	Air-start	Air-start motors were disassembled and cleaned.
77-29	8/29/77	23		Non-failure II	Cooling	Jacket water leaks were repaired.
77-18	8/26/77	23		Non-failure II	Lube oil	Pre-lube oil pressure switch had incorrect setpoint.
77-25	10/19/77	22		Non-failure II	Control	Heater terminal block had a short that caused fuses in control power to blow.
77-20	9/14/77	22		Primary failure to start/ no start attempt	Exhaust	Exhaust hood blower motor failed. Motor was replaced.
77-1	3/2/77	21		Non-failure II	Lube oil	Lube oil pressure switch developed leak and was replaced.

UNIT: Indian Point 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
76-27	12/12/76	22		Non-failure II	Lube oil	Lube oil heater shorted. It was removed and scheduled to be replaced when parts arrive.

UNIT: Indian Point 3

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-10	6/29/80	32	5:00	Non-failure II	Output Breaker	After completion of test, DG breaker would not reset. Trip latch spring was secured with screw.
78-23	8/29/78	33	0:00	Non-failure II	Fuel	Level control on the DG 33 day tank failed. Caused low fuel level in bulk tank.
76-40	11/26/76	31	3:00	Primary failure to run/ ran 3 hours	Control	Loss of speed control. Reactor tripped because of simultaneous loss of rod drive MG set 31.
76-35	10/22/76	31	74:00	Secondary failure to run/ human error/ran 1 hour	Governor	Air in governor oil caused speed variation. Air introduced during maintenance. Forty hours for parts delivery.
76-31	9/29/76	31	1:00	Secondary failure to run/ human error/ran 3 hours	Governor	Low oil in governor. Governor drain had not been tightened and oil leaked. DG was started and tripped three times.
76-20	6/25/76	32		Auto-start failure/simulated blackout	Output Breaker	Breaker did not auto-close. Spurious operation of relays. Repair time 0:01.
76-20A	6/25/76	31		Non-failure II/Human error	Human	DG 31 tripped on overload. DG was overloaded in preparation for test of DG 32.

UNIT: Kewaunee

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-42	12/12/80	1B	70	Non-failure II	Air-Start	Air-start motors did not disengage after start. DG was shut down to prevent destruction of air motors, but DG would continue to run if necessary.
80-027	06/21/80	1B	8:15	Secondary failure to start/SI signal/moisture/ran 0 minutes	Air-Start	Moisture and particles in air-start solenoid.
80-12	02/21/80	1B	0:45	Secondary failure to start/dirt/ran 0 minutes	Output Breaker	Dirty contacts on switch.
80-16	03/05/80	1B	25:00	Primary failure to start/ran 0 minutes	Air-Start	Air motors failed. Motors were replaced.
80-004	01/17/80	1B	0:33	Secondary failure to run/Maintenance error	Lube oil	Oil accidentally added to air box. Color code wrong.
79-027	10/23/79	1B	0:00	Auto-start failure	Unknown	DG failed start for simulated loss of offsite power. DG checked, and the test repeated satisfactorily.
79-025	09/22/79	-	4:00	Secondary failure to start/no start attempt	Lube oil	Broken lube oil line. Copper tube replaced with stainless steel. Vibration caused break.
79-024	09/22/79	-	10:00	Non-failure II	Human Error	DG is removed from service for 3 hours after each run. It was left out of service for 10 hours.

UNIT: Kewaunee (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-004	02/16/79	1A	99:00	Primary failure to start/ Moisture	Air-Start	Broken vane in air motor. Start signal for backup air motors was not generated because primary air flow was not blocked.
79-2	02/21/79	1A	72:00	Non-failure II	Governor	Manual speed control failed on 3 occasions. DG may have functioned in an emergency. DG 1B out for maintenance on 2/21/79.
79-2A	3/21/79	1A	4:30	Non-failure II	Governor	
79-2B	3/13/79	1A		Non-failure II	Governor	
79-001	01/10/79	1A	0:30	Primary failure to run/ Ran 80 min.	Control	Fuse blew. Fuse replaced. DG B was down for maintenance.
78-032	10/19/78	1A	3:30	Primary failure to run	Governor	Load limit switch out of adjustment. If load reached upper limit it had to decrease to 2100 kW to reset load control. Repair took 3:30.
78-026	06/21/78	1A	2:00	Non-failure II	Governor	Remote control of governor lost temporarily.
78-012	03/21/78	1A	5:15	Non-failure II	Output Breaker	Breaker trip coil failed open. Breaker was tripped locally.
77-28	10/21/77	-	6:00	Non-failure II	Air-Start	Compressor head gasket blown. Check valves leaked which lowered receiver tank press.
77-30	10/25/77	1A	0:00	Auto-start failure	Unknown	DG failed first start attempt. It started on second.

UNIT: Kewaunee (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-24	09/20/77	1A		Auto-start failure/A division logic test	Logic	Under voltage relays were sticking. Delayed start. Repair took 16 hours.
77-22	08/24/77	1B		Non-failure II	Fire Protection	DG 1B down for maintenance. CO2 tested, but CO2 sent cont. trip to DG. CO2 repaired when DG returned.
77-38	12/21/77	1B	7:00	Secondary failure to start/vibration	Governor	Limit switches out of adjustment.
77-23	09/20/77	1A	0:00	Non-failure II	Turbo-charger	Fire in exhaust, but DG was operable. Monthly tests changed to 4 hr. duration.
77-36	12/14/77	1A	25:00	Secondary failure to start corrosion	Logic	Undervoltage relay contacts were corroded. The relay was replaced with a sealed relay.

UNIT: LaCrosse

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-014	12/15/78	1B		Auto-start failure	Governor	Two trips on overspeed. 12/15 & 18 overspeed switch set to low. Retested. Repair time 0:05.
78-14A	12/18/78	1B		Auto start failure	Governor	Adjusted setpoint on 12/18 and retested. Repair time 0:04 the setpoint was incorrect for 83 hours.
78-10	8/11/78	1A	1:12	Non-failure II	Lube oil	Oil change. Fuel oil in lube. Apparently from residual fuel in injectors.
76-16	12/3/76	1A	7:00	Non-failure II	Cooling	Slow start. Coolant immersion heater failed.
76-15	11/18/76		7:00	Non-failure I	Fuel	Lube oil sample failed analysis. Sample taken from bottom of sump.
76-09	9/15/76	1B	12:00	Secondary failure to run/ human error	Fuel	DG could not carry full test load. Manual fuel shutoff not fully reset because of paint on cable.
	4/1/76	1A	6:00	Non-failure II	N/A	PM.
	4/5/76	1A	0:19	Non-failure II	N/A	Install EDG1B.
	5/11/76	1A	334 :00	Non-failure II	Exhaust	Exhaust leak. Install new seals.
	6/16/76	1A	0:30	Non-failure II	Battery	Change batteries.

UNIT: LaCrosse (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	6/22/76	1B	0:45	Non-failure II	Lube oil	Install oil pressure switch.
	7/9/76	1A	5:30	Non-failure II	Lube oil	Oil leak in line to turbo. Repaired leak.
	8/4/76	1A	8:00	Non-failure II	Lube oil	PM and oil change.
	9/1/76	1A	0:09	Non-failure II	Lube oil	Filter gasket leak. Replaced gasket.
	11/16/76	1A	0:17	Non-failure II	Unknown	Electrical resistance checks.
	5/20/77	1B	142	Non-failure II	Cooling	Cooling water leak. Rewelded bad weld.
	5/27/77	1B	72:00	Non-failure II	N/A	PM.
	5/30/77	1B	72:30	Non-failure II	N/A	PM.
	7/11/77	1B	0:30	Non-failure II	Fire Protection	CO_2 test.
	8/26/77	1A	3:15	Non-failure II	N/A	PM.
	8/26/77	1B	1:15	Non-failure II	N/A	PM.
	9/9/77	1A	1:45	Non-failure II	N/A	PM.
	10/10/77	1A	2:30	Non-failure II	Cooling	Replace hose.

UNIT: LaCrosse (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	12/20/77	1A	2:00	Non-failure II	Lube oil	Check time delay on lube oil pressure trip.
	12/21/77	1A	2:00	Non-failure II	Control	Replace-auto shutdown solenoid.
	12/22/77	1A	1:30	Non-failure II	Fuel and Control	Repair fuel leak. Complete solenoid installation.
	1/4/78	1A	1:15	Non-failure II	Fuel	Mod. to fuel shutoff valve location.
	1/12/78	1A	4:00	Non-failure II	Fuel	Fuel shutoff valve leak.
	5/1/78	1B	0:10	Non-failure II	Unknown	Electrical resistance measurement.
	5/2/78	1A	0:45	Non-failure II	Unknown	Electrical resistance measurement.
	10/19/78	1A	1:30	Non-failure II	Logic	PM and Mod. to include "not in auto" alarm.
	10/26/78	1A	128:00	Non-failure II	Fuel	Check for leaks. Replace #2 injector nozzle.
	1/16/79	1B	0:08	Non-failure II	Unknown	Electrical resistance testing.
	5/3/79	1A	31:30	Non-failure II	Lube oil	Fuel oil leaked into oil.
	5/14/79	1A	1:00	Non-failure II	Lube oil	Change oil.

UNIT: LaCrosse (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	5/30/79 5/30/79	1A 1B	1:38	Non-failure II	Control	Mod. to change control power after scram.
	8/31/79	1A	1:30	Non-failure II	Battery	Change batteries.
	4/18/80	1B	0:30	Non-failure II	Unknown	Wiring modification.
	4/24/80	1B	4:45	Non-failure II	N/A	PM.
	6/25/80	1A	1:00	Non-failure II	N/A	PM.
	6/27/80	1B	0:10	Non-failure II	Unknown	Unknown.
	10/7/80	1B	2:15	Non-failure II	Battery	Change starting battery.
	11/15/80	1B	7:00	Non-failure II	Battery	18 mo. battery test.
	12/9/80	1B	1:00	Non-failure II	Unknown	Electrical resistance measurements.

UNIT: Maine Yankee

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-018	8/26/80	1B	18:00	Secondary failure to start/ vibration/ran 50 minutes	Governor	Trip on overspeed. Loose trip switch.
80-003	1/15/80	1B		Auto-start failure/simulated/ loss of offsite power	Output	Breaker opened on first test. Test immediately repeated satisfactorily. Breaker repair, 1 hour, was done when the test was completed.
79-026	10/16/79	1B	100 :00	Primary failure to run/ran 16:35	Turbocharger	Catastrophic failure of turbo. Bearing failure. Fire resulted. Turbocharger failed. Turbocharger in DG1A was replaced.
78-023	9/29/78	1B	1:00	Secondary failure to start/ maintenance error/ran 15 minutes	Fuel	Air introduced into fuel lines during maintenance. Could not maintain full load.
78-003	2/18/78	1A	6:00	Secondary failure to start/ dirt	Governor	Dirty contacts on electric Governor PC card. Governor would not respond. May not have failed in emergency.
	1/3/76	1A	6:00	Non-failure II	Logic	Replace alarm relay.
	1/26/76	1A	6:00	Non-failure II	Lube oil	Low oil. Add one barrel.
	1/26/76	1B	6:00	Non-failure II	Lube oil	Low oil. Add one barrel.
	6/4/76	1B	6:00	Non-failure II	Fuel	Replace fuel oil filter.

UNIT: Maine Yankee (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	6/7/76	1B	4:00	Non-failure II	Control	Replace dc relay.
	8/26/76	1B	9:00	Non-failure II	N/A	Annual PM.
	8/31/76	1B	4:00	Non-failure II	Unknown	Reset thermostat.
	10/7/76	1B	6:00	Non-failure II	Control	Relay failed.
	1/18/77	1B	8:00	Non-failure II	Engine	Retorqued outer rim coupling bolts.
	1/19/77	1B	8:00	Non-failure II	Engine	Retorqued outer rim coupling bolts.
	1/20/77	1B	8:00	Non-failure II	Engine	Retorqued outer rim coupling bolts.
	3/4/77	1A	2:00	Non-failure II	Exhaust	Replaced screening on exhaust silencer.
	3/29/77	1B	8:00	Non-failure II	Exhaust	Replaced screening in exhaust silencer.
	11/1/77	1B	8:00	Non-failure II	Fuel	Replaced fuel filters.
	10/10/78	1A	4:00	Non-failure II	Lube oil	High fuel oil pressure alarm during test. Tightened oil line fittings.
	12/05/78	1B	6:00	Non-failure II	Governor	Inspect governor.

UNIT: Maine Yankee (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	6/29/79	1B	8:00	Non-failure II	Lube oil	Replace lube oil pump coupling shaft.
	10/22/79	1B	8:00	Non-failure II	Fuel	Replace fuel oil filters.
	10/23/79	1B	3:00	Non-failure II	Governor	Elect governor loose on mount.
	11/5/79	1A	72:00	Non-failure II	Control	Bad contacts in control circuit. Cleaned and replaced.
	11/17/79	1B	8:00	Non-failure II	Blower	Replaced blower shaft bearings. Replaced gen. fan bearings.
	12/10/79	1A	72:00	Non-failure II	Turbocharger	Fire in DG1B turbo. Replaced DG1A turbo to prevent similar failure.
	8/5/80	1B	8:00	Non-failure II	Cooling	Small leak in cooling line.
	9/25/80	1B	6:00	Non-failure II	Fuel	Filter leak. Replaced filter and O-ring.
	9/26/80	1B	6:00	Non-failure II	Governor	Oil leak in governor. Tightened 8 screws.

UNIT: Millstone 1

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-030	10/9/79	DG	52:00	Non-failure II	Cooling	Service water pipe restraints did not meet requirements.
77-39	12/10/77	DG	8:25	Primary failure to start	Governor	DG failed and GT was unavailable because of governor failure.
77-29	9/27/77	DG	1:15	Non-failure II	Fuel	Nipple in cylinder 12 was cracked and leaking.
77-7	2/1/77	DG	4:45	Non-failure II	Fuel	Nipple in cylinder 12 was cracked and leaking. DG was shutdown from test for repair.
	2/29/76	GT	6:00	Primary failure to start	Governor	Adjust governor.
	3/8/76	GT	48:00	Non-failure II	Governor	Adjust governor.
	3/15/76	GT	120:00	Non-failure II	Governor	Circuit board failure.
	8/30/76	GT		Auto-start failure		
	8/10/76	GT	4:45	Secondary failure to start/ loss of offsite power	Unknown	Incorrect alternate feeds for GT aux. Procedure change.
77-1	1/3/77	GT	29:00	Primary failure to start	Turbine	Broken sense line in governor controls. GT would not reach rated speed.
77-27	9/9/77	GT		Auto-start failure	Governor	Speed switch spurious operation. Repair time 0:20.

UNIT: Millstone 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-39	12/10/77	GT	48:00	Primary failure to start	Unknown	Burned transformer. DG failed subsequent check because of a governor shutdown solenoid malfunction.
78-12	5/19/78	GT	12:00	Primary failure to start	Governor	Governor failed. Tested OK.
78-14	6/13/78	GT	10:20	Primary failure to start	Governor	Speed switch failed. Replaced.
	7/6/78	GT	7:15	Non-failure II	Governor	Replace speed switch.
78-21	9/14/78	GT	49:00	Primary failure to start	Governor	Speed switch failed. Electronic control unit replaced.
78-29	11/22/78	GT	4:45	Non-failure II	Control	Shorted light socket caused oil pump breaker to open.
79-7	2/14/79	GT	2:30	Primary failure to start	Governor	Speed switch malfunctioned. Tested OK.

*GT = Emergency Cas Turbine

UNIT: Millstone 2

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-029	8/12/80	12U	8:00	Primary failure to start	Governor	Short circuit in speed sensor.
80-21	5/6/80	13U	12:00	Non-failure II	Output breaker	Breaker did not remain open, but reclosed on circuit.
79-019	6/27/79	12U	4:00	Non-failure II	Output breaker	Breaker could not be opened remotely.
78-019	8/3/78	13U	8:00	Non-failure II/ran 30 minutes	Fuel	Leaking fuel injectors. DG could continue to run in an emergency.
78-19A	1/25/79	13U	10:00	Non-failure II	Fuel	Leaking fuel injectors. Manufacturing defect. Other assemblies checked OK. DG could continue to run in an emergency.
78-033	12/5/78	12U	9:30	Secondary failure to start/ ran 12 minutes	Cooling	Mussel fouling of heat exchanger. Low cooling water flow.
78-9	5/8/78	12U	5:30	Secondary failure to start	Cooling	Mussel fouling of heat exchanger. Alarm low flow.
77-09	2/9/77	13U	9:30	Non-failure II/ran 0 minutes	Lube oil	Lube temperature switch caused trip. Miscalibrated. Will not trip in emergency. Wells installed for in-situ calibration.

UNIT: Millstone 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-20	5/15/77	12U& 13U		Auto-start failure/no start attempt/common cause/ human error	Fuel	Both DGs fuel supply valves were closed. Reactor was at zero power.
77-2	1/10/77	13U	24:00	Secondary failure to run/ ran 6 minutes	Engine	DG was vibrating excessively. DG had just been replaced. Supports were improved.
76-63	12/18/76	13U	475: 00	Secondary failure to run/ lubrication	Engine	Threw rod. Not sufficient lube for emergency starts. DG was replaced.
76-59	12/18/76	13U	5:00	Secondary failure to start	Cooling	Mussel fouling of heat exchanger. No water flow.
76-54	9/22/76	12U	6:30	Secondary failure to start/ ran 10 minutes	Cooling	Mussel fouling of heat exchanger.
76-53	9/19/76	12U	15:00	Primary failure to start	Lube oil	Oil filter gasket had a large leak. DG shutdown.
76-52	9/1/76	13U	26:00	Primary failure to start	Fuel	Injector leaking fuel and small fire resulted.
76-51	9/15/76	12U	77:00	Primary failure to start	Fuel	Fuel oil servomotor failed. Worn washers were ordered. DG failed 2 starts.

UNIT: Millstone 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
76-39	6/17/76	13U	0:03	Non-failure II	Lube oil	Standby lube oil pump failed and caused low lube temperature. Trip was not bypassed which would prohibit DG from starting. The trip is now bypassed in an emergency.
76-37	6/2/76	13U	16:00	Non-failure II	Engine	Crankcase eductor was dirty and caused pressure in crankcase-trip. DG would not trip on loss loss of offsite power.
76-23 76-23A	4/21/76 4/21/76	13U 12U		Non-failure I Primary failure to start/no start attempt		DG not tested on time. Fire in MCC B51 made 12U unavailable.
76-10	3/15/76			Non-failure I	Fuel	Fuel oil samples not taken on time.
76-08	2/28/76	12U	28:00	Primary failure to start/ Ran 0 min.	Engine	Governor wires loose.
76-06	2/24/76	12U 13U	6:30 3:00	Non-failure II	Human error	DGs alternately tagged out for service without required tests being performed.
	1/10/76	13U	0:09	Non-failure I	N/A	Slow start. Second start OK.
	1/13/76	13U	3:45	Primary failure to start/ no start attempt	Air-start	Air pilot valve failed. Valve replaced.
	1/13/76	13U 12U	4:00	Non-failure II	Control	Time delay relays inaccurate. Replaced.

UNIT: Millstone 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	2/17/76	12U	2:00	Non-failure II	Lube oil	Changed oil filter.
	2/18/76	12U	21:45	Non-failure II	Engine	Crankcase eductor cleaned.
76-08A	2/23/76	12U	126:00	Primary failure to run	Engine	Piston failed. Overhauled engine.
	11/3/76	12U	0:15	Non-failure II	Cooling	Shortened thermocouple lead.
	12/1/76	13U	6:00	Secondary failure to start/ no start attempt	Cooling	Lube oil Hx head cracked. Replaced. Torque limited.
	12/19/76	12U	12:00	Non-failure II	Lube oil	Eductor replaced.
	2/2/77	13U	17:45	Non-failure II	Engine	Eductor replaced.
	4/13/77	13U	1:15	Non-failure II/Human	Lube oil	Loss of crankcase vacuum while adding oil caused trip.
	8/10/77	12U	7:00	Primary failure to start	Air-start	Air receiver pressure too low. Pressure increased.
	8/17/77	12U	7:15	Secondary failure to start/ no start attempt	Cooling	Mussel fouling of Hx.
	8/26/77	12U	7:15	Secondary failure to start/ no start attempt	Cooling	Mussel fouling of Hx.
	9/20/77	12U	6:00	Secondary failure to start/ no start attempt	Cooling	Mussel fouling of Hx.

UNIT: Millstone 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	9/24/77	12U	8:30	Non-failure II	Governor	Overspeed trip out of adjustment. Readjusted.
	11/9/77	13U	8:00	Non-failure II/Human error	Control	Voltage mismatch between gen. and bus.
	5/5/78	12U	96:00	Primary failure to start/ no start attempt	Cooling	Jacket water pump failed. Motor rewound.
	1/3/79	13U	6:45	Non-failure II	Cooling	Pressure switch failed.
	2/5/80	13U	25:45	Primary failure to start	Engine	High crankcase press trip. Lube oil vent vented oil. Removed vent.
	2/26/80	12U	9:45	Primary failure to start	Output breaker	Breaker did not close. Cleaned contacts.
	3/5/80	12U	9:00	Non-failure II	Output breaker	Syncho switch failed. Not needed for emergency.
	7/8/80	13U	0:20	Non-failure II/Human error	Human error	DG removed from service by operator inadvertently.

UNIT: Monticello

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-010	04/26/79	All		Non-failure I	Turbo-charger	EMD design error. Lack of turbo lube after shutdown. Rust in air-start relay on backup starting system.
76-22	11/9/76	11		Non-failure II	Air-start	Rust in air-start relay on backup starting system.

UNIT: Nine Mile Point

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-018	8/8/80	103	8:00	Non-failure II	Fuel	Day tank drain line inadvertently opened. Low level alarm received.
79-23	10/4/79	103	21:00	Non-failure II	Cooling	Breakers opened on cooling water pump. There is a redundant pump, but temp increased to 210°F.
79-4	4/2/79	102		Auto-start failure	Output Breaker	Breaker would not close. Reason unknown. Subsequent tests were successful. Repair took 13 hours (parts delivery).
78-14	3/7/78	102	8:00	Secondary failure to run/ ran 38 minutes	Fuel	Day tank fill pump lost its prime when fuel sample was taken. Foot valve was mistakenly operated.
	12/28/79	102	43:10	Secondary failure to start/ no start attempt	Exciter	Control transformer neutral grounded caused 3rd harmonic currents to overheat. Transformers were replaced.
	10/4/79	103	12:00	Non-failure II	Fuel	Fuel oil pump had a leak. Pipe nozzle replaced.
	10/5/79	103	12:00	Non-failure II	NA	Routine inspection.

UNIT: Nine Mile Point (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	12/20/79	103	48:00	Secondary failure to start/ no start attempt	Exciter	Third harmonics were heating control transformer.

UNIT: North Anna 1

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-096	11/14/80	1H 1J 2H 2J	6:00 6:00 2:30 2:30	Non-failure I/Design error	Logic	Power transfer to DG now has time delay to prevent out-of-phase transfer.
80-051	05/23/80	1J	0:00	Non-failure II	Fuel	Low day tank level. Transfer pumps were inoperable.
80-032	02/15/80	1H	27:00	Primary failure to start	Governor	Booster servo failed. DG tripped on 02/15 and 03/2, 6, 10, and 11. DG unavailable for 97 hours.
80-021	02/02/80	1H	45:00	Primary failure to run	Engine	Trip on high crankcase pressure. No repair. DG started 45 hours later. Trip bypassed for emergency start, but DG may have been damaged if it continued to run.
79-064	05/03/79	1H	13:00	Non-failure II	Cooling	Leaks in supercharger cooling lines.
79-131	09/26/79	1H		Auto-start failure	Fuel	Air in fuel line. DG restarted immediately. Repair time 0:20.
79-110	09/10/79	All	0:00	Non-failure II/Design error	Ventilation	Ventilation fans may not be of sufficient capacity.
79-086	06/28/79	All	0:00	Non-failure I	Battery	DG battery inspection not performed on time.

UNIT: North Anna 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-088	07/02/79	1H	0:00	Auto-start failure	Unknown	DG failed first start attempt, but started immediately on second attempt. Repair took 24 hours.
79-062	05/03/79	1H+ IJ	1:30	Non-failure II	Cooling	Construction braces not removed upon completion of construction.
79-019	02/16/79	1H	3:00	Non-failure II	Unknown	Slow start. More than 10 seconds.
79-005	01/29/79	1H 1J	12:00 22:00	Non-failure II	Exhaust	Mufflers were not seismically qualified.

UNIT: Oyster Creek

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-014	3/2/80	1	3:00	Primary failure to start	Output breaker	Loose fuse holder. DG #2 down for maintenance. Both DGs were unavailable.
80-59	12/15/80	All	0:00	Non-failure I	Battery	DG and main station battery tests were not performed as required. Tests scheduled for August 1 and November 21 were not performed.
79-038	11/5/79	1	6:30	Primary failure to start	Logic	Output breaker position switch failed to close when output breaker racked in. Did not allow start permissive.
78-034	12/13/78	1,2		Non-failure I/human error		Station and DG batteries were not tested on time.
78-031	11/30/78	1	7:30	Primary failure to start/LOSP t test		Bound relay caused failure to excite the generator. Service water pump #1 did not trip on undervoltage. It started when DG energized bus. SW #2 had a similar failure for DG #2.
78-011	6/22/78			Non-failure II	Load Sequencer	Timer set point drift (SW pump)
78-008	5/24/78	1,2		Non-failure I/human error		DG and station batteries were not tested on time.

UNIT: Oyster Creek (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-001	1/3/78	1	5:30	Primary failure to start	Cooling	Damper not opened by louver control temperature switch. DG tripped on high temperature.
76-016	6/8/76	2	9:00	Primary failure to start	Air-start	Air-start pinion engagement switch did not close. No problems found.
76-005	3/3/76	2	12:00	Secondary failure to start/ vibration/LOSP test	Exciter	Field not flashed because of a chattering relay.
76-004	1/23/76	1	116: 00	Primary failure to run/ ran 12 minutes	Cooling	Leak in radiator tube caused loss of cooling water pressure
77-004	3/18/77	1	105: 00	Primary failure to start	Distribution	C phase grounded and caused trip of bus 1C breaker.

UNIT: Palisades

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-41	10/30/80	1-2	0:05	Non-failure II	Engine	PM leak test on cylinders after start;
79-36	8/21/79	1-1	16:30	Secondary failure to start/ contaminated governor oil	Governor	Dirty governor oil. Oil changed one month earlier but system not flushed well.
79-5	1/3/79	1-1	15:00	Secondary failure to run/ Vibration	Fuel	Fuel line broke. There were 150 gallons of fuel sprayed out.
79-16	4/6/79	1-1	4:00	Non-failure II/Design error	Load Sequencer	Relay failure to reset-may cause DG breaker to lockout.
78-37	10/31/78	1-2	0:00	Non-failure II	Lube oil	DG removed from service to repair pre-lube pump. Charging pump removed while DG was down. DG returned to service.
77-52	10/26/77	1-2	0:00	Non-failure II	N/A	DG 1-2 down for maintenance. DG 1-1 operation was not verified on time.
77-41	8/23/77		0:00	Non-failure I	Fuel	Fuel below TS limits. Delivery was late.
77-18	2/11/77	1-2		Primary failure to start/ no start attempt	Cooling	Jacket water leak to a pressure switch caused the air-start to cycle between start and stop. The air was depleted. Nipple was replaced.

UNIT: Palisades (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
76-14	5/25/76	1-1		Maintenance	NA	DG taken down for PM while HPSI pump was inoperable.

UNIT: Point Beach 1 & 2

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-16	12/17/80	4D	3:00	Non-failure II	Logic	Breaker logic did not sense DG speed. Breaker would have functioned upon SI signal speed sensing generator shaft tightened.
80-4	4/9/80	4D	5:00	Non-failure II	Start	Starting air motor failed. Redundant air system would have started DG but was not tested.
79-16	10/3/79	3D	13:00	Primary failure to start/ ran 0 minutes	Governor	Governor (UG8) failed. The governor was replaced.
79-8	5/2/79	All	0:00	Non-failure II/design error	Logic	DGs may be overloaded. It was possible to get an SI signal for both units and cause overload.
79-7	4/24/79	All	0:00	Non-failure I	Turbo-charger	EMD design error. May cause turbo failure if there is a start 15 to 180 minutes after a DG shutdown.
78-8	5/15/78	4D	7:00	Primary failure to start/ ran 0 minutes	Output breaker	Breaker did not close. Latch checking switch failed.

UNIT: Point Beach 1 & 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-8	6/29/79	3D	8:00	Primary failure to start/ ran 0 minutes	Logic	Starting sequence logic failure. Started locally. Second attempt locally failed. Speed sense setpoint drift. Insufficient speed after 4 seconds. Setpoint was adjusted. Would not fail for SI signal but would for LOSP without SIAS.
77-1	2/9/77	3D	12:00	Secondary failure to start/ ran 0 minutes	Output breaker	Breaker would not close. Dirt on overcurrent relay timing disc.
	1980	3D	103 :00	Non-failure II/reactor operating	Engine	PM. Overhaul DG.
	1980	4D	106 :00	Non-failure II/reactor operating	Engine	PM. Overhaul DG.
	1979	3D	103 :00	Non-failure II/reactor operating	Engine	PM. Overhaul DG.
	1979	4D	83:00	Non-failure II/reactor operating	Engine	PM. Overhaul DG.
	1979	4D	4:00	Non-failure II/reactor operating	Unknown	Special tests.
	1978	3D	104: 00	Non-failure II/reactor operating	Engine	PM. Overhaul DG.

UNIT: Point Beach 1 & 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	1978	4D	99:00	Non-failure II/reactor operating	Engine	PM. Overhaul DG.
	1977	3D	84:00	Non-failure II/reactor operating	Engine	PM. Overhaul DG.
	1977	4D	81:00	Non-failure II/reactor operating	Engine	PM. Overhaul DG.
	1976	3D	79:00	Non-failure II/reactor operating	Engine	PM. Overhaul DG.
	1976	4D	60:00	Non-failure II/reactor operating	Engine	PM. Overhaul DG.
	1976	3D	60:00	Non-failure II/reactor operating	Unknown	Special tests.

UNIT: Peach Bottom 2

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-14	8/8/80		0:00	Non-failure I	Fuel	Fuel overflowed tank into pond.
80-11	7/14/80		0:00	Non-failure I	Fire Protection	CO_2 system unavailable.
79-45	9/24/79	2	0:30	Secondary failure to run/ Human error	Cooling	DG was supplying bus while one offsite source was down. Operator stopped service water. DG tripped on high lube temperature. Half scram occurred.
78-1	1/3/78	4	7:30	Non-failure II	Lube oil	Lube oil heater failed.
79-25	5/18/79	2	13:00	Secondary failure to run/ Vibration	Governor	Governor oil leaked from cracked pipe. Pipe replaced.
78-50	12/21/78	2&3		Non-failure II	Governor	Slow start.
77-37B	8/26/77	1		Auto-start failure/Human error 37A & B involved simulated LOSP for all four DGs	Cooling	Jacket water high temperature not reset and DG tripped. Operator reset and loaded DG. Modification made to alarm when not reset. Trip level raised. Repair took 1 hour.
77-37A	8/26/77	4	96:00	Secondary failure to start/ Human error	Governor	Overspeed tripped DG. Overspeed moved during maintenance and not properly reset. Shims not installed in governor.

UNIT: Peach Bottom 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-63	11/1/77	4	8:00	Non-failure II	Lube oil	Repair leaks and clean up oil. DG shutdown for cleanup.
77-56	10/18/77	3		Auto-start failure/Human Error	Engine	Root valve to intercooler pressure switches left closed. Opened immediately and test completed.
78-41	10/10/78			Non-failure II/ common cause potential	Sequencer	Two loading relays out of calibration. Relays on both units were recalibrated.
78-35	8/30/78	3		Non-failure II	Governor	Slow start. Leaking check valve in air booster relay.
78-14	2/28/78	2	10:00	Secondary failure to start	Lube oil	Water got into lube oil storage. When added to DG, it caused overpressure trip. Storage improved.
78-5	1/18/78	2	8:00	Non-failure II	Lube oil	Repair lube oil heater.
76-2	1/11/76	3	10:00	Secondary failure to start/ human error	DC	DC breaker opened at 0300 to find DC ground and mistakenly left open for 10 hours. Had DG trouble alarm.

UNIT: Peach Bottom 3

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-026	6/13/77	E1, E3,& E4	6:00	Secondary failure to start/ no start attempt	Air-start	E1 down for maintenance. E3 and E4 unavailable because of loss of compressed air. Air tank ties left open and check valves leaked.

UNIT: Peach Bottom 2 & 3 (ECCS)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	1/3/80	2	21:00	Maintenance	Unknown	Blocked to drill holes.
	1/7/80	1	12:00	Maintenance	Unknown	Modify piping.
	6/9/80	1	98:30	Maintenance	Engine	Engine overhaul.
	6/14/80	3	77:00	Maintenance	Engine	Engine overhaul.
	6/23/80	2	24:00	Maintenance	Cooling	Clean Hx.
	6/23/80	2	93:30	Maintenance	Engine	Engine overhaul.
	6/30/80	4	67:15	Maintenance	Engine	Engine overhaul.
	7/3/80	3	1:30	Maintenance	Engine	Inspect crankshaft.
	7/8/80	4	17:00	Maintenance	Governor	Reset overspeed trip.
	7/19/80	3	50:30	Maintenance	Engine	Repair thrust bearings.
	1/5/79	2	2:30	Maintenance	Governor	Replace governor.
	1/17/79	1	2:00	Maintenance	Fuel	Inspect fuel racks.
	1/22/79	3	2:30	Maintenance	Governor	Replace governor.
	3/13/79	3	4:00	Maintenance	Governor	Replace governor.
	4/22/79	3	50:30	Maintenance	Engine	Engine overhaul.
	4/25/79	2	41:00	Maintenance	Engine	Engine overhaul.

UNIT: Peach Bottom 2 & 3 (ECCS) (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	4/27/79	2	1:00	Maintenance	Fuel	Replace fuel oil line.
	4/27/79	1	77:00	Maintenance	Engine	Engine overhaul.
	5/1/79	4	26:30	Maintenance	Engine	Engine overhaul.
	5/18/79	2	3:00	Maintenance	Fuel	Leak in fuel line.
	6/19/79	2	4:00	Maintenance	Governor	Replace governor.
	7/3/79	4	9:00	Maintenance	Governor	Replace governor.
	7/15/79	1	12:30	Maintenance	Governor	Replace governor.
	7/30/79	3	3:00	Maintenance	Governor	Replace tubing on governor.
	9/11/79	3	6:00	Maintenance	Distribution	Megger transformers.
	10/5/79	3	5:00	Maintenance	Governor	Replace governor linkage.
	10/5/79	2	5:00	Maintenance	Fuel	Repair fuel oil line.
	2/28/76	2	4:00	Maintenance	Engine	Clean crankcase eductor.
	3/1/78	2	19:00	Maintenance	Engine	Investigate engine trouble.
	4/24/78	4	45:30	Maintenance	Engine	Engine overhaul.
	4/26/78	3	69:45	Maintenance	Engine	Engine overhaul.
	5/1/78	2	62:30	Maintenance	Engine	Engine overhaul.

UNIT: Peach Bottom 2 & 3 (ECCS) (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	5/4/78	1	52:45	Maintenance	Engine	Engine overhaul.
	6/19/78	2	3:00	Maintenance	Cooling	Repair Hx.
	6/30/78	2	4:00	Maintenance	Cooling	Repair Hx.
	8/22/78	4	2:00	Maintenance	Cooling	Repair reservoir valve.
	9/28/78	3	1:00	Maintenance	Governor	Replace booster air tubing.
	9/27/78	3	2:00	Maintenance	Governor	Replace engine governor.
	4/27/77	2	6:30	Maintenance	Lube oil	Repair oil leak.
	5/31/77	4	112	Maintenance	Engine	Engine overhaul.
	6/6/77	3	91:15	Maintenance	Engine	Engine overhaul.
	6/8/77	3	57:30	Maintenance	Unknown	Modification.
	6/13/77	1	33:30	Maintenance	Engine	Engine overhaul.
	6/14/77	4	4:00	Maintenance	Unknown	Calibrate switches.
	6/17/77	2	24:00	Maintenance	Unknown	Modification.
	6/17/77	2	40:45	Maintenance	Engine	Engine overhaul.
	6/20/77	1	21:30	Maintenance	Engine	Engine overhaul.
	6/21/77	3	1:30	Maintenance	Fuel	Repair fuel leak.

UNIT: Peach Bottom 2 & 3 (ECCS) (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	6/27/77	3	9:00	Maintenance	Cooling	Calibrate temperature switch.
	8/26/77	1	8:30	Maintenance	Cooling	Calibrate temperature switch.
	8/28/77	3	9:30	Maintenance	Cooling	Calibrate temperature switch.
77-71	11/22/77	2	2:00	Non-failure II	Fuel	DG shutdown for oil cleanup.
77-77	12/19/77	1	24:00	Primary failure to run	Logic	Trip on A phase differential relay.
	5/10/76	1	24:00	Maintenance	Unknown	Maintenance.
	5/17/76	2	23:00	Maintenance	Unknown	Maintenance.
	5/19/76	3	33:30	Maintenance	Unknown	Maintenance.
	5/20/76	4	18:00	Maintenance	Unknown	Maintenance.
	7/30/76	2	4:00	Maintenance	Unknown	Maintenance.
	8/3/76		10:00	Maintenance	Lube	Repair oil leak.

UNIT: Pilgrim

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-50	9/11/80			Non-failure I		Tech. spec. violation of component cooling water system.
80-62	9/3/80	A		Secondary failure to run/ vibration	Fuel	Fuel line to cylinder 9R had broken.
80-17A	5/3/80	A		24-hour test had 3 failures 1) secondary failure to run/ human error	Fuel	Loss of fuel. Fuel transfer pump breaker not reset after pre-start check.
80-17B	5/3/80	A		2) Non-failure II/test started over	Fuel	AC fuel pump belt broke. DC fuel pump was available.
80-17C	5/5/80	A		3) Primary failure to run	Exciter	Exciter failed. Exciter was replaced.
80-15	4/1/80	A		Non-failure I	Fire protection	Heat sensor failed.
79-49	11/29/79	A	11:00	Non-failure II	Logic	Differential target dropped. No problem found.
78-49	10/11/78	B	381 :45	Primary failure to run/ran 16 minutes	Generator	Generator coil shorted. All generator coils were replaced.
78-39	8/2/78	B	46:50	Secondary failure to start/ no start attempt	Voltage regulator	Incorrect shutdown. Procedures caused regulator failure.

UNIT: Pilgrim (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
76-31	12/1/76 11/18/76	B	11:20	Non-failure II	Exhaust	Exhaust was leaking into DG room. Weld failure in bellows.
76-25	10/21/76	A	15:00	Non-failure II	Exhaust	Exhaust was leaking into DG room. Weld failure in bellows.
	1/23/76	B	120 :00	Primary failure to start	Unknown	Unknown.
	8/15/76	B	114 :00	Non-failure II	Start	Air compressor relief valve failed.
	9/24/76	B	3:30	Non-failure II	Engine	Crankcase exhaust failure alarm.
	12/2/76	B	4:30	Non-failure II	Unknown	Maintenance.
	12/2/76	A	5:45	Non-failure II	Unknown	Maintenance.
	1/28/77	B	71:00	Non-failure II	Lube	Replaced pre-lube pump o-rings.
	12/29/77	A	2:50	Non-failure II	Fuel	Fuel pump drive belt broken.
	3/16/78	A	8:00	Non-failure II	Fuel	Replace belt on fuel oil pump.
	4/3/78	A	0:20	Non-failure II	Sequencer	Faulty agastat.
	4/27/78	A	3:00	Non-failure II	Unknown	Maintenance.
	5/6/78	A	24:00	Non-failure II	Cooling	Fan inspection.
	5/17/78	B	36:30	Primary failure to run	Governor	Governor failed.

UNIT: Pilgrim (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	6/8/78	B	1:15	Non-failure II	Unknown	Maintenance.
	6/29/78	B	5:30	Non-failure II	Governor	Replace governor.
	9/20/78	A	5:35	Non-failure II	Fuel	Fuel oil leak.
	12/28/78	A	1:45	Non-failure II	Governor	Change oil in governor.
	2/26/79	A	2:13	Non-failure II	Governor	Change oil in governor.
	3/7/79	A	11:45	Non-failure II	Governor	Replace governor.
	4/19/79	B	5:08	Non-failure II	Governor	Replace governor.
	5/16/79	B	29:45	Non-failure II	Lube oil	Tighten drain cocks and reconnect broken prelube pump.
	10/9/79	B	3:52	Non-failure II	Control	Check frequency oscillations.
	10/9/79	A	2:37	Non-failure II	Fuel	Replace fuel oil pump belt.
	11/28/79	B	6:00	Non-failure II	Governor	Repair governor.

UNIT: Prairie Island 1

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-7	2/21/80	D1	0:00	Secondary failure to start/ human error/ran for 12 minutes	Governor	DG could only be loaded to 1400 kilowatts instead of 2750 kilowatts. Governor load limit set incorrectly.
80-5	1/21/80	D1	0:08	Non-failure II	Lube oil	DG lockout on low lube oil pressure during pre-lube.
80-2	1/7/80	D1	1:10	Non-failure II	Logic	DG could not be auto-synchronized to bus. Relay failure.
80-6	1/23/80	D2	4:20	Primary failure to run/ran for 20 minutes	Engine	Eductor hose came loose and DG tripped on high crankcase pressure. SIAS bypasses trip.
80-6A	1/23/80	D2		Primary failure to start/ Test for failure 80-6	Cooling	Jacket cooling water hose ruptured.
79-32	12/21/79	D2		Primary failure to start/ DG loaded and kept running for Z83 hours.	Lube oil	DG tripped on high crankcase pressure. If kept hot it will not trip. Cooling water accumulates in oil during shutdown.
79-5	3/13/79		0:00	Non-failure I	Lube oil	Lube oil sample not taken on time.
79-2	1/26/79	D2	14:00	Primary failure to start	Cooling	Cooling water pump did not start because of a speed switch failure.

UNIT: Prairie Island 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-14	6/22/78	D1	0:00	Non-failure II/Human error	Fuel	Valve from bulk storage to day tank left closed. Probably closed for 13 days. Valves locked open. D 2 down for maintenance. Sufficient fuel for 5 hours run time.
77-42	12/9/77	All	0:10	Non-failure II/Inadvertant SI Demand	Logic	Both DGs started on SI. SI not reset prior to stopping DGs. Both DGs were unavailable for 10 minutes.
77-23	6/17/77	D2	1:00	Non-failure II/ran 1:30	Governor	No manual control of load. Linkage lever loose. Retightened, peened, and lockwired. Load could not be decreased below 2500 kW. Would not fail for LOSP.
77-6	2/25/77	D1		Primary failure to start	Governor	Cooling water pump tripped on overspeed. The governor was sluggish.
76-18	4/29/76	D1	0:00	Non-failure II/Human error	Logic	Technician actuated relay that caused the DG to lockout. Lockout was reset immediately.
76-2	1/19/76	All		Non-failure II	Ventilation	Ice buildup on damper did not permit it to open fully. DG test was completed with damper partially closed.

UNIT: Prairie Island 2

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-30	10/8/80	D2	3:00	Primary failure to run	Engine	Educator hose broke and DG tripped on high crankcase pressure. Hose was replaced. SIAS bypasses trip.
78-7	3/29/78	D1		Non-failure II/18-month test	Cooling	Test jumper installed too soon. DG unavailable for 1 min. Cooling water pump locked out.
77-14	4/12/77	D2	0:30	Non-failure II	Logic	Control power lost when light socket shorted. Resistors placed in series with lights.
76-38	9/20/76	D1	0:20	Secondary failure to start/ ran 9 minutes	Engine	Eductor hose came loose and caused a trip on high crankcase pressure. Clamp was left loose after PM in August. SIAS bypasses trip.

UNIT: Quad Cities 1

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-026	10/11/80	1/2	26:00	Primary failure to run/ ran 1:50	Cooling	Cooling water pump motor shorted. DG tripped. The motor was replaced.
80-8	3/8/80	1/2		Auto-start failure	Control	DG would not start from control room; it started locally. Bad connection at fuse. Repair time 0:30.
79-37	11/16/79	1/2	0:00	Non-failure II	Air-start	One air-start supply valve was found closed. It was opened and locked. There are two air systems for each DG.
79-33	10/25/79	1/2	70:00	Secondary failure to run/ dirt in fuel	Fuel	DG would not accept full load. Plugged fuel filter.
79-22	6/22/79	1	2:40	Non-failure II	Fuel	Replace fuel filter gasket.
79-5	1/23/79	1/2	2:45	Primary failure to start	Air-start	Air-start solenoid stuck open. Replaced valve.
78-27	9/28/78	1	12:35	Non-failure II	Fuel	Replace fuel supply lines.
77-47	11/28/77	1/2	2:40	Primary failure to start	Exciter	Field breaker diode failed.
77-38	3/24/77	1	2:30	Primary failure to start	Control	Tachometer set screw came loose and caused loss of voltage, frequency, and synchro displays and governor.

UNIT: Quad Cities 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-24	5/6/77	1/2	1:30	Non-failure II	Fuel	Fuel oil leaks repaired.
77-22	4/25/77		77:00	Primary failure to start	Control	Voltage suppression diodes failed and frequency governor coupling came loose.
76-23	8/25/76	1/2	2:30	Non-failure II		DG out for inspection 55 minutes too long.
76-13	4/15/76	1/2	1:35	Non-failure II		DG out for PM too long.
76-5	2/11/76		185: 00	Secondary failure to start/ corrosion	Air-start	Air-start solenoid stuck, cleaned and reinstalled. Added to semi-annual PM.

UNIT: Quad Cities 2

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-12	6/22/79	2	2:00	Non-failure II	Generator	Maintenance took 20 minutes longer than allowed by technical specification limit.
77-26	8/10/77	2	46:00	Non-failure II	Cooling	Cooling water leak. Leak repaired.

UNIT: Rancho Seco

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-049	12/19/80	B	91:20	Primary failure to start	Unknown	Several components were replaced. Problem was not found. DG started successfully.
80-41	8/23/80	B		Primary failure to start	Voltage Regulator	Did not achieve rated voltage. Regulator was adjusted.
80-24	4/9/80	A		Non-failure II	Governor	Governor booster pump was not coupled during installation. DG started slowly.
80-013	2/18/80	B		Non-failure II	Start	Redundant dc compressor had a leak. No start failure.
80-12	2/19/80	A		Non-failure II	Logic	Remote control relay failed. Bypassed in emergency.
79-17	11/9/79	A		Auto start failure	Logic	DG could not be started remotely. It was started locally. Repair time 5:20.
78-16	10/24/78	A	6:45	Primary failure to start	Voltage Regulator	Blown fuse in regulator. Fuses replaced and VR tested, then DG started DG B out of service.
78-14	10/4/78	A	0:50	Secondary failure to run/ vibration	Fuel	Fuel oil leaking from strainer. DG B also out of service.

UNIT: Rancho Seco (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-1	2/14/77	A		Auto-start failure	Cooling	Service water pump did not auto-start. First attempt at manual start failed. Breaker to pump was reset (flag had failed). Pump was manually started.
76-16	12/6/76	A	50:45	Non-failure II/25 min. run	Logic	Remote speed control switch failed closed. (DG would still be functional for emergency)
76-14	10/14/76	B	340:00	Secondary failure to start/dirt	Governor	Governor oil was dirty. Governor flushed and refilled. (17 successful starts after flushing)
76-10	8/30/76	A	216:00	Primary failure to start	Air-start	Starting gears would not mesh.
76-9	8/13/76	B		Auto-start failure	Unknown	Several start failures. Cause could not be found. It was then started 13 times.

UNIT: H. B. Robinson 2

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-009	04/14/79	All	0:00	Non-failure II/simulated loss of offsite power	Load Sequencer	DGs did not load in 50 sec. time period. Timer relay set-point drift.
78-08	04/10/78	A	4:00	Primary failure to start	Governor	Brush came out of governor speed changing motor. Load would not go above 900kW.
77-21	09/13/77	A	11:00	Secondary failure to start/ dirt	Fuel	Sticking fuel injector rods. Engine could not develop full horsepower.
76-004	3/01/76	B	5:00	Secondary failure to start/ dirt	Fuel	Fuel injector pumps were galled. Cylinder no. 12 was not working.
	5/26/76	A	1:20	Non-failure II	Air-start	Repair leaking air-start solenoid.
	7/20/76	A	5:30	Non-failure II	Fuel	Repair fuel and lube oil leaks.
	8/31/77	A	6:00	Non-failure II	Lube oil	Clean oil cooler tubes.
	9/12/77	A	12:30	Non-failure II	Fuel	Replace fuel oil filters.
	9/15/77	A	9:00	Non-failure II	Fuel	Adjust fuel racks.
	11/02/77	A	1:30	Non-failure II	Cooling	Replace expansion tank sight glass.
	12/09/77	A	58:30	Non-failure II	Engine	Inspect cams and repair fuel lines.

UNIT: H. B. Robinson 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	12/14/77	A	20:40	Non-failure II	Fuel	Fuel oil line modification.
	4/03/78	A	25:30	Non-failure II	Lube oil	Repair oil leaks.
	7/03/78	A	7:00	Non-failure II	Air-start	Replace air-start solenoids.
	10/18/78	A	10:15	Non-failure II	Air-start	Repair air-start solenoids.
	11/30/78	A	3:45	Non-failure II	Fuel	Change fuel oil filters.
	1/09/79	A	2:10	Non-failure II	Governor	Check governor motor brushes.
	1/29/79	A	7:00	Non-failure II	Unknown	Install modification.
	2/08/79	A	28:00	Non-failure II	Lube oil	Repair oil recirculation pump.
	11/05/79	A	7:30	Non-failure II	Lube oil	Repair cooler line leaks.
	11/06/79	A	8:30	Non-failure II	Lube oil	Repair cooler line leaks.
	12/17/79	A	1:45	Non-failure II	Air-start	Install mod. to ensure starting air for 10 seconds.
	12/31/79	A	4:15	Non-failure II	Fuel	Repair day tank makeup solenoid valves.
	1/14/80	A	3:10	Non-failure II	Fuel	Repair fuel oil leak.
	4/09/80	A	3:10	Non-failure II	Fuel	Repair fuel oil leak.

UNIT: H. B. Robinson 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	5/19/80	A	11:10	Non-failure II	Cooling	Clean service water cooler.
	6/16/80	A	5:45	Non-failure II	Air-start	Repair air-start solenoid.
	7/21/80	A	2:30	Non-failure II	Air-start	Repair air-start solenoid.
	2/30/76	B	7:20	Non-failure II	Fuel	Replace injectors and repair turbo leaks.
	2/25/76	B	7:45	Non-failure II	Cooling	Repair water leak.
	5/26/76	B	1:45	Non-failure II	Air-start	Repair air-start solenoid.
	12/26/76	B	2:50	Non-failure II	Fuel	Change fuel oil filters.
	12/21/76	B	5:30	Non-failure II	Lube oil	Oil filter O-ring leak.
	1/31/76	B	6:15	Non-failure II	Unknown	Unknown.
	2/01/77	B	10:30	Non-failure II	Unknown	Unknown.
	8/29/77	B	9:01	Non-failure II	Generator	Check generator ground alarm.
	11/02/77	B	1:45	Non-failure II	Cooling	Replace expansion tank sight glass.
	12/08/77	B	27:45	Non-failure II	Turbo-charger	Repair turbo.

UNIT: H. B. Robinson 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	12/12/77	B	55:15	Non-failure II	Engine	Inspect cams.
	4/04/78	B	39:45	Non-failure II	Lube oil	Repair oil leaks.
	10/11/78	B	0:50	Non-failure II	Air-start	Repair start system.
	10/13/78	B	8:45	Non-failure II	Air-start	Clean start check valves.
	10/17/78	B	8:00	Non-failure II	Air-start	Clean start solenoids.
	11/14/78	B	21:20	Non-failure II	Logic	Calibrate temperature coolant trip.
	01/09/79	B	2:15	Non-failure II	Governor	Check governor motor brushes.
	01/16/79	B	4:45	Non-failure II	Logic	Repair synchroscope switch.
	01/19/79	B	7:45	Non-failure II	Unknown	Install mod.
	02/06/79	B	26:15	Non-failure I	N/A	Loading time not met.
	02/15/79	B	6:00	Non-failure II	Lube oil	Replace lube oil pump bearing.
	08/03/79	B	7:00	Non-failure II	Lube oil	Repair oil recirculation pump.
	08/06/79	B	9:30	Non-failure II	Lube oil	Repair oil recirculation pump.
	11/19/79	B	3:00	Non-failure II	Fuel	Clean day tank makeup.

UNIT: H. B. Robinson 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	12/10/79	B	3:00	Non-failure II	Air-start	Replace flexible conduit.
	12/17/79	B	2:15	Non-failure II	Air-start	Mod. - starting air for about 10 seconds.
	4/14/80	B	4:30	Non-failure II	Fuel	Fuel oil leak.
	7/14/80	B	6:00	Non-failure II	Air-start	Repair start solenoid.

UNIT: Salem 1

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-060	10/8/80	All		Secondary failure to start/ human error	Cooling	Operator disabled SW from train 2 while train 1 down for maintenance.
77-080	12/2/77	1B		Primary failure to run	Turbocharger	Blade failure.
77-059	7/30/77	1A & 1B		Secondary failure to start/ insufficient lubrication	Fuel	Bound fuel rack linkage because of lack of lube. Now lubricated each month.
78-069	10/11/78	1B		Non-failure II	Cooling	Leak in jacket water heater sheath. Pre-lube oil pump shorted.
76-012	11/1/76	1A		Primary failure to start/ Note all DGs depending on same SW train -- see 80-060	Cooling	Valve operator separated from valve. No start attempt on other DGs but they were failed.

UNIT: San Onofre

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-012	3/24/80	2	6:00	Primary failure to start	Fuel	Fuel transfer pumps flooded Sump pump failed and caused high water level.
79-021	11/14/79	2	7:16	Primary failure to start/ no start attempt	Load Sequencer	15v dc power supply for the load sequencer tripped.
79-019	11/16/79	All		Non failure II	Fuel	Missing fuel pipe supports.
79-014	8/29/79	2		Primary failure to start	Load Sequencer	Failed transistor in 15v dc power supply for load sequencer. The sequencer was erratic.
78-008	7/18/78	1		Primary failure to start	Fuel	Bound fuel rack linkage.
78-004	3/28/78	1	1:00	Secondary failure to start	Fuel	Dry bearings in fuel linkage-lack of lubrication.
77-007	5/10/77	1&2		Non-failure II	Fuel	Missing fuel pipe supports.

UNIT: Sequoyah 1

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-183	11/15/80			Non-failure I	NA	Faulty procedures.
80-171	10/16/80	1B-B		Non-failure II	Logic	Faulty indicator socket.
80-152	08/12/80	1B-B		Secondary failure to start/ no start attempt	DG Battery	Faulty procedure. Battery discharged.
80-074	05/21/80	1B-B		Non-failure II	Unknown	Unknown.
80-143	07/31/80	1B-B 2A-A 2B-B		Primary failure to start	Unknown	Unknown.
80-145	08/07/80	1B-B		Non-failure II	DG Battery	Battery shorted.
80-140	08/09/80	All		Secondary failure to start/ no start attempt	Logic	Relays reset in incorrect order. Operator error. Shorted DG coils on relays.
80-132A	07/14/80	1A-A		Non-failure II	Lube oil	High crankcase pressure trip. Cause unknown.

UNIT: St. Lucie

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-056	10/1/80	1A	12:00	Primary failure to start	Cooling	Air in cooling system. Relief valve was relieving continuously.
80-055	9/3/80	1A	6:00	Primary failure to run	Cooling	Engine overheated. Loss of coolant through leaking relief valve.
80-024	5/16/80		0:00	Secondary failure to start/ no start attempt/reactor down	Multiple	Several subsystem failures and setpoints out of tolerance. DG was not started.
80-021	5/7/80	1A	0:00	Non-failure II	Human	DG could not be synched to bus. Relay set incorrectly.
80-015	3/16/80	-	0:00	Secondary failure to start/ no start attempt	Multiple	Several DG subsystem failures and setpoints out of tolerance.
80-012	2/22/80	B	1:00	Primary failure to start	Fuel	Fuel linkages were sticking. DG did not reach rated speed. Linkages were lubricated.
80-013	3/17/80	A	24:00	Secondary failure to start/ design error	Exciter	Exciter cables burned. Cables on A and B were too small. Common failure unlikely. DG would not accept full load.
80-1	1/20/80	1A	0:00	Auto-start failure	Fuel	Fuel transfer pump failed. DG could have run several hours on gravity feed of fuel. DG was shutdown for repair. Repair took 0:45.

UNIT: St. Lucie (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-032	10/16/79	1A	2:00	Primary failure to start	Voltage regulator	Voltage regulator surge suppressor failed.
79-028	9/3/79	B	24:00	Primary failure to start/ offsite power lost to B train. Demand.	Logic	Relay in auto-start circuit was binding. Hurricane caused loss of B startup transformer. Manual start in 24 hours; auto-start confirmed in 48 hours.
78-36	9/5/78	1A		Auto-start failure	Output breaker	Breaker could not be closed remotely. Relay contacts were cleaned. Repair time 3:30.
79-021	6/25/79	All	0:00	Non-failure I	Turbo-charger	EMD design error. Insufficient turbo lubrication may occur on a second start within 3 hours of DG shutdown.
79-018	5/8/79	All	0:00	Non-failure I	Lube oil	Valves installed on lube system without approval.
79-013	3/31/79	1A	0:00	Auto-start failure	Fuel	Day tank low level switch failed to open fill valve. It was manually opened.
79-014	4/9/79	All	0:00	Non-failure I	Cooling	Design error in coupling shaft to cooling fans. Shafts were replaced during annual overhaul.
79-008	2/22/79	1A	0:00	Non-failure II	Fuel	Day tank level indicator stuck. Fuel below tech. spec. limits.

UNIT: St. Lucie (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-8	2/27/78		0:00	Non-failure I		Fuel tank level not recorded.
77-42	9/20/77	1A	65:00	Primary failure to run/ran for 20 minutes	Turbo-charger	DG loaded to full emergency load. Attempted to pick-up full design load. Turbo thrust bearing and clutch were damaged. Turbo replaced.
77-15	3/1/77	1A	1:00	Secondary failure to start/ human error	Logic	Spurious alarm when barring engine. Lockout relay reset, but overspeed not reset.
77-2	1/18/77	1B	69:00	Primary failure to run/ ran 55 minutes	Turbo-charger	Turbocharger failed. New unit installed.
77-3	1/19/77	1A	1:30	Secondary failure to start/ insuffecent lube oil or cold weather	Fuel	DG would not start because of dirty fuel rack linkage.
76-44	12/2/76	1A	1:00	Secondary failure to start/ common cause potential	Air-start	Incorrect air isolation valve alignment. Valves were opened.
76-21	6/18/76 5/18/76	1A	8:00	Secondary failure to start/ moisture and corrosion	Air-start	Air lines clogged. PMs incorporated to clean air lines.
	6/2/76	1A	0:30	Non-failure II	Output breaker	Adjust timer.
	6/2/76	1B	0:30	Non-failure II	Output breaker	Adjust timer.

UNIT: St. Lucie (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
	5/10/76	1B	3:00	Non-failure II	Control	DG would not stop from control room.
	1/11/77	1B	1:00	Non-failure II	Output breaker	Breaker light out. Replaced.
	1/20/77	1B	8:00	Non-failure II	Generator	Check phase balance.
	2/27/78	1A	2:00	Non-failure II	Control	Clean switchgear.
	3/10/78	1A	1:00	Non-failure II	Unknown	Install modification.
	3/13/78	1B	2:00	Non-failure II	Unknown	Install modification.
			3:00	Maintenance/January & July		Semi-annual PM.
			1:00	Maintenance/monthly		Monthly PM.
78-17	5/14/78	1B		Non-failure II/loss of offsite power		DG down for maintenance during refueling.

UNIT: Surry 1

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-070	11/14/80	All	0:00	Non-failure I/design error	Logic	Time delay after loss of off-site power (2 seconds) to prevent DGs from connecting to rotating motors out of phase.
80-066	09/02/80	1	3:00	Non-failure II	Fuel	Day tank low level control switch stuck. Fuel was not being replenished. Switch was returned to normal.
80-044	07/07/80	1	0:00	Non-failure II/Human error	Fuel	Breaker to fuel transfer pump left open. Redundant pump supplied fuel.
79-044	12/30/79	3	158:00	Primary failure to start	Turbocharger	Turbocharger failed and was replaced.
79-017	05/02/79	All	0:00	Non-failure I/Design error	Turbocharger	EMD design error. Turbo bearing damage may result from start too soon after shutdown.
78-040	10/31/78	1&3	0:00	Non-failure I	N/A	Refueling tests not performed on time.
78-026	08/02/78	3	1:00	Primary failure to run	Cooling	Pressure gauge blew out of pipe. Steel plug inserted since press. Need not be monitored.

UNIT: Surry 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
76-07	7/2/76	1	13:50	Secondary failure to start/ no start attempt	Engine	Heat stress caused cylinder head crack.
76-10	9/4/76	1	183: 00	Secondary failure to start/ no start attempt	Engine	Heat stress caused cylinder head crack. Water in cylinder sixth failure. All cylinders to be replaced.
76-06	5/8/76	1	10:30	Secondary failure to start/ no start attempt	Engine	Crack in cylinder head.
76-04	5/12/76	1	52:00	Secondary failure to start/ heat stress	Engine	Crack in cylinder head, bent rod, and broken piston. Engine not barred over before testing water in cylinder.

UNIT: Surry 2

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-042	11/15/80	3	4:20	Non-failure II	Air-start	Air motor No. 1 failed. Air motor No. 2 was selected and DG started.

UNIT: Turkey Point 3

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-004	2/25/80	A	45:00	Secondary failure to start/ ran 0 minutes	Cooling	Fan forced object into radiator and caused leaking (second occurrence).
79-14	4/24/79	B	3:00	Secondary failure to start/ no start attempt	Logic	Lamp replacement caused short in 125V dc.
79-020	5/26/79	A		Secondary failure to run/ 24-hour test/design error	Exciter	Third harmonics overheated exciter transformer. Design modified.
79-015	4/26/79	B	60:00	Primary failure to run	Fuel	Fuel starvation caused by cracked nipple in fuel line. Could load to 2300kw.
78-6	6/1/78	B		Non-failure II	Fuel	Level switch in day tank would not shut off pump. Engine mounted fuel tank reached high level alarm.
77-6	6/10/77	B		Non-failure II (maintenance later)	Cooling	Radiators deteriorated. Will be replaced.
77-4	3/31/77	B		Non-failure II	Fuel	Slow start. Air in fuel from cracks in tubing.
77-3	2/3/77	B		Secondary failure to start/ vibration/ran 0 minutes	Fuel	Air in fuel line, second start successful, see 77-4.

UNIT: Turkey Point 3 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
76-7	10/15/76	A		Non-failure II	Cooling	Low cooling water surge tank level. Sample valve not closed completely. Human error.
76-6	9/23/76	A		Primary failure to start/ no start attempt	Output breaker	Closing springs not energized. Bushing failure and motor failure. DG was not being tested.
76-2	3/19/76	B		Primary failure to start/ no start attempt	Output breaker	Closing springs not energized. Bushing failure and motor failure. Indicator light revealed failure.

UNIT: Turkey Point 4

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
79-8	5/26/79	A		Primary failure to start	Load sequencer	Undervoltage relays did not remove load from bus in time. This caused the DG to stop on lockout. Improper relay setting.

UNIT: Trojan

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-011	6/11/80	All	2:00	Secondary failure to start/ no start attempt	Human	Both DGs unavailable. One for equalizing charge on battery.
79-004	4/11/79		0:00	Non-failure I	Human	Test performed late.
78-06	2/17/78		0:00	Non-failure I	Procedures	Trip by-pass not verified during test (DG phase differential).
77-17	5/28/77		0:00	Auto-start failure	Load sequencer	Several loads did not sequence on.
77-22	6/22/77	West	3:00	Secondary failure to start/ vibration	Governor	Brush fell out of governor motor.
77-10	4/29/77	West	0:00	Auto-start failure/Loose Demand	Logic	Two successive partial losses of offsite. Operator did not reset DG after first start.
76-46	6/14/76		0:00	Non-failure I	Fuel	Day tank level below required level. Setpoint adjusted.
76-44	6/14/76		0:00	Non-failure I	Fuel	Sample not taken on schedule.
80-27	11/27/80	East	64:00	Non-failure II	Logic	Generator lockout relay found tripped. Lockout relay is to be added to alarm.

UNIT: Vermont Yankee

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-2	1/24/78	A	3:00	Primary failure to run/ ran 7:30 at load.	Cooling	DG trip on high jacket water temp. Set point drift in the switch. The switch was calibrated.
77-18	7/26/77	A	3:30	Secondary failure to start/ debris	Air-start	Air-start valve failed to open. Debris in line. Valves to be replaced by improved valves.
77-17	6/23/77	B	2:30	Primary failure to run/ ran 13 minutes	Engine	Eductor hose came loose. DG tripped on high crankcase pressure. Improved hose clamps to be installed.
76-28	9/24/76	B	6:15	Non-failure II/8-hour load test	Fuel	Slight leak in fuel header.
76-10	6/2/76	B		Auto start failure	Engine	DG tripped on high crankcase pressure. Restarted in 1 min. Eductor slightly dirty.

UNIT: Yankee Rowe

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
77-42	08/02/77	3	264:00	Secondary failure to run/ ran 30 minutes/sludge	Cooling	Sludge plugged radiator tubes. Reactor was down. See 77-41.
78-8	01/28/78	1	5:10	Non-failure I	Cooling	One of two heaters in DG 1 jacket water failed, discovered in walk-through.
77-11	03/01/77	1	3:00	Primary failure to start/ ran 0 minutes	Air-start	Electric motor starter shaft broke during test start.
77-41	08/02/77	1	169:00	Secondary failure to run/ sludge	Cooling	Radiator removed and sent to shop for cleaning. See 77-42.

UNIT: Zion 1

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-28	5/24/80	1B		Primary failure to run	Fuel	Ran 5 minutes. Air leak to fuel shut-off pistons caused the fuel to be shutoff. Fitting was tightened.
80-32	6/16/80	0		Non-failure I	Fuel	Fuel bulk storage tank below T. S. limit. DG was being tested every three days.
80-12	3/12/80	1B		Secondary failure to start/ no start attempt	Control	DC circuit breaker tripped. Annunciator slow blow fuses were changed to fast blow.
80-17	4/2/80	0		Secondary failure to run/ Ran 0:40. Vibration	Fuel	Control air (30 psi) vibrated loose and caused trip. DG1A to be taken down for maintenance.
80-19	4/7/80	0		Non-failure II	Governor	DG was started to look for oil leaks. Governor caused trip. There were leaks in governor.
79-18	3/15/79	1A		Non-failure II/human error	Lube oil	Pre-lube strainer blocked with rags. Will improve quality control.
79-15	3/7/79	1B		Primary failure to start	Logic	Overspeed trip setpoint to low. It was calibrated.
78-132	12/5/78	1B		Secondary failure to start/ Inadvertent SI signal. Vibration. Demand.	Control	Leaking fitting for control air.

UNIT: Zion 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-87	9/2/78	1B		Primary failure to start	Air-start	Air-start distributor timing 20° off. Camshaft had rotated. IA out of service.
78-92	9/14/78	1A		Secondary failure to start/ Inadvertent SI signal. Human error	Lube oil	Reactor trip. DG started and tripped. DG attempted 5 starts after SI. Low lube oil pressure trip not by-passed-valve failure. Rag in lube oil strainer caused low pressure.
78-65	7/17/78	1A		Primary failure to start	Lube oil	Lube oil cooler tube leak got water in oil. High velocity water eroded tube.
78-72	8/17/78	1B		Primary failure to start	Air-start	Air-start pilot valve leaked. DG would not start.
78-9	1/16/78	1A		Primary failure to start	Lube oil	Oil cooler tube leak caused high pressure across filter.
78-9A	1/16/78	0		Non-failure II	Control	DGO started when 1A tripped. DGO had low control air pressure. It was tripped for repair.
78-2	1/3/78	1B		Primary failure to start	Voltage regulator	Printed circuit card failed. Bad solder joint.
76-56	10/22/76	0		Primary failure to start/ SI test signal	Unknown	No failure cause found.

UNIT: Zion 1 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
76-35	7/14/76	1A		Non-failure II	Fuel	DG shutdown to repair fuel oil leak.

UNIT: Zion 2

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
80-31	12/9/80	2B		Auto-start failure	Control	Shutdown lever vibrated loose and tripped DG.
80-25	11/1/80	2A		Non-failure II	Lube oil	Lube oil leak at cracked weld in pipe.
80-15	4/8/80	2B		Primary failure to start	Fuel	Fuel injection pump stuck. Test done while 0 DG was out of service.
79-51	10/26/79	2A	2:00	Primary failure to start	Governor	Governor was out of adjustment. DG being tested while 0 DG was down.
79-43	8/6/79	2B		Primary failure to start	Governor	Probably caused by overspeed trip. Oil addition to governor may have introduced air. Governor was exercised and DG started.
79-34	5/11/79	0		Primary failure to start/ no start attempt	Air-start	Air valve leaked air reservoirs. 2A RHR pump out of service.
79-17	3/10/79	2A		Primary failure to run	Voltage Regulator	Defective amplifier. Regulator was replaced.
79-12	2/21/79	0	4:00	Non-failure II	Logic	Maintenance on DG for failure to stop. DG failed a start while performing maintenance. A switch was set incorrectly.

UNIT: Zion 2 (continued)

LER NUMBER	EVENT DATE	DG	DOWN TIME	EVENT TYPE/COMMENTS	SUBSYSTEM	CAUSE/COMMENTS
78-41	5/17/78	2A		Primary failure to run	Voltage regulator	DG voltage fluctuated. Voltage stability pot was adjusted.
78-5	1/6/78	2A		Primary failure to run	Voltage regulator	Regulator failed, and it was replaced.
78-8	1/9/78	2B		Primary failure to start	Governor	Governor synchronous indicator gear jammed.
77-69	11/17/77	0		Primary failure to run	Control	The 30 psi control air leaked and caused the master shutdown switch to trip the DG.
77-67	11/10/77	0		Primary failure to start	Lube oil	Water leaked in oil through lube oil cooler. Leaks were plugged.
77-20	5/6/77	2A		Primary failure to run/ 3:45 run of scheduled 4:00.	Control	The 30 psi control air leaked and caused DG shutdown. Nipples were changed from schedule 40 to 80.
77-18	4/27/77	2B		Primary failure to start	Governor	Governor speed control gear was jammed. It was adjusted.
76-38	9/29/76	2A		Secondary failure to run/ Human/Inadvertent SI	Control	DG parallel to system. Inadvertent battery trip, reactor trip, and SI. DG breakers would not open because of loss of DC. DG overloaded windings were destroyed.

9.5 DIESEL GENERATOR DATA COMPILATION

9.5.1 Demand Data

For this analysis, we divided demands (diesel generator start attempts) into three categories: (1) valid test demands, (2) actual demands, and (3) nonvalid demands.

Valid test demands are diesel generator starts for routine and special surveillance tests. Actual demands are diesel generator starts initiated by a loss of power to emergency buses or by safety injection signals. Nonvalid demands are start attempts to verify maintenance or starts other than the first start in a series of starts for a single test.

Table 9.5.1 presents, for each diesel generator at each plant, the number of valid test demands experienced in the years 1976–1980 and the 5-y total. Each plant's scheduled test frequency is included. Similar information is given for actual demands and for nonvalid demands in Tables 9.5.2 and 9.5.3 respectively. Figures 9.5.1 through 9.5.5 are histograms of the number of diesel generators vs the number of valid test and actual demands for the years 1976–1980 respectively. Figure 9.5.6 is a histogram of the number of diesel generators vs the average number of valid test and actual demands per year.

At several plants the diesel generators are tested much more frequently than their schedules require. At some plants the number of tests varies significantly from year to year.

9.5.2 Factors Influencing Diesel Generator Reliability

For purposes of reliability analysis, independent diesel generator failures are treated as basic events. With addition of the common-cause events to the station blackout fault trees, no further failure logic development is required. Diesel generators are not components; they are relatively complex systems. The purpose of this section is to address some of the factors that influence the reliability of diesel generators by:

(1) focusing on the contributions to failure probability from the various diesel generator subsystems, and
(2) assessing parameters that potentially influence diesel generator reliability.

Table 9.5.4 presents the number of events by type and the percentage of all events that each of these numbers represents. Nonfailures make up about two-thirds of the events because the ECCS outage data (NUREG/CR-0757) were, for the most part, nonfailures. A much smaller fraction of LERs were nonfailures. The discussions in this section are concerned with primary and secondary failures, and, in some cases, autostart failures.

Table 9.5.1. Valid test demands

Plant	Scheduled test frequency	DG*	1976	1977	1978	1979	1980	5-y Total
			No. of valid test demands per year					
Arkansas Nuclear One 1	Monthly	1	14	17	30	17	15	93
		2	13	17	23	12	16	81
Beaver Valley	Monthly	1	37	29	51	33	17	167
		2	43	47	26	25	15	156
Big Rock Point	Weekly	1	86	74	57	62	71	350
Brunswick 1,2	Monthly	1	12	12	12	12	12	60
		2	12	12	12	12	12	60
		3	12	12	12	12	12	60
		4	12	12	12	12	12	60
Calvert Cliffs 1,2	Weekly and Monthly	11	58	76	71	70	77	352
		12	56	74	72	68	68	338
		21	35	74	69	66	74	318
Cooper	Monthly	1	22	25	27	34	27	135
		2	24	22	27	31	28	132
Crystal River 3	Monthly	A	N.O.	Totals Only				114
		B						106
Davis-Besse	Monthly	1	N.O.	10	24	57	31	122
		2		10	29	61	37	137
Dresden 2,3	Monthly	2	13	62	48	21	13	157
		2/3	12	78	74	16	13	193
		3	13	53	48	12	12	138
Joseph M. Farley 1,2		1B	N.O.	22	76	52	86	236
		1C		12	77	66	85	240
		1-2A	N.O.	19	74	70	50	213
		2C		16	75	44	83	218
James A. FitzPatrick	Monthly	A	15	17	19	32	22	105
		C	15	17	19	32	20	103
		B	17	13	18	32	24	104
		D	17	13	18	31	24	103
Fort Calhoun	Monthly	1	14	11	15	12	13	65
		2	13	12	14	12	15	66
Robert E. Ginna	Monthly	A	15	16	14	13	14	72
		B	15	14	14	14	12	69
Edwin I. Hatch 1		1A	74	72	51	33	48	278
		B	68	55	57	60	84	314
		1C	68	66	40	29	42	245
Edwin I. Hatch 2		2A	N.O.	N.O.	16	29	48	93
		2C			19	48	99	166
Indian Point 2	Monthly	21	17	14	11	11	12	65
		22	17	14	11	11	12	65
		23	17	14	11	11	12	65
Indian Point 3	Monthly	31	17	13	14	15	24	83
		32	18	13	14	15	24	84
		33	18	13	14	15	23	83
Kewaunee	Monthly	1A	26	24	25	23	25	123
		1B	26	23	25	23	25	122
La Crosse	Monthly	1A	Totals Only					120
		1B						93
Maine Yankee		1A	15	12	13	24	13	77
		1B	15	13	13	25	19	85
Millstone 1		DG	53	60	62	57	48	280
Millstone 2		12U	131	68	61	61	73	394
		13U	121	71	63	69	71	395
Nine Mile Point	Monthly	102	12	14	12	13	13	64
		103	12	16	12	13	12	65
North Ana 1		1H	N.O.	15	17	26	39	97
		1J		15	20	25	19	79
Palisades	Monthly	1	13	12	13	13	13	64
		2	13	12	13	12	13	63
Peach Bottom 2,3	Weekly	1	68	68	73	74	71	354
		2	69	73	75	74	69	360
		3	67	68	70	71	69	345
		4	68	64	67	72	72	343
Point Beach 1,2	Bi-weekly	3D	35	35	34	34	44	182
		4D	37	37	36	35	42	187

Table 9.5.1. (continued)

Plant	Scheduled test frequency	DG*	No. of valid test demands per year 1976	1977	1978	1979	1980	5-y Total
Prairie Island 1,2		1	62	43	34	41	52	232
		2	57	42	33	38	38	208
Quad-Cities 1,2	Monthly	1	19	28	23	26	32	128
		1/2	24	29	36	41	36	166
		2	21	26	25	24	32	128
Rancho Seco	Monthly	A	24	22	20	20	25	111
		B	21	23	16	17	21	98
H. B. Robinson 2	Bi-Weekly	2A	28	27	30	42	54	181
		2B	29	26	28	43	54	180
Surry 1,2	Monthly	1	21	22	15	14	15	87
		2	18	23	13	14	15	83
		3	27	20	15	14	15	91
Trojan	Monthly	1	44	42	18	22	39	165
		2	27	58	17	32	19	153
Turkey Point 3,4	Monthly	A	29	28	28	31	28	144
		B	29	30	29	30	28	146
Vermont Yankee	Monthly	1A	13	14	13	14	13	67
		1B	13	14	13	14	13	67
Yankee (Rowe, Mass.)	Monthly	1	54	60	59	63	57	293
		2	54	59	55	61	59	288
		3	54	60	59	61	59	293
TOTALS**			2348	2568	2698	2726	2892	13665

* Diesel generator identification assigned by nuclear plant licensee.
** The sum of the yearly subtotals plus the plant totals not reported yearly equals the grand total.
N.O. = not operating

Table 9.5.2. Automatic starts of diesels not for testing (actual demands)

Plant	DG*	No. of actual demands per year 1976	1977	1978	1979	1980	Total
Arkansas	1	0	0	0	0	2	2
Nuclear One 1	2	0	0	0	1	2	3
Beaver Valley	1	11	7	3	6	1	28
	2	8	6	3	5	1	23
Big Rock Point	1	0	0	0	0	0	0
Brunswick 1,2	1	0	0	0	0	0	0
	2	0	0	0	0	0	0
	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
Calvert Cliffs	11	0	0	2	0	1	3
1,2	12	1	0	1	0	1	3
	21	0	0	0	0	1	1
Cooper	1	8	10	6	10	6	40
	2	8	10	6	10	6	40
Crystal River 3	A	N.O.					0
	B	N.O.					0
Davis-Besse	1	N.O.	1	0	1	3	5
	2	N.O.	1	1	1	3	6
Dresden 2,3	2	0	0	0	0	0	0
	2/3	0	0	0	0	0	0
	3	0	0	0	0	0	0
Joseph M. Farley 1,2	1B	N.O.	0	1	0	0	1
	1C	N.O.	0	0	0	0	0
	1-2A	N.O.	0	0	0	0	0
	2C	N.O.	1	2	1	1	5
James A. FitzPatrick	A	0	0	0	0	0	0
	B	0	0	0	0	0	0
	C	0	0	0	0	0	0
	D	0	0	0	0	0	0
Fort Calhoun	1	8	5	1	3	2	19
	2	8	5	1	0	2	16
Robert E. Ginna	A	1	0	0	0	0	1
	B	1	0	0	0	0	1
Edwin I. Hatch 1	1A	0	0	0	0	0	0
	B	0	0	0	0	0	0
	1C	0	0	0	0	0	0
Edwin I. Hatch 2	2A	N.O.	N.O.	0	0	0	0
	2C	N.O.	N.O.	0	0	0	0
Indian Point 2	21	0	0	0	1	1	2
	22	0	0	0	1	1	2
	23	0	0	0	1	1	2
Indian Point 3	31	4	3	0	2	6	15
	32	4	4	0	2	7	17
	33	4	4	0	2	8	18
Kewaunee	1A	11	6	4	6	8	35
	1B	11	6	4	6	8	35
La Crosse	1A	Totals Only					14
	1B	Totals Only					8
Maine Yankee	1A	0	0	1	0	0	1
	1B	0	0	1	0	0	1
Millstone 1	DG	0	4	0	2	1	7
Millstone 2	12U	23	5	0	0	1	29
	13U	26	5	0	0	0	31
Nine Mile	102	0	1	0	0	1	2
Point	103	0	1	0	0	0	1

Table 9.5.2. (continued)

Plant	DG*	No. of actual demands per year 1976	1977	1978	1979	1980	Total
North Anna 1	1H	N.O.	0	3	1	4	8
	1J	N.O.	0	3	1	3	7
Palisades	1	0	3	0	0	0	3
	2	0	3	0	0	0	3
Peach Bottom 2,3	1	0	0	0	0	0	0
	2	0	0	0	0	0	0
	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
Point Beach 1,2	3D	0	0	0	0	1	1
	4D	0	0	0	0	1	1
Prairie Island 1,2	1	0	0	0	0	0	0
	2	0	0	0	0	0	0
Quad-Cities 1,2	1	0	1	1	0	0	2
	1/2	0	1	1	3	1	6
	2	0	1	1	0	2	4
Rancho Seco	A	0	0	1	0	0	1
	B	0	0	1	0	0	1
H. B. Robinson 2	2A	2	3	0	2	1	8
	2B	2	3	0	2	1	8
St. Lucie	1A	Not Available					
	1B	Not Available					
Surry 1,2	1	1	2	0	1	2	6
	2	1	1	0	0	4	6
	3	2	3	0	3	11	19
Trojan	1	4	3	0	1	0	8
	2	4	2	0	1	0	7
Turkey Point 3,4	A	0	0	0	0	0	0
	B	0	0	0	0	0	0
Vermont Yankee	1A	2	1	0	1	0	4
	1B	2	1	1	1	0	5
Yankee (Rowe, Mass.)	1	0	0	0	0	0	0
	2	3	1	4	2	2	12
	3	1	0	0	0	1	2
TOTALS**		161	114	53	80	109	539

* Diesel generator identification assigned by nuclear plant licensee.
** The column subtotals plus the plant totals not reported yearly equal the grand total.
N.O. = not operating

Table 9.5.3. Nonvalid test demands

Plant	DG*	1976	1977	1978	1979	1980	Total
Arkansas	1	1	0	2	1	5	9
Nuclear One 1	2	1	0	5	5	3	14
Beaver Valley	1	3	3	2	2	1	11
	2	2	5	5	0	1	13
Big Rock Point	1	0	1	0	1	0	2
Brunswick 1,2	1	4	12	10	5	4	35
	2	3	8	13	2	4	30
	3	5	10	14	11	5	45
	4	2	7	14	8	3	34
Calvert	11	14	15	14	15	14	72
Cliffs 1,2	12	16	16	16	14	14	76
	21	14	15	13	14	14	70
Cooper	1	1	1	1	4	6	13
	2	1	0	3	0	2	6
Crystal River 3	A	N.O.	Totals Only				12
	B	N.O.	Totals Only				11
Davis-Besse	1	N.O.	5	6	4	5	20
	2	N.O.	5	2	4	8	19
Dresden 2,3	2	0	0	0	0	0	0
	2/3	0	0	0	0	0	0
	3	0	0	0	0	0	0
Jospeh M. Farley 1,2	1B	N.O.	7	17	11	4	39
	1C	N.O.	0	6	2	9	17
	1-2A	N.O.	6	11	8	4	29
	2C	N.O.	0	4	4	2	10
James A. FitzPatrick	A	0	0	0	0	0	0
	C	0	0	0	0	0	0
	B	0	0	0	0	0	0
	D	0	0	0	0	0	0
Fort Calhoun	1	4	0	0	0	0	4
	2	2	0	2	0	0	4
Robert E. Ginna	A	2	1	1	1	0	5
	B	6	0	1	2	1	10
Edwin I. Hatch 1	1A	8	10	7	8	2	35
	B	10	13	15	8	10	56
	1C	9	10	7	7	8	41
Edwin I. Hatch 2	2A	N.O.	N.O.	4	10	5	19
	2C	N.O.	N.O.	4	8	9	21
Indian Point 2	21	2	2	1	2	2	9
	22	0	2	1	0	0	3
	23	2	2	1	0	0	5
Indian Point 3	31	0	0	0	0	0	0
	32	0	0	0	0	0	0
	33	0	0	0	0	0	0
Kewaunee	1A	0	0	0	0	0	0
	1B	0	0	0	0	0	0
La Crosse	1A	Totals Only					31
	1B	Totals Only					14
Maine Yankee	1A	5	3	5	1	0	14
	1B	4	0	2	3	3	12
Millstone 1	DG	1	2	0	2	1	6
Millstone 2	12U	16	16	19	3	9	63
	13U	4	20	3	2	6	35
Nine Mile Point	102	2	0	1	3	1	7
	103	3	0	1	3	1	8

Table 9.5.3. (continued)

Plant	DG*	1976	1977	1978	1979	1980	Total
North Anna 1	1H	X	3	0	0	10	13
	1J	X	2	0	0	0	2
Palisades	1	6	6	9	15	13	49
	2	5	8	6	11	15	45
Peach Bottom 2,3	1	0	0	0	0	0	0
	2	0	0	0	0	0	0
	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
Point Beach 1,2	3D	0	0	0	0	0	0
	4D	0	0	0	0	0	0
Prairie Island 1,2	1	11	4	4	0	3	22
	2	6	3	2	11	4	26
Quad Cities 1,2	1	8	0	0	0	0	8
	1/2	14	6	11	11	0	42
	2	9	0	6	6	0	21
Rancho Seco	A	1	0	0	0	0	1
	B	2	0	0	0	0	2
H. B. Robinson 2	2A	3	13	12	14	4	46
	2B	3	13	11	15	6	48
St. Lucie	1A	Not Available					
	1B	Not Available					
Surry 1,2	1	16	1	10	5	18	50
	2	1	14	20	9	12	56
	3	8	3	8	10	16	45
Trojan	1	19	14	28	10	9	80
	2	14	22	9	10	12	67
Turkey Point 3,4	A	0	0	0	0	0	0
	B	0	0	0	0	0	0
Vermont Yankee	1A	24	5	11	12	4	56
	1B	25	11	9	11	9	65
Yankee (Rowe, Mass.)	1	0	0	0	0	0	0
	2	0	0	0	0	0	0
	3	0	0	0	0	0	0
TOTAL**		322	325	389	328	301	1733

* Diesel generator identification assigned by nuclear plant licensee.
** The column subtotals plus the plant totals not reported yearly equal the grand total.
N.O. = not operating

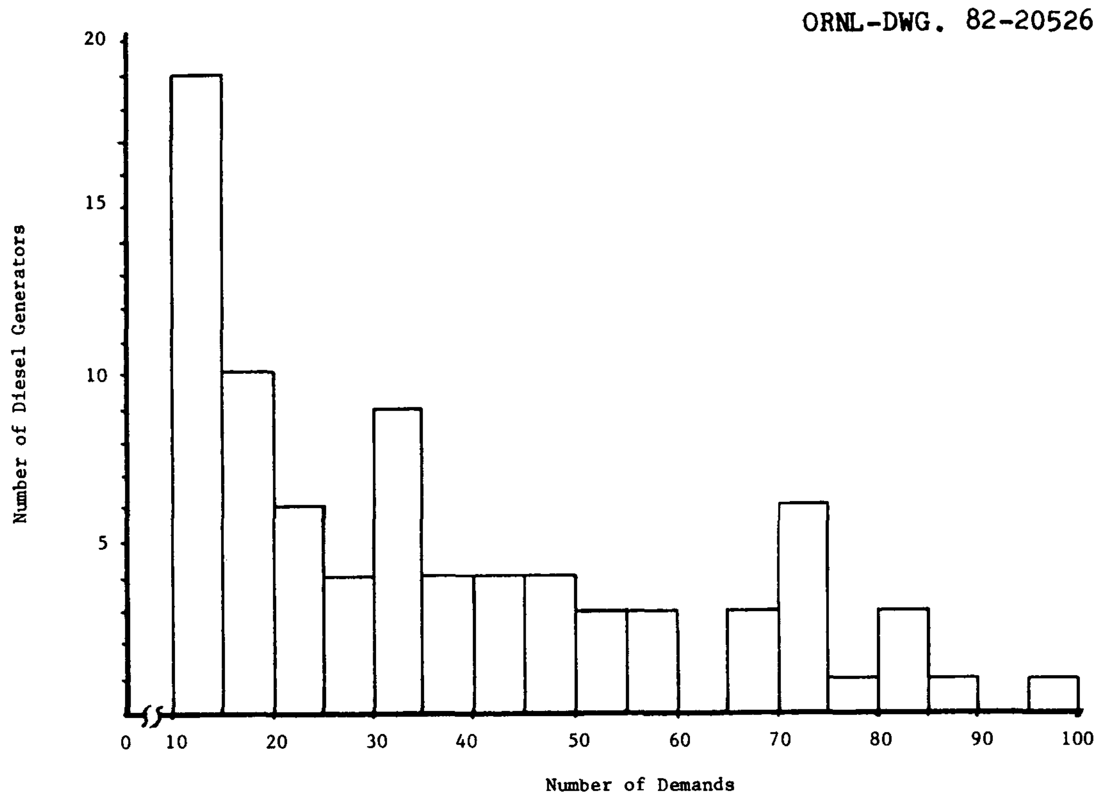

Fig. 9.5.1. Number of diesel generators vs number of demands (1980).

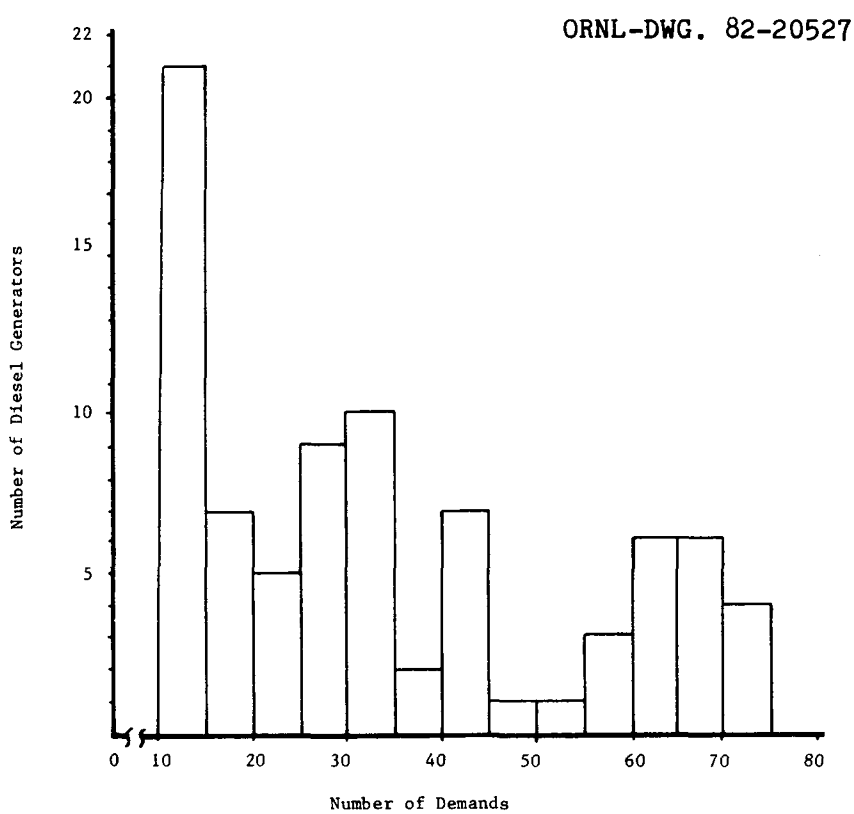

Fig. 9.5.2. Number of diesel generators vs number of demands (1979).

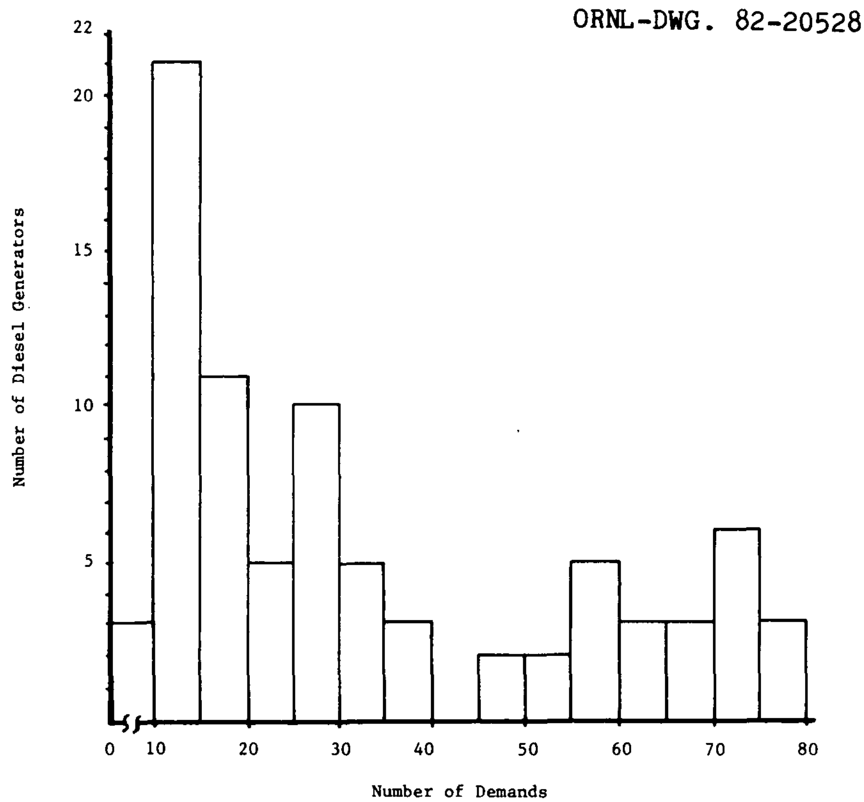

Fig. 9.5.3. Number of diesel generators vs number of demands (1978).

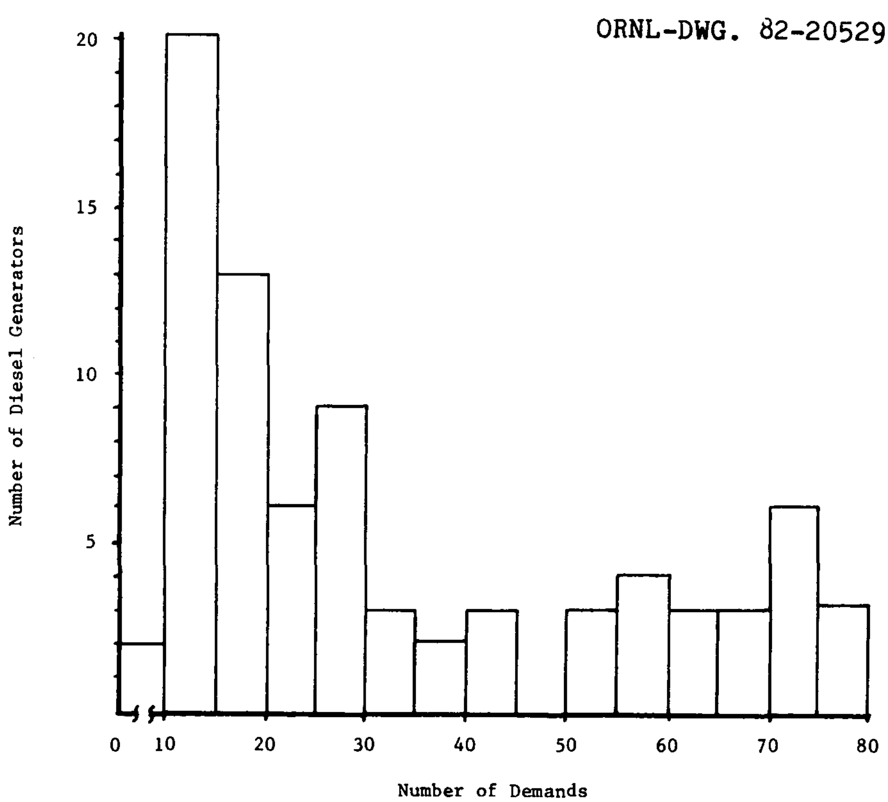

Fig. 9.5.4. Number of diesel generators vs number of demands (1977).

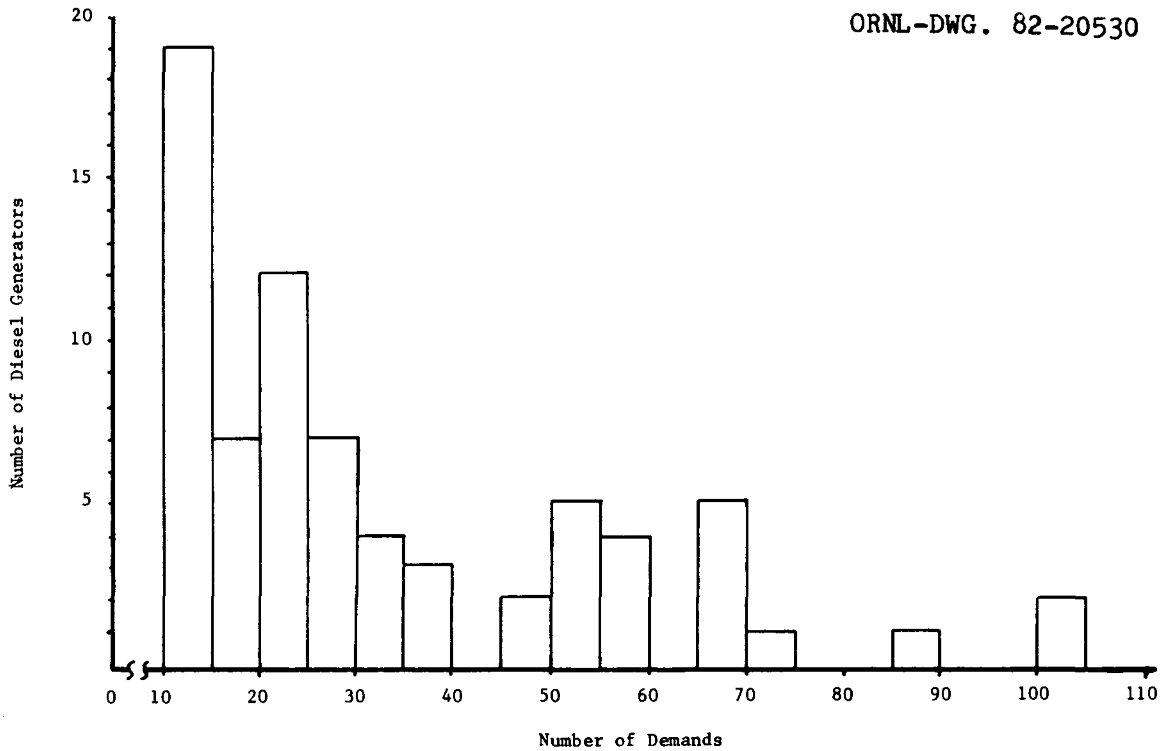

Fig. 9.5.5. Number of diesel generators vs number of demands (1976).

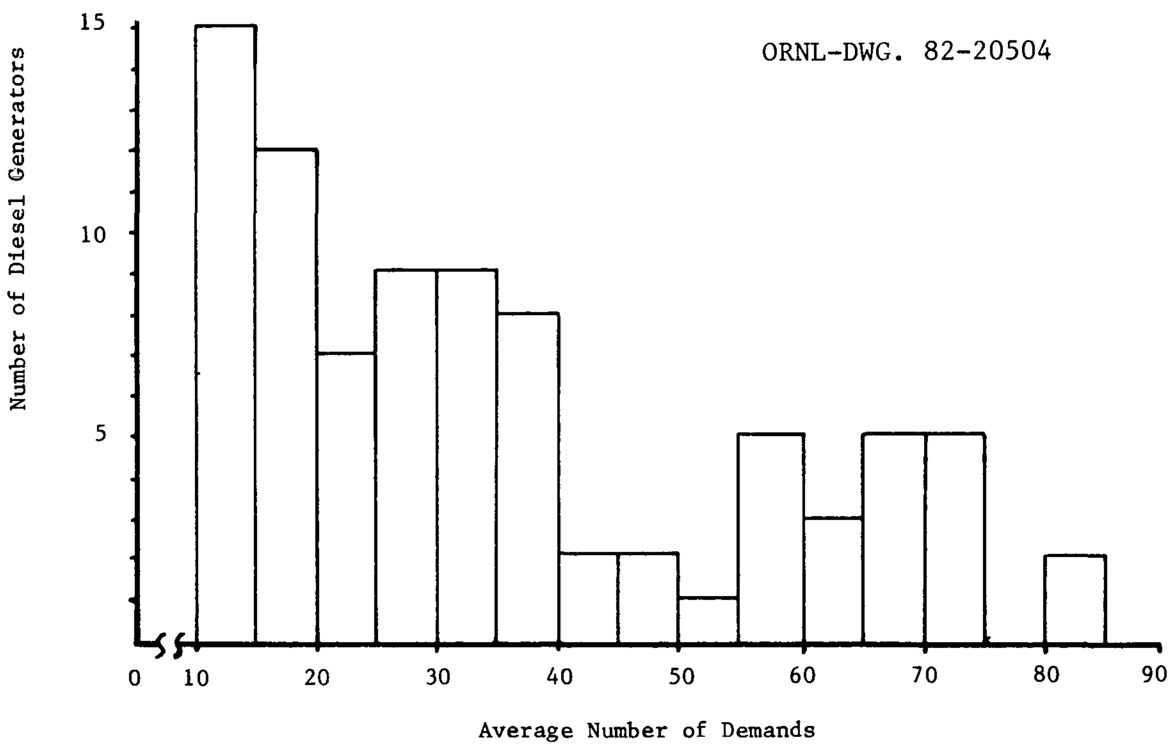

Fig. 9.5.6. Number of diesel generators vs number of failures (1976-1980).

Table 9.5.4. Number of events by event type

Event type	No. of failures	Percentage
Primary failure to start	169	11.1
Primary failure to start, no start attempt	28	1.9
Secondary failure to start	112	7.2
Secondary failure to start, no start attempt	32	2.1
Primary failure to run	50	3.3
Secondary failure to run	27	1.8
Autostart failure	69	4.6
Autostart failure, no start attempt	16	1.1
Nonfailure I	102	6.7
Nonfailure II	917	60.2

A report by Boner and Hanners[2] identified some diesel generator subsystems that needed improvement, and it also contained recommendations on how to improve diesel generator performance.

9.5.2.1. Subsystem Failure Contributions

Table 9.5.5 lists the number of primary, secondary, and autostart failures attributed to each subsystem and the percentage of failures each of these numbers represents. The subsystems that caused at least 8% of the failures are: (1) control and logic, (2) governor, (3) cooling water, (4) output breaker and sequencer, (5) fuel, and (6) air-start. Each of these subsystems is discussed below.

(1) Control and logic. The control and logic subsystems consist of the local and remote control panels, control power, switches and relay logic that start and control the generators, as well as a tachometer system that is used by some plants to open the service water valves or turn off the air-start system after the diesel reaches a set speed.

Table 9.5.6 summarizes the significant causes of control and logic failures. Many of the LERs do not specify the root cause of relay or switch failures, but environmental factors are likely causes for many. The tachometer failures are attributed to electronic circuit failure, setpoint error, loose couplings, water damage, and other factors. Several events were caused by a blown fuse in the control power circuit. The control and logic system reliability would be improved by better protection of switches and relays from environmental damage.

(2) Governor. The Woodward Company makes almost all of the governors used on emergency diesel generators at nuclear power plants. The governors are either hydraulic or electrohydraulic. A hydraulic governor uses the hydraulic pressure of oil to adjust the diesel engine fuel racks to maintain constant speed; it senses the engine speed from a gear-driven shaft on the engine. An electrohydraulic governor uses an electric-driven plunger in the hydraulic system to control the fuel rack position. A backup hydraulic governor with a slightly higher setpoint will take over control if the electric governor fails. Some governors also have pneumatically or electrically controlled booster pumps to help open the fuel racks for engine start.

Table 9.5.7 summarizes the significant contributors to governor failure. Setpoint and contaminated oil failures could be reduced by improving the maintenance procedures. Binding linkage from the governor to the fuel racks was reported as a cause of several failures. The number of failures attributed to this cause probably could be reduced by improved preventive maintenance. As shown in Table 9.5.5, governor failures accounted for 12.4% of the total number of failures. As stated for binding leakage failures, we believe that improved preventive maintenance would increase the reliability of the governor as well. More than 60% of the governor failures are caused by sense and control equipment failures, setpoint errors, and contaminated governor oil.

Table 9.5.5. Number of demand and time-related primary, secondary, and autostart failures by subsystem

Subsystem	No. of failures	Percentage
Air start	46	9.1
Battery	2	0.4
Blower	2	0.4
Cooling water	60	11.9
Control and logic	74	14.7
Distribution system	3	0.6
Engine	27	5.4
Electric start	2	0.4
Exciter	19	3.8
Exhaust	4	0.8
Fuel	45	9.0
Generator	5	1.0
Governor	62	12.3
Human	7	1.4
Lube oil	21	4.2
Output breaker and sequencer	52	10.3
Turbo charger	14	2.8
Ventilation	9	1.8
Voltage regulator	14	2.8
Unknown	35	6.9

Table 9.5.6. Control and logic subsystem failure contributions

Component/event type	Percentage contribution
Switches, relays, and wiring	33
Tachometer	21
Control power	12
Miscellaneous	34

Table 9.5.7. Governor subsystem failure contributions

Component type	Percentage contribution
Sense and control	23
Setpoint error	20
Contaminated oil	19
Miscellaneous	38

(3) Cooling water. The cooling system for a diesel engine consists of a water jacket and pump, a heat exchanger or radiator, service water or forced air for heat removal, and a standby jacket-water heating system. The jacket water is usually pumped during operation by an engine-driven pump; during engine shutdown, it is heated by an immersion heater and circulated by an electrically driven pump or by thermosyphon. Service water is not circulated through the heat exchanger when the engine is shut down. Upon engine start, a signal is sent to a valve that opens and allows service water to flow through the heat exchanger. Air-cooled engines have an engine- or electrically driven fan that forces air through the radiator.

Table 9.5.8 summarizes the significant contributors to cooling system failure. Valve failures account for 25% of the cooling system failures. Some valves fail to open, and some fail to control the flow of service water. In some instances, operators leave block valves closed.

Debris, such as mud in the strainer or mussel buildup throughout the service water system, caused 22% of the cooling system failures. Air-cooled engines have experienced similar failures when the fan forced debris through the radiator and damaged it. Some radiators have failed because corrosion caused blockage of the jacket-water flow.

There are many pump failure causes: loose couplings, loss of suction (air-bound), bearing failure, incorrect trip setpoint, and loss of ac power to the pump motor. Leaks in the cooling system caused some failures and about 22% of the nonfailures. Some leaks, such as from a ruptured hose, have caused diesel generator failure, but most were small enough that they could be controlled and the repair scheduled for a convenient time.

Improved valve performance and elimination of debris from the cooling water would improve diesel generator reliability. Valve corrosion would be reduced by using stainless steel valves. Improved procedures to ensure proper positioning of block valves could reduce human failures.

(4) Output breaker and sequencer. The generator output breaker voltage is usually 4160 V. The breaker has one trip and one closing coil, can be operated manually from local or remote consoles, will automatically close onto the emergency bus when bus voltage has been lost and the diesel generator voltage and frequency are present, and is interlocked with the other bus feeder breakers. DC control power is needed by a motor to cock a spring for closing and opening the main breaker contacts and to power breaker auxiliary relays. The sequencer consists of electromechanical or solid state timer relays that operate the emergency bus load breakers. Table 9.5.9 contains a summary of the significant contributors to output breaker and load sequencer failures.

Of the breaker failues, 53% were autostart failures such as loss of local or remote manual control or failure of the breaker to close

Table 9.5.8. Cooling water subsystem failure contributions

Component/event type	Percentage contribution
Valves	25
Debris	22
Pumps	17
Pipe and heat exchanger leaks	14
Miscellaneous	22

Table 9.5.9. Output breaker and sequencer subsystem failure contributions

Component/event type	Percentage contribution
Breaker auxiliary relays	25
Autoclose failure	25
Breaker failure to close	22
Manual control failure	11
Sequencer	11
Miscellaneous	6

automatically. These failures required human intervention to have the generator functioning properly in a few minutes. Similarly to the control and logic subsystems, many of the breaker and sequencer failures were the result of relay and switch failures.

It appears that breaker and sequencer reliability may be improved by protecting the auxiliary relays and switches from dust and moisture. Mechanical timer setpoint drift caused the load to be picked up out of the specified time, but there are no data that indicate that this caused a diesel trip. Occasionally the sequencer fails to connect a load, but this would be categorized as an autostart failure for which the operator could close the load breaker manually. Most sequencer failures were classified as autostart failures.

(5) Fuel. Fuel storage and supply system designs vary. Some systems have completely independent fuel subsystems for each diesel; others have a single large bulk storage tank that supplies smaller storage tanks. Fuel is transferred by redundant ac and dc pumps or by gravity feed. Fuel is fed to the injectors from a day tank by an engine- or electrically-driven pump (usually only one pump) or by gravity feed. The injectors, which are timed by cams driven by the engine, meter the fuel to each cylinder and are positioned to control fuel flow by racks controlled by the governor. The injectors are machined to close tolerances because they have to inject fuel into the cylinders under very high pressure. Table 9.5.10 summarizes the significant contributors to fuel system failures.

Pipe leaks and breaks were responsible for 25% of the fuel system failures. Only two fires were reported as the result of fuel system leaks, but if a fuel leak is found during testing, the diesel generator is usually shut down immediately to repair the leak as a precaution against fire hazards. For large leaks, the diesel engine would have to be tripped to prevent a fire. However, some of the leaks are small enough that the diesel engine could be left running and the fuel spill controlled.

Table 9.5.10. Fuel subsystem failure contributions

Component/event type	Percentage contribution
Pipe leaks and breaks	25
Injectors	25
Linkage	19
Miscellaneous	31

Some plants have replaced synthetic hoses in the fuel system with metal pipes because synthetic hoses deteriorate and leak.

Injectors contributed as many failures as leaking pipes. Injector failures are typically caused by leaking, sticking, or vibrating till loose. For these types of failures, if there is not a fire hazard it may be possible to load the diesel to less than full capacity and continue operation. Binding linkages from the governor to the fuel racks contributed 19% of the fuel system failures.

The most economical fuel subsystem improvements may be attained by ensuring that the fuel system linkages are properly lubricated and that synthetic hoses in the fuel subsystem are replaced with metal pipes.

(6) Air-start. The start system for most diesel engines at nuclear power plants is pneumatic, but a few of the smaller engines have electric starters. Since the data on electric start systems are sparse, they were not reviewed.

A pneumatic starting system usually consists of two trains of air compressors, receiver tanks, pipes, and valves. The air drives the air starting motors or the engine's pistons by direct air injection into two banks of cylinders. For most designs, either train can start an engine independently. At several plants the air-start systems of redundant diesel generators are connected through normally closed block valves. At least one CCF has occurred because of such a connection. Some plants have installed chillers or refrigerators to remove moisture from the compressed air, but many use manual blowdown.

Table 9.5.11 lists the significant contributors to air-start system failures, with valve and pipe failures caused by corrosion being the most significant.

In summary, the most significant improvements in diesel generator reliability can be realized by improving the reliability of relays and switches. Control logic and output breaker switches and relays caused 7% of the diesel generator failures; protection of these switches and relays from the environment will improve their reliability. Governor

Table 9.5.11. Air-start subsystem failure contributions

Component type	Percentage contribution
Valves and piping	60
Air motors	16
Miscellaneous	24

setpoint error and contaminated oil caused 5% of the failures; improved maintenance procedures would increase the reliability of the governor. Air system valve and piping failures caused 5% of the failures; removal of moisture from compressed air will increase the reliability of the generator air-start system. If all failures caused by these three sets of components were eliminated, the industry-wide total number of diesel generator failures would be reduced only 17% (a factor of 1.2 reduction in the probability of failure on demand), and it would not be possible to eliminate all of these failures. However, plants that have a particular problem with these or other subsystems may be able to significantly reduce the probability of diesel generator failure by improving one or more subsystems.

Individual diesel generator subsystems that failed twice or more in the five years covered by this study (1976-1980) are summarized in Table 9.5.12. The average number of failures is 2.6 and the maximum is 7. Only four diesels have had a single subsystem fail five times or more. However, it cannot be concluded from these data that there is a diesel generator that has an excessive failure probability because of problems with one of its subsystems. On the contrary, the data show that most diesels do not have many failures caused by a single subsystem.

9.5.2.2 Diesel Generator Reliability Parameters

(1) Failure to start. Tables 9.5.13 and 9.5.14 summarize the available data that are pertinent to estimating the probability that diesel generators at each plant will fail to start. The failure data for all primary and secondary failures are in Table 9.5.13 and for auto start failures in Table 9.5.14. The appropriate plant-specific data were used in the fault tree models. Figures 9.5.7 through 9.5.12 are histograms of the number of diesel generators vs the number of primary, secondary, and autostart failures for each year from 1976 through 1980 and for the entire 5-y period. The failure distribution changes very little from year to year.

(2) Failure to run. Table 9.5.15 summarizes all attempts to run diesel generators for 6 h or longer, that is, for each scheduled run time, the number of attempts, the number of failures, and the actual run time for each failure. The operating failure rate estimated from these data is 2.4×10^{-3} failure/h.

(3) Repair times. Mean repair times for repairs following primary and secondary failures provide input to the quantitative reliability analysis (Table 9.5.16). The median plant-specific mean repair time is 17 h. The 90% tolerance interval limits are 2.6 and 92 h.

Repair times taken from test data probably overestimate the mean repair times for the diesel generators during a loss of offsite power. During normal operation, diesel generator failures compete with other plant equipment failures for repair crews. During a loss of offsite power, diesel generators are so critical that they would receive top

Table 9.5.12. Recurring diesel generator failures

Plant	Diesel generator	Subsystem	No. of failures
Duane Arnold	31	Governor	2
Beaver Valley	1	Breaker	6
	2	Breaker	4
	1	Exciter	2
	2	Exciter	2
Big Rock Point	DG	Breaker	4
	DG	Cooling	4
	DG	Electric start	2
Browns Ferry 1, 2, 3	D	Governor	2
Brunswick 1, 2	2	Air start	2
	3	Control	2
	1	Exciter	2
	1	Fuel oil	3
	2	Fuel oil	2
	2	Governor	3
Calvert Cliffs 1 and 2	11	Control	2
	11	Cooling	2
	12	Cooling	3
	12	Governor	2
	11	Logic	3
	21	Logic	3
	12	Ventilation	4
Connecticut Yankee	2B	Governor	2
Donald C. Cook 1	1CD	Control	2
Cooper	2	Engine	2
	1	Fuel oil	2
Crystal River 3	B	Control	2
	B	Governor	2
	B	Turbocharger	2
Davis-Besse	1-1	Governor	2
	1-1	Turbocharger	2
Dresden 2, 3	2	Air start	3
	2/3	Air start	6
	U3	Control	2

Table 9.5.12. (continued)

Plant	Diesel generator	Subsystem	No. of failures
	2/3	Control	3
	U3	Cooling	2
	2/3	Cooling	4
	2	Fuel oil	2
	2	Governor	4
Joseph M. Farley 1, 2	1B	Air start	3
	1-2A	Air start	2
	1B	Breaker	2
	2C	Breaker	2
	1B	Sequencer	2
	1-2A	Sequencer	2
James A. FitzPatrick	A	Control	2
	A	Lube oil	2
Fort Calhoun	2	Air start	2
	1	Exciter	3
Robert E. Ginna	1B	Breaker	5
Edwin I. Hatch 1, 2	1B	Cooling	3
	2C	Engine	2
	1C	Governor	3
Indian Point 2, 3	31	Governor	2
Kewaunee	1B	Air start	2
	1A	Logic	2
La Crosse	1B	Governor	2
Millstone 2	12U	Cooling	7
	13U	Cooling	2
	13U	Engine	4
	12U	Fuel oil	2
	13U	Fuel oil	3
	12U	Governor	2
Pilgrim	A	Fuel oil	2
Prairie Island 1, 2	D2	Engine	2
	D1	Governor	2
Quad-Cities 1, 2	1/2	Control	2

Table 9.5.12. (continued)

Plant	Diesel generator	Subsystem	No. of failures
St. Lucie	1A	Air start	2
	1A	Cooling	2
	1A	Fuel oil	3
	1B	Logic	2
Salem 1	1A	Cooling	2
	1B	Cooling	2
	1C	Cooling	2
San Onofre 1	1	Fuel oil	2
	2	Sequencer	2
Surry 1, 2	1	Engine	4
Turkey Point 3, 4		Fuel oil	2
Vermont Yankee	B	Engine	3
Zion 1, 2	1B	Air start	2
	1B	Control	2
	2A	Control	3
	2B	Governor	3
	1A	Lube oil	3
	2A	Regulator	3

Table 9.5.13. Failure to start data

Plant	Number of DGs	Total time (h)	Number of trials	Number of failures	Number of failures during trials	Standby failure rate (h^{-1})	Probability of failure on demand
Arkansas Nuclear One 1	2	87,696	179	7	6	7.98×10^{-5}	3.35×10^{-2}
Duane Arnold	2	87,696	*	11	10	1.25×10^{-4}	
Beaver Valley	2	81,456	374	9	9	9.82×10^{-5}	2.41×10^{-2}
Big Rock Point	1	43,848	350	13	12	2.96×10^{-4}	3.43×10^{-2}
Browns Ferry 1,2	4	175,392	*	4	3	2.28×10^{-5}	
Browns Ferry 3	4	154,272	*	7	6	4.53×10^{-5}	
Brunswick	4	175,392	240	18	15	1.03×10^{-4}	6.25×10^{-2}
Calvert Cliffs 1,2	3	123,528	1,015	21	19	1.70×10^{-4}	1.87×10^{-2}
Connecticut Yankee	2	87,696	*	7	4	7.98×10^{-5}	
Donald C. Cook 1	2	87,696	*	4	3	4.56×10^{-5}	
Donald C. Cook 2	2	49,344	*	9	6	1.82×10^{-4}	
Cooper	2	87,696	347	9	8	1.03×10^{-4}	2.31×10^{-2}
Crystal River 3	2	69,504	220	11	10	1.58×10^{-4}	4.55×10^{-2}
Davis Besse	2	58,032	270	12	10	2.07×10^{-4}	3.70×10^{-2}
Dresden 2,3	3	131,544	488	29	25	2.20×10^{-4}	5.12×10^{-2}
Joseph M. Farley 1,2	4	119,136	913	14	12	1.18×10^{-4}	1.31×10^{-2}
James A. FitzPatrick	4	175,392	415	11	11	6.27×10^{-5}	2.65×10^{-2}
Fort Calhoun	2	87,696	166	9	9	1.03×10^{-4}	5.42×10^{-2}
Robert E. Ginna	2	87,696	143	3	3	3.42×10^{-5}	2.10×10^{-2}
Edwin I. Hatch	5	184,008	1,096	21	21	1.14×10^{-4}	1.92×10^{-2}
Indian Point 2	3	131,544	201	3	1	2.28×10^{-5}	4.98×10^{-3}
Indian Point 3	3	124,632	300	3	3	2.41×10^{-5}	1.00×10^{-2}
Kewaunee	2	87,696	315	10	9	1.14×10^{-4}	2.86×10^{-2}
La Crosse	2	87,696	235	1	1	1.14×10^{-5}	4.26×10^{-3}
Maine Yankee	2	87,696	164	4	4	4.56×10^{-5}	2.44×10^{-2}
Millstone 1	1	43,848	287	1	1	2.28×10^{-5}	3.48×10^{-3}
Millstone 2	2	87,696	849	24	17	2.74×10^{-4}	2.00×10^{-2}
Monticello	2	87,696	*	0	0		
Nine Mile Point	2	87,696	132	3	1	3.42×10^{-5}	7.58×10^{-3}
North Anna 1	2	48,096	191	2	2	4.16×10^{-5}	1.05×10^{-2}
Oyster Creek	2	87,696	*	8	8	9.12×10^{-5}	
Palisades	2	87,696	133	3	2	3.42×10^{-5}	1.50×10^{-2}

Table 9.5.13. (continued)

Plant	Number of DGs	Total time (hours)	Number of trials	Number of dailures	Number of failures during trials	Standby failure rate (hr^{-1})	Probability of failure on demand
Peach Bottom 2,3	4	175,392	1,402	8	6	4.56×10^{-5}	4.28×10^{-3}
Pilgrim	2	87,696	*	7	6	7.98×10^{-5}	
Point Beach 1	2	87,696	371	4	4	4.56×10^{-5}	1.08×10^{-2}
Prairie Island 1,2	2	87,696	440	8	8	9.12×10^{-5}	1.82×10^{-2}
Quad-Cities 1,2	3	131,544	434	7	7	5.32×10^{-5}	1.61×10^{-2}
Rancho Seco	2	87,696	211	6	6	6.84×10^{-5}	2.84×10^{-2}
H. B. Robinson 2	2	87,696	377	3	3	3.42×10^{-5}	7.96×10^{-3}
St. Lucie	2	82,320*	*	14	12	1.70×10^{-4}	
Salem 1	3	106,704	*	9	7	8.43×10^{-5}	
San Onofre	2	87,696	*	5	4	5.70×10^{-5}	
Surry 1,2	3	131,544	292	6	3	4.56×10^{-5}	1.03×10^{-2}
Trojan	2	87,696	333	2	1	2.28×10^{-5}	3.00×10^{-3}
Turkey Point 3,4	2	87,696	290	8	5	9.12×10^{-5}	1.72×10^{-2}
Vermont Yankee	2	87,696	143	4	4	4.56×10^{-5}	2.80×10^{-2}
Yankee (Rowe, Mass.)	3	131,544	888	3	3	2.28×10^{-5}	3.38×10^{-3}
Zion 1,2	5	219,240	*	25	23	1.14×10^{-4}	

*Data not available.

Table 9.5.14. Autostart failure data

Plant	Number of DGs	Total time (h)	Number of trials	Number of autostart failures	Number of autostart failures during trials	Standby failure rate (h^{-1})	Probability of failure on demand
Arkansas Nuclear One 1	2	87,696	179	0	0		
Duane Arnold	2	87,696	*	0	0		
Beaver Valley	2	81,456	374	8	8	9.82×10^{-5}	2.14×10^{-2}
Big Rock Point	1	43,848	350	2	2	4.56×10^{-5}	5.71×10^{-3}
Browns Ferry 1,2	4	175,392	*	1	1	5.70×10^{-6}	
Browns Ferry 3	4	154,272	*	0	0		
Brunswick 1,2	4	175,392	240	1	0	5.70×10^{-6}	
Calvert Cliffs 1,2	3	123,528	1,015	8	7	6.48×10^{-5}	6.90×10^{-3}
Connecticut Yankee	2	87,696	*	1	0	1.14×10^{-5}	
Donald C. Cook 1	2	87,696	*	1	1	1.14×10^{-5}	
Donald C. Cook 2	2	49,344	*	2	0	4.05×10^{-5}	
Cooper	2	87,696	347	0	0		
Crystal River 3	2	69,504	220	2	2	2.88×10^{-5}	9.09×10^{-3}
Davis-Besse	2	58,032	270	3	3	5.17×10^{-5}	1.11×10^{-2}
Dresden 2,3	3	131,544	488	6	5	4.56×10^{-5}	1.02×10^{-2}
Jospeh M. Farley 1,2	4	119,136	913	10	6	8.39×10^{-5}	6.57×10^{-3}
James A. FitzPatrick	4	175,392	415	0	0		
Fort Calhoun	2	87,696	166	2	2	2.28×10^{-5}	1.20×10^{-2}
Robert E. Ginna	2	87,696	143	3	2	3.42×10^{-5}	1.40×10^{-2}
Edwin I. Hatch	5	184,008	1,096	8	7	4.35×10^{-5}	6.39×10^{-3}
Indian Point 2	3	131,544	204	1	1	7.60×10^{-6}	4.90×10^{-3}
Indian Point 3	3	124,632	300	1	1	8.02×10^{-6}	3.33×10^{-3}
Kewaunee	2	87,696	315	3	3	3.42×10^{-5}	9.52×10^{-3}
La Crosse	2	87,696	235	2	2	2.28×10^{-5}	8.51×10^{-3}
Maine Yankee	2	87,696	164	1	1	1.14×10^{-5}	6.10×10^{-3}
Millstone 1	1	43,848	287	0	0		
Millstone 2	2	87,696	849	2	0	2.28×10^{-5}	
Monticello	2	87,696	*	0	0		
Nine Mile Point	2	87,696	132	1	1	1.14×10^{-5}	7.58×10^{-3}
North Anna 1	2	48,096	191	2	2	4.16×10^{-5}	1.05×10^{-2}
Oyster Creek	2	87,696	*	0	0		
Palisades	2	87,696	133	0	0		

Table 9.5.14. (continued)

Plant	Number of DGs	Total time (h)	Number of trials	Number of autostart failures	Number of autostart failures during trials	Standby failure rate (h^{-1})	Probability of failure on demand
Peach Bottom 2,3	4	175,392	1,402	2	2	1.14×10^{-5}	1.43×10^{-3}
Pilgrim	2	87,696	*	0	0		
Point Beach 1	2	87,696	371	0	0		
Prairie Island 1,2	2	87,696	440	0	0		
Quad Cities 1,2	3	131,544	434	1	1	7.60×10^{-6}	2.30×10^{-3}
Rancho Seco	2	87,696	211	3	3	3.42×10^{-5}	1.42×10^{-2}
H. B. Robinson 2	2	87,696	377	0	0		
St. Lucie	2	82,320	*	4	3	4.86×10^{-5}	
Salem 1	3	106,704	*	0	0		
San Onofre	2	87,696	*	0	0		
Surry, 1,2	3	131,544	292	0	0		
Trojan	2	87,696	333	3	2	3.42×10^{-5}	6.01×10^{-3}
Turkey Point 3,4	2	87,696	290	0	0		
Vermont Yankee	2	87,696	143	1	1	1.14×10^{-5}	6.99×10^{-3}
Yankee (Rowe, Mass.)	3	131,544	888	0	0		
Zion 1,2	5	219,240	*	1	1	4.56×10^{-6}	

*Data not available.

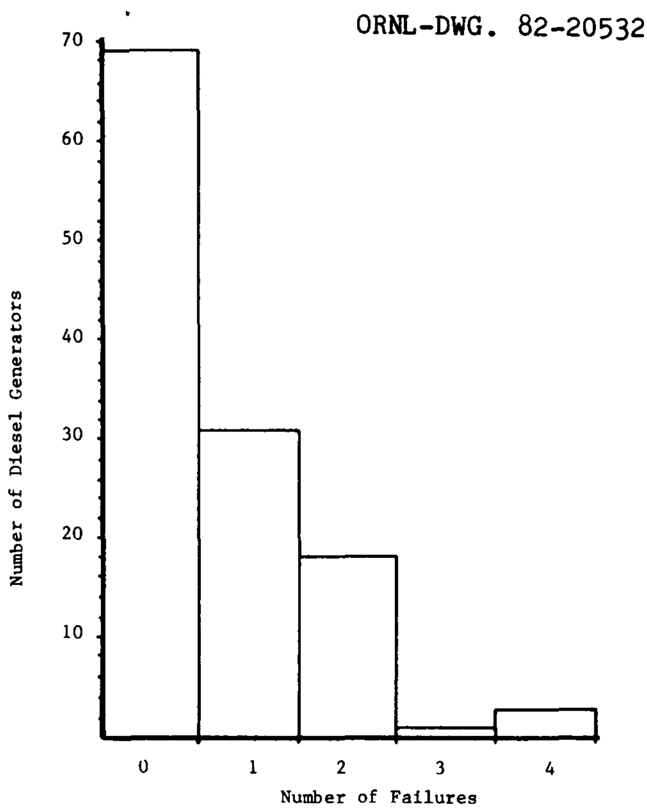

Fig. 9.5.7. Number of diesel generators vs number of failures (1980).

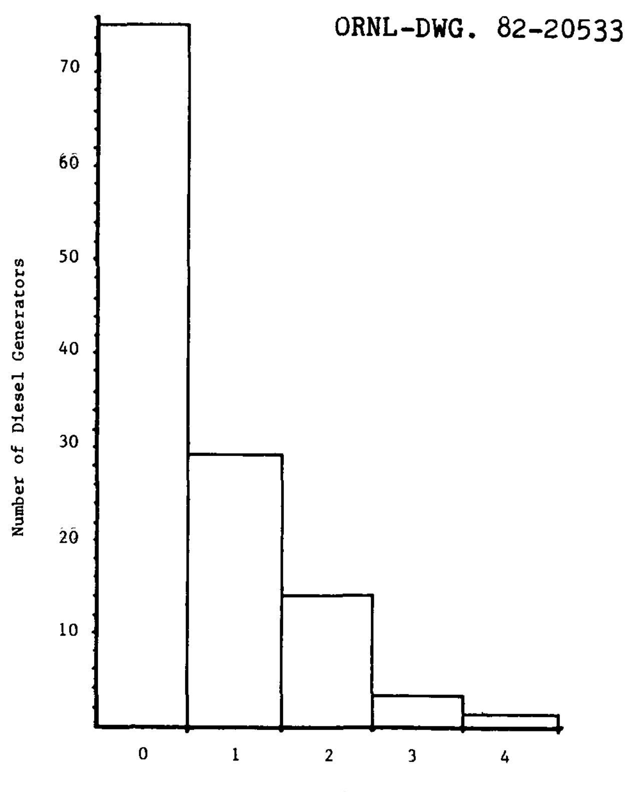

Fig. 9.5.8. Number of diesel generators vs number of failures (1979).

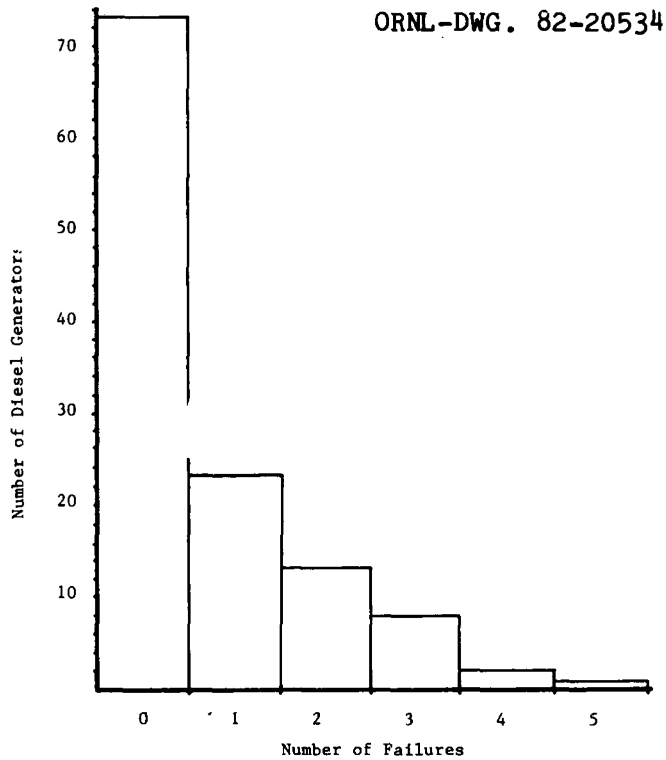

Fig. 9.5.9. Number of diesel generators vs number of failures (1978).

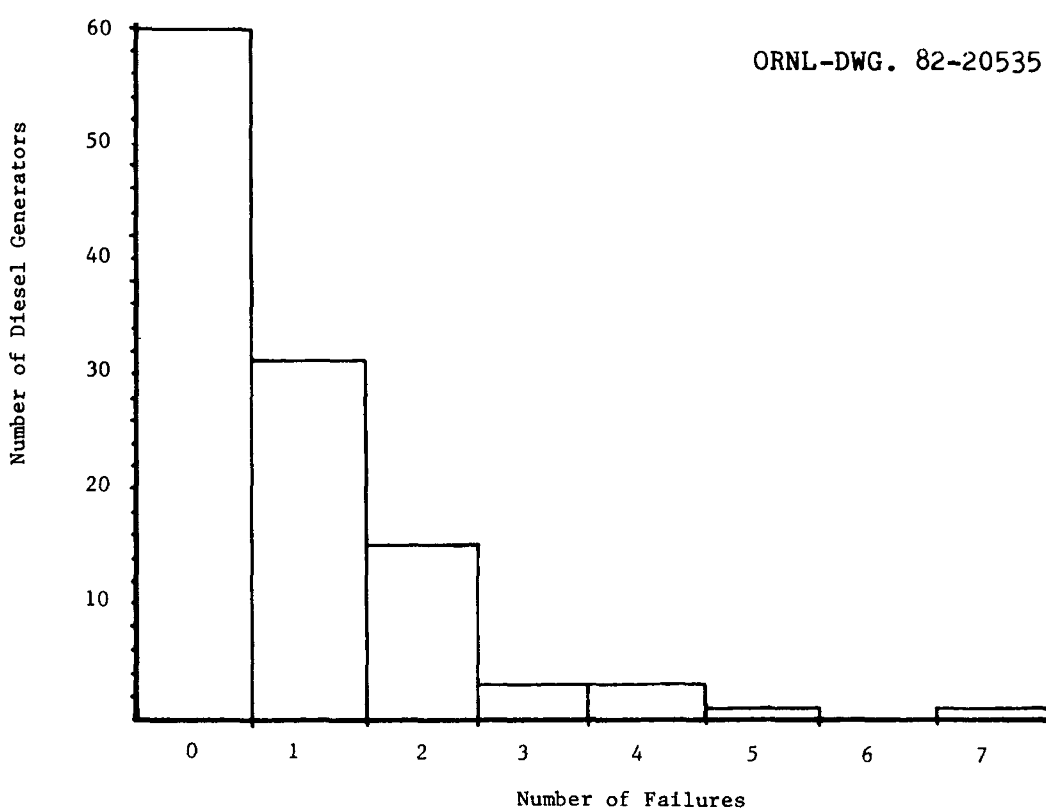

Fig. 9.5.10. Number of diesel generators vs number of failures (1977).

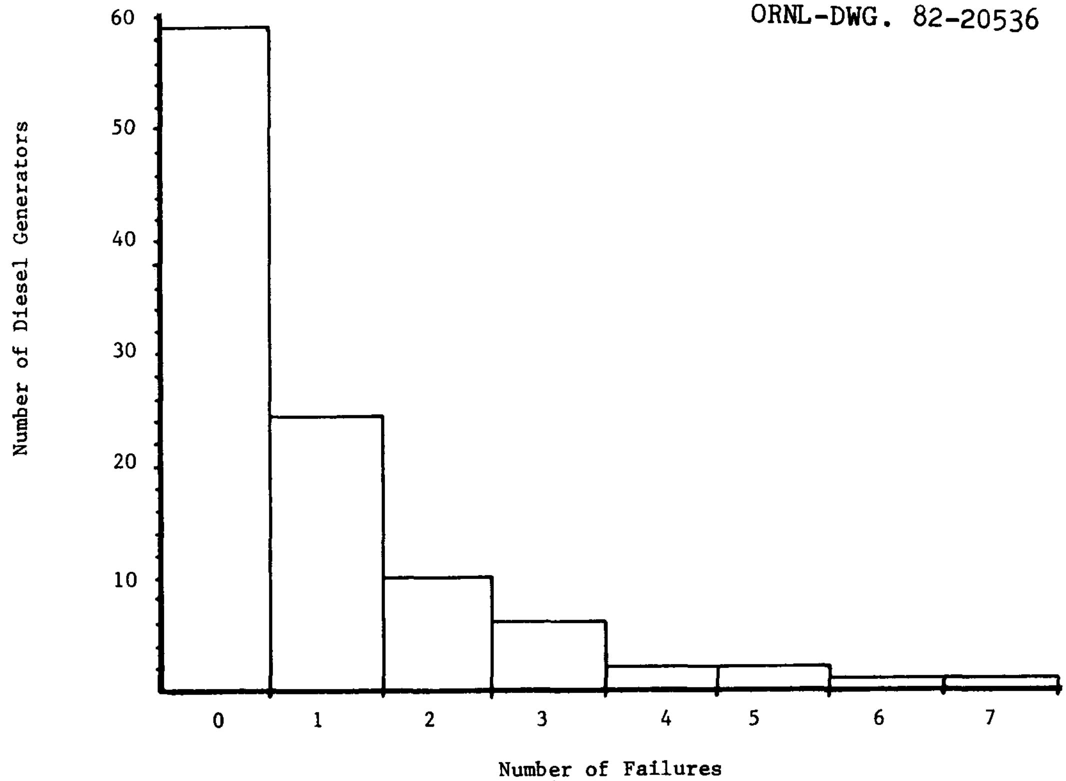

Fig. 9.5.11. Number of diesel generators vs number of failures (1976).

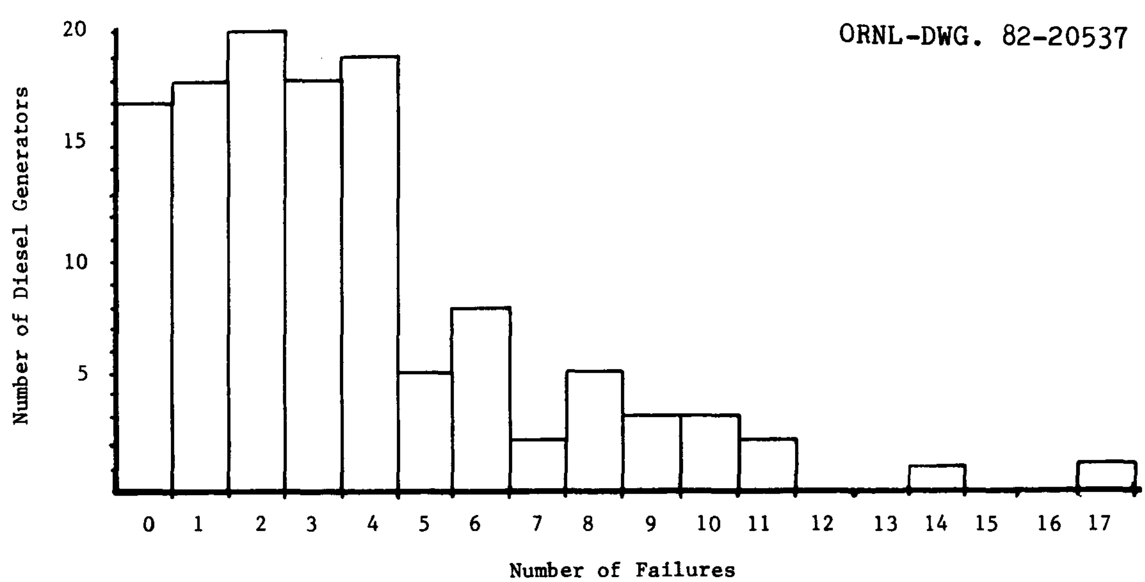

Fig. 9.5.12. Number of diesel generators vs number of failures (1976-1980).

Table 9.5.15. Failure to run data

Scheduled run time	No. of attempts	No. of failures	Actual run time for failure (h:min)
6	120	1	Unknown
8	119	2	7:44; 13:00
11	4	0	
12	11	0	
16	2	0	
19	2	0	
24	52	6	3:00; 4:50; 10:00; 16:35; 22:35: unknown
32	1	0	
268	1	0	
284	2	0	

Table 9.5.16. Diesel generator repair times

Plant	Mean-time-to-repair (h)
Nuclear One 1	20.8
Duane Arnold	47.2
Beaver Valley	11.1
Big Rock Point	7.9
Browns Ferry 1, 2	6.7
Browns Ferry 3	24.1
Brunswick	10.3
Calvert Cliffs 1, 2	15.2
Connecticut Yankee	7.1
Donald C. Cook 1	Unknown
Donald C. Cook 2	14.4
Cooper	89.1
Crystal River 3	16.9
Davis-Besse	41.6
Dresden 2, 3	6.4
Joseph M. Farley 1, 2	6.3
James A. FitzPatrick	60.7
Fort Calhoun	4.0
Robert E. Ginna	4.6
Edwin I. Hatch 1, 2	91.7
Indian Point 3	26.0
Kewaunee	19.2
LaCrosse	12.0
Maine Yankee	30.3
Millstone 1	8.4
Millstone 2	43.3
Monticello	Unknown
Nine Mile Point	33.1
North Anna 1	36.0
Oyster Creek	33.2
Palisades	16.5
Peach Bottom 2, 3	20.7
Pilgrim	146.3
Point Beach 1	10.0
Prairie Island 1, 2	4.7
Quad Cities 1, 2	52.3
Rancho Seco	33.0
Robinson 2	6.6
St. Lucie	13.6
Salem 1	Unknown
San Onofre	4.7
Surry 1, 2	69.7
Trojan	2.5
Turkey Point 3, 4	36.0
Vermont Yankee	2.6
Yankee (Rowe, Mass.)	145.3
Zion 1, 2	2.0

priority for repair. Repair crews probably could work faster during an emergency than during daily routine. In addition, some of the reported failures probably occur during cold shutdown when there is little urgency to repair a failed diesel generator.

From the station blackout questionnaire responses, the repair time was classified as troubleshooting, parts delivery, and repair/ replacement. For almost all events, little time was reported for parts delivery. Apparently, most plants had enough spare parts in inventory that parts delivery did not delay maintenance.

Diesel generator repair times used in the reliability analysis had little effect on the station blackout frequency results. Almost all losses of offsite power were sufficiently short that power was restored before a failed diesel generator could be repaired.

A histogram showing the percentage of primary and secondary failures repaired as a function of time is shown in Fig. 9.5.13. The data used to construct this histogram comprise the available repair times from all plants. For 416 primary and secondary failures, 312 repair times were known. The mean of these repair times is 36 h, and the sample standard deviation is 135 h.

(4) Test and Maintenance Unavailability. Table 9.5.17 lists the total number of hours of scheduled downtime for each diesel generator at each plant, taken from licensee responses to the station blackout questionnaire. Table 9.5.18 shows the diesel generator unavailabilities for scheduled maintenance, that is, the fraction of the total time the diesel generators were out of service for maintenance. Appropriate maintenance unavailabilities for the reliability analysis were obtained by dividing the unavailabilities during reactor operation in Table 9.5.18 by the fraction of time the reactor operated. The analysis assumed a plant availability factor of 0.7.

Information obtained during plant visits indicated that testing made little or no contribution to diesel generator unavailability. Therefore, the total T&M unavailability is the maintenance unavailability.

Figures 9.5.14 through 9.5.18 are histograms of the number of diesel generators vs their T&M unavailability for each year from 1976 through 1980. Figure 9.5.19 is a histogram of number of diesel generators vs their average T&M unavailability over the 5-y period. Figure 9.5.20 is a histogram of the number of diesel generators vs their average unavailability during reactor operating or during shutdown over the 5-y period.

Tables 9.5.17 and 9.5.18 show substantial variations in scheduled maintenance time from plant to plant during reactor operation. These T&M unavailabilities make significant contributions to onsite power system failure probabilities in some cases. These are contributions that can be avoided by scheduling diesel generator maintenance for times when the reactor is shut down.

Table 9.5.17. Hours of diesel generator downtime for scheduled maintenance

Plant	DG	Reactor operating 1976	1977	1978	1979	1980	Sub-total	Reactor shutdown 1976	1977	1978	1979	1980	Sub-total	Total downtime
Arkansas Nuclear	1	4	0	0	0	0	4	120	120	120	120	120	600	604
One #1	2	0	0	0	0	0	0	120	120	120	120	120	600	600
Beaver Valley 1	1	0	8	0	0	0	8	96	82	150	98	119	545	553
	2	0	0	38	0	0	38	102	132	101	65	133	533	571
Big Rock Point	1	86	28	42	5	0	161	38	102	8	240	46	434	595
Brunswick 1,2	1	0	128	45	46	115	334	17	1	0	1	0	19	353
	2	0	103	2	22	108	235	0	8	0	0	0	8	243
	3	0	83	87	39	82	291	0	3	0	0	8	11	302
	4	29	122	95	133	99	478	117	1	0	0	25	143	621
Calvert Cliffs	11	135	186	156	154	144	775	12	13	32	27	32	116	891
1 and 2	12	159	172	137	177	172	817	16	42	28	13	22	121	938
	21	0	87	129	138	202	556	0	0	12	34	37	83	639
Cooper	1	1	37	98	201	72	409	119	0	0	0	0	119	518
	2	0	78	196	43	110	427	0	0	0	0	0	0	427
Crystal River 3	A	N.O.	0	0	0	19	19	N.O.	0	64	136	1139	1339	1358
	B	N.O.	0	22	3	8	33	N.O.	0	3	234	131	368	401
Davis-Besse	1	N.O.	2	58	45	34	139	N.O.	60	27	80	464	631	770
	2	N.O.	9	11	89	19	128	N.O.	69	72	38	85	264	392
Dresden 2,3	2	310	264	300	330	210	1414	336	0	0	0	0	336	1750
	2/3	310	312	340	380	270	1612	0	0	0	336	0	336	1948
	3	310	270	312	320	215	1427	336	0	0	0	0	336	1763
Joseph M. Farley 1	1B	N.O.	0	150	48	60	258	N.O.	0	0	38	0	38	296
	1C	N.O.	0	88	0	134	222	N.O.	6	0	39	0	45	267
	1/2A	N.O.	0	101	19	45	165	N.O.	0	0	41	0	41	206
	2C	N.O.	0	74	0	36	110	N.O.	6	0	38	0	44	154
James A.	A	0	0	2	0	0	2	108	70	111	20	61	370	372
FitzPatrick	C	0	0	0	0	0	0	15	40	111	20	77	263	263
	B	0	0	0	30	0	30	9	52	124	15	175	375	384
	D	0	0	0	0	0	0	30	52	452	0	163	697	697
Fort Calhoun	1	157	104	209	246	185	901	501	8	0	0	0	509	1410
	2	32	153	111	166	38	500	265	7	0	0	0	272	772
Robert E. Ginna	A	65	65	65	68	66	329	0	0	0	0	0	0	329
	B	90	72	76	72	75	385	0	0	0	0	0	0	385
Edwin I. Hatch 1,2	1A	51	88	15	30	18	202	4	74	23	0	6	107	309
	B	37	153	149	56	154	549	11	17	238	35	10	311	860
	1C	51	30	51	41	44	217	0	77	19	47	0	143	360
	2A	N.O.	N.O.	14	45	62	121	N.O.	N.O.	0	0	0	0	121
	2C	N.O.	N.O.	10	34	33	77	N.O.	N.O.	0	0	0	0	77
Indian Point 2	21	0	110	0	256	35	401	Not available						
	22	0	22	107	72	9	210	Not available						
	23	0	165	47	35	77	324	Not available						
Indian Point 3	31	96	0	0	0	38	134	0	0	0	0	299	299	433
	32	156	5	88	2	31	282	5	0	0	0	8	13	295
	33	156	99	0	3	19	277	0	7	0	0	40	47	324
Kewaunee	1A	0	0	0	0	0	0	48	48	72	24	24	216	216
	1B	0	0	0	0	0	0	72	24	48	24	24	192	192
LaCrosse	1A	0	0	1	2	0	3	405	38	135	33	2	613	616
	1B	4	0	0	0	2	6	1	283	0	0	12	296	302
Maine Yankee	1A	10	7	18	89	23	147	0	0	0	27	9	36	183
	1B	17	3	22	0	22	64	0	7	0	60	7	74	138
Millstone 1	DG	0	0	0	0	0	0	168	0	168	168	168	672	672
Millstone 2	12U	583	265	202	4	222	1276	146	692	1156	415	577	2986	4262
	13U	340	262	193	10	196	1001	360	627	186	773	623	2569	3570
Nine Mile Point	102	0	0	0	48	53	101	0	0	0	24	0	24	125
	103	0	0	0	43	24	67	0	0	0	24	0	24	91
North Anna 1	1H	N.O.	N.O.	13	12	55	80	0	53	36	171	93	353	433
	1J	N.O.	N.O.	19	26	112	157	0	0	27	401	0	428	585
Palisades	1	97	20	46	125	89	377	0	16	16	108	137	277	654
	2	71	68	24	90	129	382	8	8	91	185	202	494	876
Peach Bottom	1	0	15	0	2	24	41	24	62	53	77	98	314	355
3,4	2	10	0	38	10	25	83	23	41	62	41	94	261	344
	3	10	6	3	17	3	39	34	91	70	50	77	322	361
	4	0	40	11	2	28	81	22	113	46	26	67	274	355

Table 9.5.17. (continued)

Plant	DG	Reactor operating 1976	1977	1978	1979	1980	Sub-total	Reactor shut down 1976	1977	1978	1979	1980	Sub-total	Total downtime
Point Beach	3D	139	92	104	107	126	568	0	0	0	0	0	0	568
1,2	4D	60	81	99	83	120	443	0	0	0	0	0	0	443
Prairie Island	1	63	123	34	91	124	435	9	0	0	0	15	24	459
	2	45	105	78	266	31	525	0	0	0	0	122	122	647
Quad-Cities	1	10	10	14	12	8	54	1	2	4	1	75	83	137
1,2	1/2	31	18	34	63	151	297	0	0	8	0	0	8	306
	2	4	10	10	9	6	39	0	2	1	170	29	202	241
Rancho Seco	A	9	40	176	37	3	265	156	360	148	5	446	1115	1380
	B	11	39	4	125	14	193	108	456	281	0	410	1255	1448
H. B. Robinson 2	2A	0	0	0	0	0	0	48	0	72	96	330	216	216
	2B	0	0	0	0	0	0	0	0	72	96	330	498	498
St. Lucie	A	19	0	21	18	18	76	0	0	57	69	297	423	499
	B	22	0	20	18	18	78	0	0	98	167	117	382	460
Surry 1,2	1	165	17	24	51	17	274	85	0	34	5	18	142	416
	2	9	20	16	6	59	110	45	0	0	7	71	123	233
	3	18	28	54	8	61	169	72	0	0	0	5	79	246
Trojan	1	17	122	8	48	9	204	0	97	37	23	11	168	372
	2	95	94	2	44	28	263	0	23	16	8	40	87	350
Vermont Yankee	1A	0	0	0	2	0	2	121	75	183	54	150	583	585
	1B	0	0	0	0	0	0	128	90	156	91	133	598	598
Yankee (Rowe, Mass.)	1	0	0	5	0	0	5	0	240	176	34	343	793	798
	2	0	0	0	0	0	0	0	50	223	52	4	329	329
	3	0	4	0	0	0	4	0	37	57	512	43	649	653

Table 9.5.18. Diesel generator test and maintenance unavailability

Plant	DG	1976	1977	1978	1979	1980	Average unavailability (during reactor operation)	Average unavailability (all time)
Arkansas Nuclear	1	0	0	0	0	0	0	.014
One #1	2	0	0	0	0	0	0	.014
Beaver Valley	1	0	.001	0	0	0	0	.013
	2	0	0	.004	0	0	.001	.013
Big Rock Point	1	.010	.003	.005	.001	0	.004	.007
Brunswick 1,2	2	0	.015	0	.005	.014	.007	.007
	2	0	.012	0	.002	.014	.006	.006
	3	0	.010	.010	.004	.010	.007	.008
	4	.003	.042	.011	.015	.012	.017	.020
Calvert Cliffs	11	.015	.021	.018	.018	.016	.018	.020
1,2	12	.018	.020	.015	.020	.020	.019	.022
	21	0	.010	.015	.015	.023	.013	.014
Cooper	1	0	.004	.011	.023	.008	.009	.012
	2	0	.009	.022	.005	.013	.010	.010
Crystal River 3	A	N.O.	0	0	0	.002	.001	.052
	B	N.O.	0	.002	0	.001	.001	.015
Davis-Besse	1	N.O.	.001	.007	.005	.004	.004	.022
	2	N.O.	.002	.001	.010	.002	.015	.011
Dresden 2,3	2	.035	.030	.034	.038	.024	.032	.040
	2/3	.035	.035	.039	.043	.031	.037	.044
	3	.035	.030	.035	.037	.025	.032	.040
Joseph M. Farley	1B	N.O.	0	.017	.006	.007	.008	.009
	1C	N.O.	0	.010	0	.015	.006	.008
	1/2A	N.O.	0	.012	.002	.005	.005	.007
	2C	N.O.	0	.008	0	.004	.003	.004
James A.	A	0	0	0	0	0	0	.008
FitzPatrick	C	0	0	0	.0	0	0	.006
	B	0	0	0	.003	0	.001	.009
	D	0	0	0	0	0	0	.016
Fort Calhoun	1	.018	.012	.024	.028	.021	.021	.032
	2	.004	.018	.013	.019	.004	.012	.018
Robert E. Ginna	A	.007	.007	.007	.008	.008	.007	.007
	B	.010	.008	.009	.008	.009	.009	.009
Edwin I. Hatch 1	1A	.006	.010	.002	.003	.002	.005	.007
	B	.004	.018	.017	.006	.018	.013	.020
	1C	.006	.003	.006	.005	.005	.005	.009
Edwin I. Hatch 2	2A	N.O.	N.O.	.002	.005	.007	.005	.005
	2C	N.O.	N.O.	.001	.004	.004	.003	.003
Indian Point 2	21	0	.013	0	.029	.004	.009	Not available
	22	0	.003	.012	.008	.001	.005	Not available
	23	0	.019	.005	.004	.009	.007	Not available
Indian Point 3	31	.011	0	0	0	.004	.003	.010
	32	.018	.001	.010	0	.004	.007	.007
	33	.018	.011	0	0	.002	.006	.007
Kewaunee	1A	0	0	0	0	0	0	.005
	1B	0	0	0	0	0	0	.005
LaCrosse	1A	0	0	0	0	0	0	.014
	1B	0	0	0	0	0	0	.009
Maine Yankee	1A	.001	.001	.002	.010	.003	.003	.004
	1B	.002	0	.003	0	.003	.002	.003
Millstone 1	DG	0	0	0	0	0	0	.015
Millstone 2	12U	.067	.030	.023	.001	.025	.029	.098
	13U	.039	.030	.022	.001	.022	.023	.081
Nine Mile Point	102	0	0	0	.006	.006	.002	.003
	103	0	0	0	.005	.003	.002	.002
North Anna 1	1H	N.O.	N.O.	.002	.001	.006	.003	.014
	1J	N.O.	N.O.	.002	.003	.013	.006	.013
Palisades	1	.011	.002	.005	.014	.010	.009	.008
	2	.008	.008	.003	.010	.015	.009	.010
Peach Bottom	1	0	.002	0	0	.003	.001	.008
2,3	2	.001	0	.004	.001	.003	.002	.008
	3	.001	.001	0	.002	0	.001	.008
	4	0	.004	.001	0	.003	.002	.008

Table 9.5.18. (continued)

Plant name	DG	1976	1977	1978	1979	1980	Average unavailability (during reactor operation)	Average unavailability (all time)
Point Beach 1,2	3D	.016	.011	.012	.012	.014	.013	.013
	4D	.007	.009	.011	.010	.014	.010	.010
Prairie Island 1,2	1	.007	.014	.004	.010	.014	.010	.010
	2	.005	.012	.009	.030	.004	.012	.015
Quad-Cities 1,2	1	.001	.001	.002	.001	.001	.001	.003
	1/2	.004	.002	.004	.007	.017	.007	.007
	2	.001	.001	.001	.001	.001	.001	.005
Rancho Seco	A	.001	.005	.020	.004	0	.006	.016
	B	.001	.004	.001	.014	.002	.004	.016
Robinson 2	2A	0	0	0	0	0	0	.013
	2B	0	0	0	0	0	0	.011
St. Lucie	1A	.002	0	.002	.002	.002	.002	.011
	1B	.003	0	.002	.002	.002	.002	.010
Surry 1,2	1	.019	.002	.003	.006	.002	.006	.010
	2	.001	.002	.002	.001	.007	.003	.005
	3	.002	.003	.006	.001	.007	.004	.006
Trojan	1	.002	.014	.001	.006	.001	.005	.009
	2	.011	.011	0	.005	.003	.006	.008
Turkey Point 3,4	A	Not available						
	B	Not available						
Vermont Yankee	1A	0	0	0	0	0	0	.013
	1B	0	0	0	0	0	0	.014
Yankee (Rowe, Mass.)	1	0	0	.006	0	0	.001	.020
	2	0	.001	0	0	0	0	.008
	3	0	.001	0	0	0	0	.015

ORNL-DWG. 82-20538

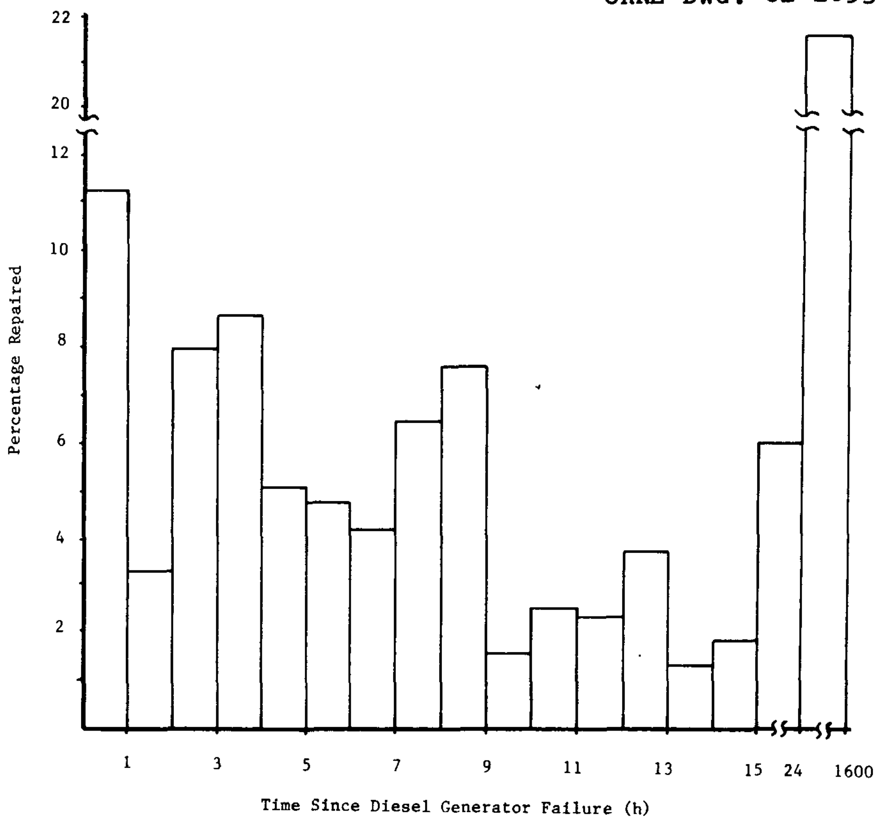

Fig. 9.5.13. Percentage of failures repaired vs time since failure.

ORNL-DWG. 82-20539

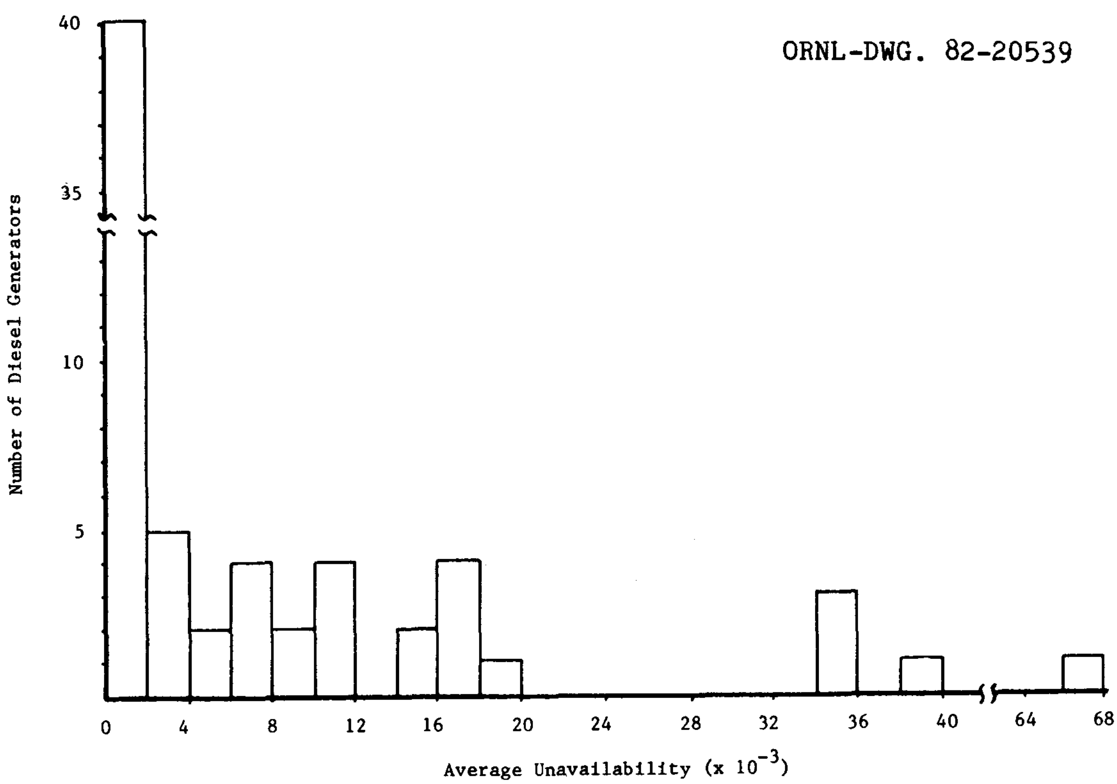

Fig. 9.5.14. Number of diesel generators vs T&M unavailability (1976).

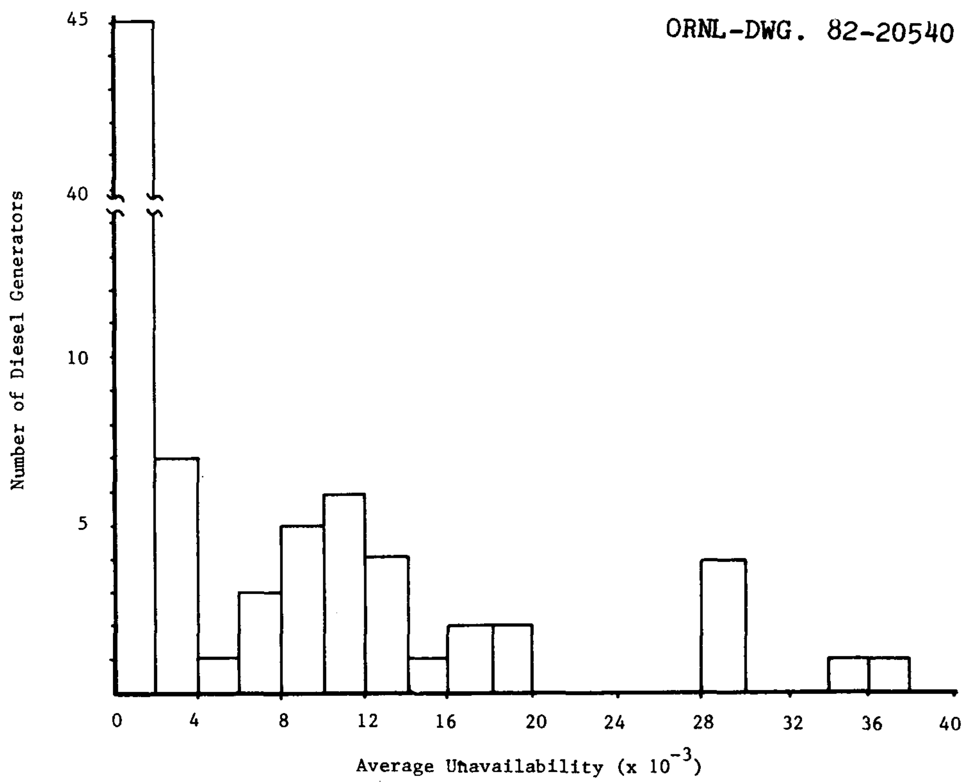

Fig. 9.5.15. Number of diesel generators vs T&M unavailability (1977).

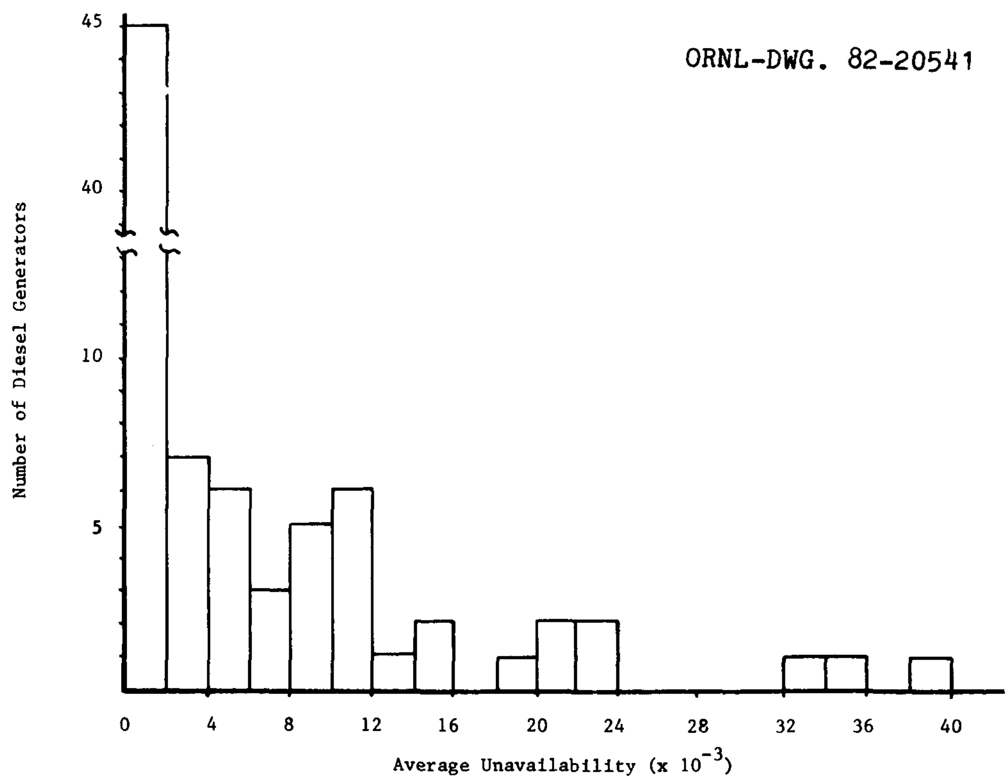

Fig. 9.5.16. Number of diesel generators vs T&M unavailability (1978).

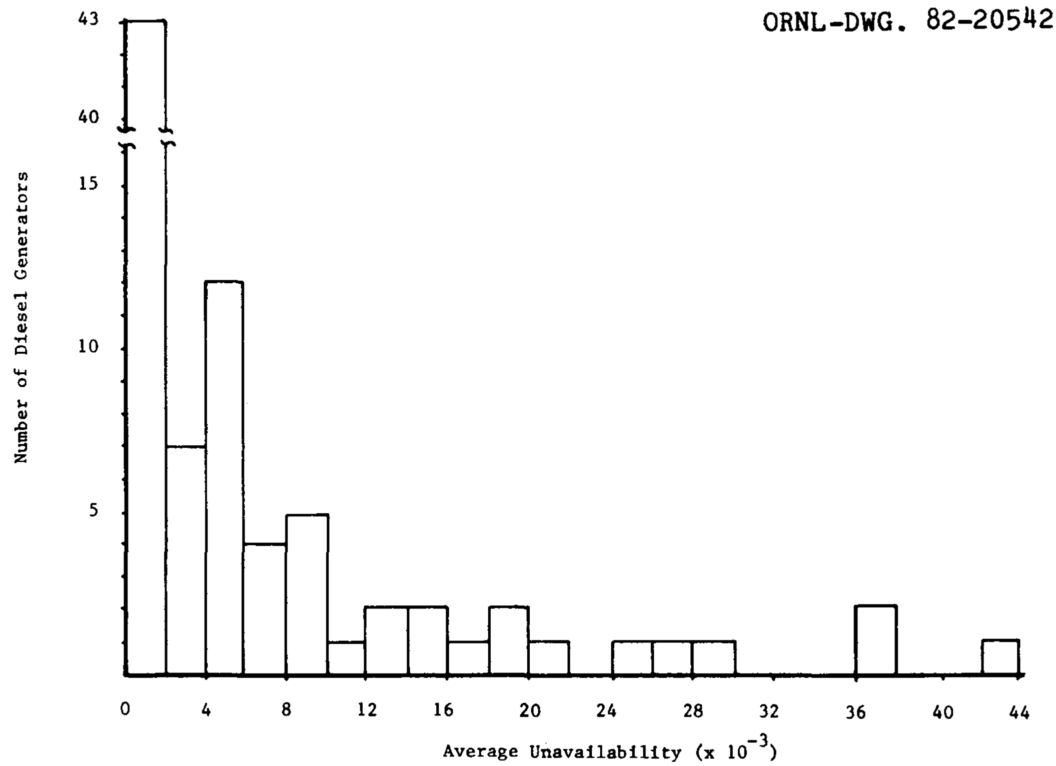

Fig. 9.5.17. Number of diesel generators vs T&M unavailability (1979).

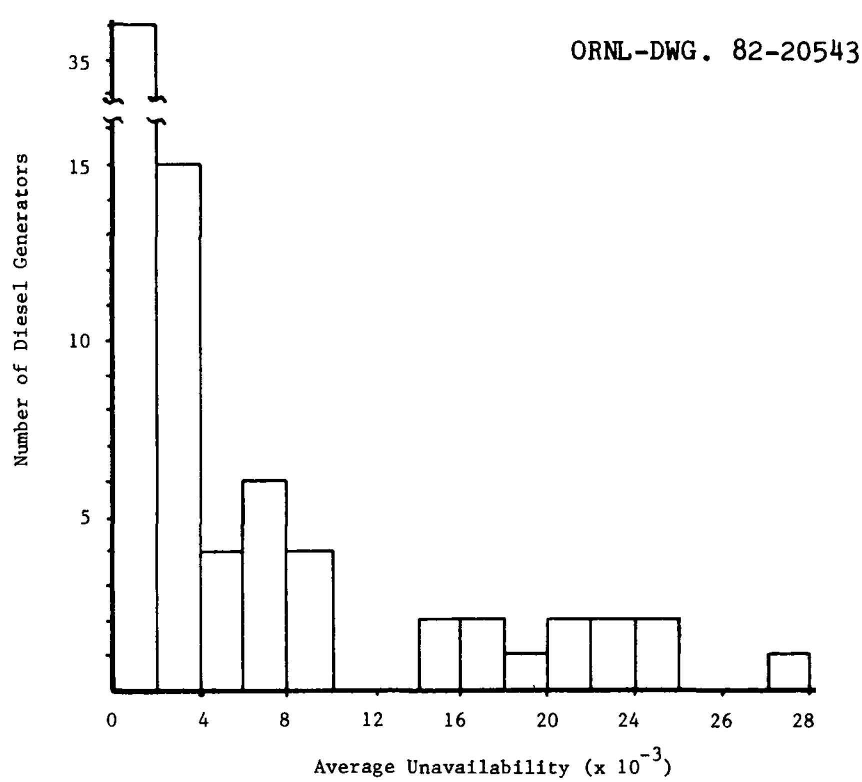

Fig. 9.5.18. Number of diesel generators vs T&M unavailability (1980).

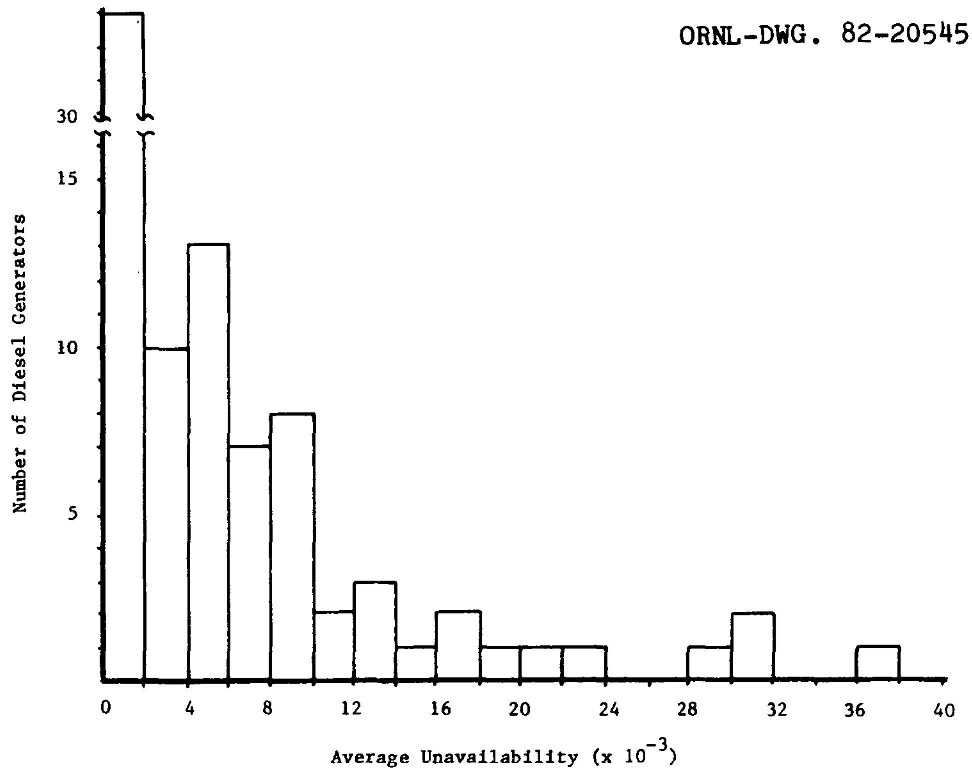

Fig. 9.5.19. Number of diesel generators vs average T&M unavailability (1976-1980).

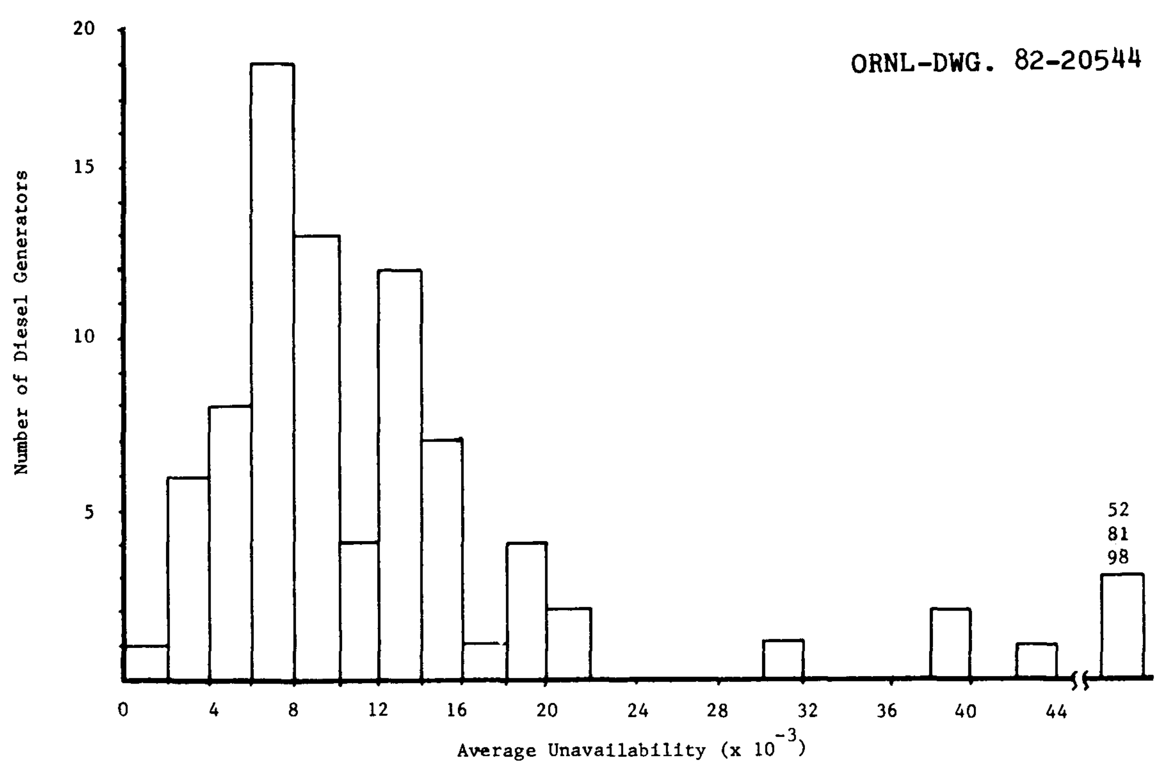

Fig. 9.5.20. Number of diesel generators vs unavailability (reactor operating or shut down, 1976-1980).

5. Data Comparisons. Diesel generator failure probabilities and rates from a number of sources are compared in Table 9.5.19. The probability of failure to start calculated for this study was estimated using the median standby failure rate, the median autostart standby failure rate, and a 30-day test interval as described in Sect. 4. Most estimates of probability of failure to start agree fairly well. Larsson and Wallin[3] report a failure probability of 3×10^{-3} per demand, which is about an order of magnitude lower than most other estimates. The operating failure rate estimates do not agree as well, probably because there are not as much run data as in start data. The estimates range from 2×10^{-5}/h to 4×10^{-2}/h.

A small subset of the diesel generator failure between 1976 and 1980 occurred during actual demands. Failures that occurred during losses of offsite power and failures that occurred during other actual demands are listed in Tables 9.5.20 and 9.5.21 respectively. In Table 9.5.22 diesel generator experience during tests is compared to the experience during loss of offsite power and during all actual demands. The failures during tests were counted only for the plants for which there are demand data. The probabilities of failure on demand agree quite well.

Estimated frequencies of loss of offsite power for seven time intervals are given in Table 9.5.23. These frequencies and time intervals were used in Eqs. (6.2) through (6.4).

Table 9.5.19. Comparison of diesel generator failure data

Source	Failure mode	Failure probability rate
Larsson and Wallin[3] (Swedish Nuclear Power Inspectorate)	Start	3×10^{-3}/demand
	Run	6×10^{-4}/h
A. E. Green[4] (United Kingdom)	Start	1×10^{-2}/demand
	Run	2×10^{-5}/h
NUREG/CR1362[5]	Start (weekly test)	1×10^{-2}/demand
	Start (monthly test)	4×10^{-2}/demand
	Run (weekly test)	6×10^{-3}/h
	Run (monthly test)	3×10^{-2}/h
Crooks and Vissing[6]	Start	2.8×10^{-2}/demand
WASH-1400[7]	Start	3×10^{-2}/demand
	Run	3×10^{-3}/h
NRC Internal Review by Power Systems Branch (unpublished)	Start	1.9×10^{-2}/demand
	Run	2.8×10^{-2}/demand
P. W. Baranowsky (NRC) (unpublished)	Start	2×10^{-2}/demand
R. F. Scholl (NRC) (unpublished)		1.4×10^{-2}/demand
IEEE Std. 500-1977[8]		8×10^{-3}/demand
		1.3×10^{-4}/h
This study	Start	2.5×10^{-2}/demand
	Run	2.3×10^{-3}/h

Table 9.5.20. Diesel generator failures on loss of offsite power

Plant	Date	LER No.	Event type
Beaver Valley	7/28/78	78-43	Autostart failure
Calvert Cliffs	4/13/78	78-20	Primary failure to start
Davis Besse	11/29/77	77-96	Secondary failure to start
Davis Besse	10/15/79	79-96	Autostart failure
FitzPatrick	3/27/79	79-21	Unavailable A&C DG
Indian Point 2	3/27/79	79-21	Autostart failure
St. Lucie	5/14/78	78-17	Unavailable
San Onofre	4/22/80	80-15	Unavailable

Table 9.5.21. Diesel generator failures for actual demands other than loss of offsite power

Plant	Date	LER No.	Event type
Browns Ferry 3	5/01/80	ECCS	Primary failure to start
Brunswick	1/23/76	76-5	Primary failure to start
Calvert Cliffs	7/13/77	77-65	Secondary failure to start
Calvert Cliffs	4/11/78	78-26	Autostart failure
Calvert Cliffs	8/01/76	76-36	Secondary failure to start
Farley	3/06/79	79-14	Secondary failure to start
Farley	8/27/78	78-60	Primary failure to start
Farley	8/12/78	78-55	Autostart failure
Kewaunee	6/21/80	80-27	Secondary failure to start
North Anna	2/15/80	80-32	Primary failure to start
Trojan	4/29/77	77-10	Secondary failure to start
Zion 1	12/05/78	78-132	Secondary failure to start
Zion 1	9/14/78	78-92	Secondary failure to start
Zion 1	10/22/76	76-56	Primary failure to start
Zion 2	9/29/76	76-38	Secondary failure to run

Table 9.5.22. Comparison of test and actual demand data

Data category	Valid demands	No. of primary and secondary failures on demand	Probability of primary or secondary failure on demand	No. of autostart failures on demand	Probability of autostart failure on demand	No. of DGs unavailable for T&M	T&M unavailability
Test	13,665	253	0.019	55	0.004	-	0.006
Loss of offsite power	78	2	0.026	2	0.026	3	0.038
All actual demands	539	14	0.026	5	0.009	3	0.0056

Table 9.5.23. Expected number per year for loss of offsite power for all causes

Duration (h)	Frequency (y^{-1})
0–0.5	0.048
0.5–1	0.021
1–2	0.012
2–3	0.012
3–5	0.010
5–8	0.008
8–24	0.008

9.6 COMMON-CAUSE FAILURE DATA

A discussion of the probability of an onsite ac power system failing because of a CCF is presented in Sect. 5. Events that caused or had potential to cause a CCF are listed as hardware failure or human error. Hardware failures are listed in Table 9.6.1, their categories of susceptibility to CCF are identified in Table 9.6.2, and the plants that belong in each category are listed in Table 9.6.3. Human error failures are listed in Table 9.6.4. Most human error CCFs resulted from errors during maintenance. We evaluated procedures and determined that procedure quality was correlated with the number of human error CCFs. Table 9.6.5 lists the generic human errors found in the list of events in Table 9.6.4 and Table 9.6.6 contains a ranking of procedures of plants for which we had procedures. Table 9.6.7 describes characteristics of procedures for the specific plants. The failure rates for the common-cause categories we identified are in Table 9.6.8. These were calculated as explained in Sects. 5 and 9.7. The failure rates were assigned to each plant, and if a plant were in more than one category, the failure rates for those categories were added to obtain an overall common-cause failure rate.

Table 9.6.1. Hardware CCF potential

Plant	LER No.	Hardware CCF potential	Event description
Beaver Valley	79048	C2	Electric fuel pump suction blocked by desiccant bag.
Big Rock Point	76008	C2	Cooling water inlet screen plugged.
Crystal River 3	01/04/79	C1	Both diesel generators would not start because room temperature was 280°F.
Dresden 3	77029	C2	Hot environment caused cooling-water pump breaker trip.
Fort Calhoun	79006	C2	Cracked pipe leaked water into bulk fuel oil storage.
Millstone 2	78033 78009 76059 76054	C2	Mussel fouling of heat exchanger.
Peach Bottom 3	77026	C1	Two diesel generators (E3 and E4) were unavailable because an air tank tie was left open and check valves leaked. Diesel E1 was down for maintenance.
Yankee (Rowe, Mass.)	77042 77041	C1	Sludge plugged radiator tubes.

Table 9.6.2. Hardware common-cause susceptibility

Susceptibility	Classification
Fuel blockage	Generic
Room temperature	Generic
Water in fuel	Subpopulation 1
Jacket cooling corrosion	Subpopulation 2
Service water blockage	Subpopulation 3
Air-start system bleed-down	Subpopulation 4

Table 9.6.3. Subpopulations of hardware CCF

1. Water in fuel	
Big Rock Point	Maine Yankee
Calvert Cliffs 1 and 2	Palisades
Cooper	Salem
Fort Calhoun	Trojan
Indian Point 2 and 3	Turkey Point 3 and 4
Kewaunee	Yankee (Rowe, Mass.)
La Crosse	Zion 1 and 2
2. Jacket cooling-water corrosion	
Big Rock Point	La Crosse
Hatch 1 and 2	Yankee (Rowe, Mass.)
3. Service water blockage	
Arkansas Nuclear One 1	Hatch 1 and 2
Arnold	Indian Point 2 and 3
Beaver Valley	Kewaunee
Big Rock Point	Maine Yankee
Browns Ferry 1, 2, and 3	Millstone 2
Brunswick 1 and 2	Monticello
Calvert Cliffs 1 and 2	Nine Mile Point
Connecticut Yankee	Palisades
Cook 1 and 2	Peach Bottom 2 and 3
Cooper	Quad Cities 1 and 2
Davis-Besse	Robinson 2
Dresden 2 and 3	Salem
Farley	Trojan
FitzPatrick	Vermont Yankee
Ginna	Zion 1 and 2
4. Air-start system bleed-down	
Calvert Cliffs 1 and 2	Millstone 2
Cooper	Peach Bottom 2 and 3
Ginna	Robinson 2
Indian Point 2 and 3	Trojan
Kewaunee	Turkey Point 3 and 4

Table 9.6.4. Human error CCF potential

Plant	LER No.	Human failure potential	Event description
Arkansas Nuclear One 1	76033	H2	Inadvertent fire system operation.
Arnold	80018	H2	Governor oil leaked; petcock not closed.
Arnold	78020	H2	Lube oil filter drain left open. Found during annual inspection.
Arnold	77043	H3	Governor setpoint not reset after maintenance.
Beaver Valley	79048	H3	Desiccant bag in fuel tank for DG1.
Beaver Valley	78037	H3	Lube oil pressure gauge installed improperly, causing oil leak.
Big Rock Point	80036	H2	Improper annual preventive maintenance caused exciter diode failure.
Big Rock Point	77027	H2	Breaker rewired incorrectly.
Browns Ferry 1 and 2	80052	H3	Switch not set for parallel operation. Then, on second start attempt, field breaker was not reset.
Brunswick 1	80043	H3	Operator shorted out control circuit by forcing lamp into socket.
Brunswick 1	77083	H2	Broken and shorted wires on governor from previous maintenance.
Brunswick 1	77001	H1	Standby heater temperature setpoint too low. Both diesels tripped on low lube oil pressure (emergency trip).

Table 9.6.4. (continued)

Plant	LER No.	Human failure potential	Event description
Brunswick 2	76085	H2	Water in fuel. Vent line cut below ground by work crew.
Brunswick 2	78015	H3	Lockout switch would not reset. Procedures changed.
Calvert Cliffs	77065	H3	Isolation valve to the jacket cooling pressure switch was inadvertently left closed.
Calvert Cliffs	80036	H2	Maintenance crew left water on speed and voltage controls.
Calvert Cliffs	80010	H3	DG was shut down before start signal was reset.
Calvert Cliffs	77053	H2	Cylinder relief valve fell off after improper maintenance.
Calvert Cliffs	76044	H1	Operator left both cooling-water discharge valves closed.
Calvert Cliffs	76036	H2	Maintenance error left both cooling system pumps airbound.
Calvert Cliffs	79023	H2	Maintenance error left lube oil pressure switch isolated. This was an emergency trip with 2/3 logic.
Connecticut Yankee	6/17/80	H3	Diesel engine jacking gear left engaged.
Connecticut Yankee	7/9/80	H2	Start relay crushed by worker.
Connecticut Yankee	76006	H2	DG overspeed caused by tool left in injector rack after maintenance.

Table 9.6.4. (continued)

Plant	LER No.	Human failure potential	Event description
Connecticut Yankee	80002	H2	Transformer neutral leads cut.
Donald C. Cook 1	76036	H2	No exciter output and governor inverter failure. Transfer switch valves left open.
Donald C. Cook 1	79009	H1	Both DGs simultaneously unavailable.
Donald C. Cook 2	79042	H3	Contractor began to remove DG from service and blew an inverter fuse.
Donald C. Cook 2	78037	H1	Both DGs incapable of auto-start. Operators closed the wrong air-start valves.
Cooper	76047	H2	Breaker would not close. Improper maintenance caused blown fuse. Manual operation of breaker may have worked.
Crystal River	77094	H3	Local control panel trips not reset. Procedure inadequate.
Davis-Besse	80065	H1	Both DGs unavailable. A service representative removed control power from essential bus.
Davis-Besse	77096	H2	Governor high-speed limit switch setpoint was incorrect.
Davis-Besse	79040	H2	Water from fire sprinkler test wet down generator and regulator.

Table 9.6.4. (continued)

Plant	LER No.	Human failure potential	Event description
Davis-Besse	79126	H1	DG1-1 was unavailable due to unscheduled maintenance, but operators took DG1-2 out of service, i.e., took wrong DG out of service for maintenance.
Dresden 2	79052	H2	Maintenance left water in control cabinet, which caused control failure.
Dresden 2	78041	H2	Cooling water pump trip was set too low.
Dresden 2	79037	H3	Operator inadvertently tripped fault relay.
Dresden 2	78033	H2	Governor speed set too high.
Dresden 2	79024	H2	Air-start lines reversed.
Dresden 2	78021	H2	Governor compensation out of adjustment.
Dresden 2	77065	H2	Operator inadvertently isolated service water (did not follow procedure).
Dresden 2	77025	H2	Frequency control improperly set.
Dresden 2	76064	H2	Shutdown solenoid out of adjustment.
Joseph M. Farley 1	80040	H2	Lube oil drain valve left open after yearly maintenance.
Joseph M. Farley 1	80033	H3	Test equipment caused fuse to blow; speed control lost.

Table 9.6.4. (continued)

Plant	LER No.	Human failure potential	Event description
Joseph M. Farley 1	80035	H2	Cooling water pump switch left in wrong position. DG would not autostart.
Joseph M. Farley 1	80007	H3	Service water valve would not open. Caused by test equipment used for LOSP test.
Joseph M. Farley 1	79032	H3	DG1C and DG2C breakers left racked out after PM.
Joseph M. Farley 1	79014	H2	Construction personnel removed cables. Breaker would not close.
James A. FitzPatrick	78098	H2	Governor misadjusted. DG would not load on bus.
R. E. Ginna	80001	H2	DG would not accept full load. Governor setpoint wrong. Setpoint label not removed after overhaul.
R. E. Ginna	77019	H2	Breaker would not close. Secondary contact fingers bent during maintenance.
Edwin I. Hatch 1	79018	H2	Service-water valve left closed after maintenance.
Edwin I. Hatch 1	79035	H2	Governor cams to monitor speed were misaligned.
Edwin I. Hatch 1	77091	H2	Regulator voltage set too high.
Edwin I. Hatch 2	80006	H2	Governor speed control set wrong.
Edwin I. Hatch 2	79047	H2	Service water valves left closed.

Table 9.6.4. (continued)

Plant	LER No.	Human failure potential	Event description
Indian Point 3	80010	H3	DG breaker would not reset. Trip latch spring was secured by a screw.
Indian Point 3	76035	H2	Air in governor oil caused speed variation. Air introduced during maintenance.
Indian Point 3	76031	H2	Low oil level in governor. Drain left partially open.
Kewaunee	77038	H3	Synchronizer motor limit switches miscalibrated during maintenance. Procedures changed to detect this error.
Kewaunee	80004	H3	Oil accidentally added to air box.
Kewaunee	79024	H3	DG was removed from service for 3 h after each run.
La Crosse	76009	H3	Manual fuel shutoff cable would not fully reset because of paint on the cable.
Maine Yankee	78023	H2	Air was introduced into fuel lines during maintenance.
Millstone 2	77020	H1	Both DG fuel supply valves were left closed.
Palisades	79036	H2	Improper flushing of governor oil.
Peach Bottom 2	79045	H2	Operator stopped service water.
Peach Bottom 2	77037B	H3	High cooling-water temperature trip not reset (emergency trip 2/3 logic).

Table 9.6.4. (continued)

Plant	LER No.	Human failure potential	Event description
Peach Bottom 2	76002	H3	DG breaker opened at 0300 to find dc ground and mistakenly left open for 10 h. Had DG trouble start.
Peach Bottom 2	77026	H2	DGE1 down for maintenance. E3 and 4 air-start out. Air tank ties were left open and check valves leaked.
Peach Bottom 2	77037A	H2	Overspeed trip not reset properly after maintenance.
Peach Bottom 2	77056	H2	Root valves to pressure switches left closed.
Pilgrim	80017A	H3	Fuel transfer pump breaker not reset after prestart check.
Prairie Island 1	80007	H3	Load limit set incorrectly. DG could pick up only a half-load.
Prairie Island 1	78014	H3	Valve from bulk fuel storage left closed for 13 days.
Prairie Island 2	76038	H3	Eductor hose came loose and caused a high crankcase pressure trip. Clamp had not been tightened after previous monthly preventive maintenance.
Salem 1	77059	H3	Bound fuel rack linkage due to lack of lube. Now lubricated once per month.
Salem 1	80060	H1	Human error disabled service water from train 2 while train 1 was down for maintenance.

Table 9.6.4. (continued)

Plant	LER No.	Human failure potential	Event description
Sequoyah 1	80140	H2	Relays reset in incorrect order. Shorted DG coils on relays. Operator error.
St. Lucie 1	76044	H2	Incorrect air isolation valve alignment.
Trojan	80011	H2	One DG battery taken out of service for equalization charge. Other battery taken out of service.
Turkey Point 3	79014	H3	Lamp replacement caused short in 125-V dc.
Turkey Point 3	76007	H2	Low cooling water surge tank level. Sample valve left partially open.
Zion 1	78092	H2	Rag left in oil strainer.
Zion 1	79018	H2	Prelube strainer blocked with rags.
Zion 2	76038	H3	Inadvertent battery trip. Breaker would not open. DG overloaded and windings were destroyed.

Table 9.6.5. Generic human errors

1. Inadvertent fire system operation.
2. Breaker rewired incorrectly.
3. Broken and shorted wires on governor from previous maintenance.
4. Water in fuel. Vent line cut below ground by work crew.
5. Maintenance crew left water on speed and voltage controls.
6. Start relay crushed by worker.
7. DG overspeed caused by tool left in injector rack after maintenance.
8. Transformer neutral leads cut.
9. Air-start lines reversed.
10. Construction personnel removed cables. Breaker would not close.
11. Maintenance crew left water in control cabinet, which caused control failure.
12. Breaker would not close. Secondary contact fingers bent during maintenance.
13. Air in governor oil caused speed variation. Air introduced during maintenance.
14. Air introduced into fuel lines during maintenance.
15. Human error disabled service water from train 2 while train 1 was down for maintenance.
16. Rag left in oil strainer.
17. Prelube strainer blocked with rags.
18. Desiccant bag in fuel tank for DG1.
19. Both DGs unavailable. A service representative removed control power from essential bus.
20. Water from fire sprinkler test got on a generator and regulator.
21. DG1-1 was unavailable due to unscheduled maintenance, but operators took DG1-2 out of service.

Table 9.6.6. Plant procedure evaluations

Plant	Procedures available	No. of human errors H1	H2	H3	Rank
Arkansas Nuclear One 1	Test	0	0	0	1
Arnold	Maintenance and test	0	2	1	2
Beaver Valley	Test	0	0	2	2
Big Rock Point	Maintenance and test	0	2		2
Browns Ferry	Maintenance and test	0	0	1	3
Brunswick 1 and 2	Maintenance and test	1	2	2	2
Calvert Cliffs 1 and 2	Maintenance and test	1	4	2	1
Connecticut Yankee	Maintenance and test	0	3	1	3
Donald C. Cook 1 and 2	None	1	2	1	-
Cooper	Maintenance and test	0	1		3
Crystal River	Maintenance and test	0	0	0	2
Davis-Besse	Maintenance and test	2	2	0	3
Dresden 2	Maintenance and test	0	8	1	1
Joseph M. Farley 1	None	0	3	3	-
James M. FitzPatrick	Maintenance and test	0	1	0	3
R. E. Ginna	Maintenance and test	0	2	0	2
Edwin I. Hatch 1 and 2	Maintenance and test	0	5	0	3
Indian Point 2	Maintenance and test	0	0	0	2
Indian Point 3	Maintenance and test	0	2	1	1
Maine Yankee	Maintenance and test	0	1	0	2
Millstone 2	Maintenance and test	1	0	0	1
Monticello	Maintenance and test	0	0	0	1
Nine Mile Point	Test	0	0	0	1
Oyster Creek 1	Test	0	0	0	2
Palisades	Maintenance and test	0	1	0	3
Peach Bottom 2	Maintenance and test	0	4	2	2
Pilgrim 1	Test	0	0	1	1
Point Beach	Maintenance and test	0	0	0	3
H. B. Robinson	Test	0	0	0	2
St. Lucie	Maintenance and test	0	1	0	1
Salem 1	Maintenance	1	0	1	2
San Onofre	Test	0	0	0	2
Sequoyah 1	None	0	1	0	-
Surry	Maintenance and test	0	0	0	2

Table 9.6.6. (continued)

Plant	Procedures available	No. of human errors H1	H2	H3	Rank
Trojan	Maintenance and test	0	1	0	3
Turkey Point 3	Test	0	1	1	2
Vermont Yankee	Maintenance and test	0	0	0	2
Zion 1 and 2	Maintenance and test	0	2	1	1

Table 9.6.7. Plant procedure characteristics

Plant	Characteristics
Arkansas Nuclear One 1	Test procedures were below average quality. They lacked detailed checklists, were sometimes difficult to follow, and did not always indicate what normal test values should be.
Duane Arnold	Test procedures were average, having detailed checklists and return to normal status instructions. Maintenance procedures were below average quality, lacking sufficient detail or precautionary measures for performing work.
Big Rock Point	Test procedures were average, but lacked a return to normal status check. Maintenance procedures were above average quality, having sufficient detail and requiring testing after maintenance.
Beaver Valley	Test procedures were average quality, having detailed checklists and return to normal status instructions.
Browns Ferry	Both test and maintenance procedures and checklists were above average quality. Return to normal status after testing and testing after maintenance were specified.
Brunswick	Test procedures were average quality. Maintenance procedures were above average quality. They had detailed checklists. The maintenance procedures indicated testing after maintenance.
Calvert Cliffs	Both test and maintenance procedures were below average quality. Both lacked detailed checklists. Procedures do not indicate either return to normal status after testing or testing after maintenance.
Connecticut Yankee	Both test and maintenance procedures were above average quality. Procedures were detailed and had good checklists. Test procedures indicated a check for return to normal status.

Table 9.6.7. (continued)

Plant	Characteristics
Cooper	Both test and maintenance procedures were above average quality. Both were detailed and had good checklists. Testing after maintenance and checks for returning to normal status after testing were indicated.
Crystal River 3	Both test and maintenance procedures were average quality. Testing procedures were detailed but difficult to follow.
Davis-Besse	Both test and maintenance procedures were above average quality. Return to normal status after testing and testing after maintenance were required.
Dresden 2	Both test and maintenance procedures were below average quality and lacked detail. Return to normal status after testing was not indicated.
James A. FitzPatrick	Both test and maintenance procedures were below average quality. Both had detailed checklists. Return to normal status after testing was specified.
R. E. Ginna	Testing and maintenance procedures were average quality. Both were detailed. Testing after maintenance was indicated. Testing checklist did not indicate a return to normal status.
Edwin I. Hatch 1, 2	Testing and maintenance procedures were above average quality. Test procedures indicated several daily checks were performed. Return to normal status after testing and testing after maintenance were specified.
Indian Point 2	Testing and maintenance procedures were average. Testing after maintenance was not required by the procedures.
Indian Point 3	Testing and maintenance procedures were below average quality. They lacked detail and checklists were sketchy. Testing after maintenance was not required by the procedures.

Table 9.6.7. (continued)

Plant	Characteristics
Maine Yankee	Testing procedures were above average, and maintenance procedures were average. Return to normal status after testing was indicated. Maintenance procedures lacked detail.
Millstone 2	Testing and maintenance procedures were below average. Both procedures lacked detail and had poor checklists. Testing after maintenance was not required by the procedures.
Monticello	Testing and maintenance procedure checklists were below average. Both lacked detail. Return to normal status after testing and testing after maintenance were not indicated.
Nine Mile Point	Testing procedures were below average. Testing procedures and checklists lacked detail.
Oyster Creek	Testing procedures were average. Testing procedures were detailed. Return to normal status after testing was indicated.
Palisades	Testing and maintenance procedures were above average and detailed. Test precautions were good. Return to normal status after testing was indicated.
Peach Bottom 2	Test and maintenance procedures were above average and detailed. Testing after maintenance and return to normal status after testing was indicated. Test precautions were poor.
Pilgrim 1	Test procedures and checklists were below average and lacked detail. Procedures indicated a return to normal status after testing.
Point Beach	Procedures were above average. Testing and maintenance procedures were very detailed. Return to normal status after testing and testing after maintenance were indicated.

Table 9.6.7. (continued)

Plant	Characteristics
H. B. Robinson	Testing procedures had were average. They were detailed. Return to normal status after testing was indicated.
St. Lucie	Testing and maintenance procedures were below average. Testing and maintenance procedures and checklists lacked detail. Precautions for maintenance were poor.
Salem 1	Maintenance procedures were average. They were detailed. Testing after maintenance was indicated.
San Onofre	Testing procedures were average. Return to normal status after testing was indicated.
Surry	Both testing and maintenance procedures were average. Maintenance procedures were very detailed. Testing procedures were as detailed as most plants. Return to normal status after testing was indicated, but testing after maintenance was not indicated.
Trojan	Both testing and maintenance procedures were above average. Return to normal status after testing was indicated.
Turkey Point 3, 4	Testing procedures were average. Return to normal status after testing was indicated in the test precautions, but it was not included in the checklists.
Vermont Yankee	Testing and maintenance procedures were average. Testing checklists were not as detailed as most plants. Return to normal status after testing was indicated, but testing after maintenance was not indicated.
Zion 1, 2	Testing and maintenance procedures were below average. Both lacked detail. Return to normal status after testing was not indicated.

Table 9.6.8. Common cause failure rate contributions

Diesel generator configuration	Failure rate contribution (h^{-1})
Generic hardware	
1 of 2	3×10^{-7}
1 of 3	2×10^{-7}
2 of 3	8×10^{-7}
2 of 4	4×10^{-7}
2 of 5	3×10^{-7}
Service water cooled group	
1 of 2	5×10^{-7}
1 of 3	3×10^{-7}
2 of 3	1.5×10^{-6}
2 of 4	9×10^{-7}
2 of 5	7×10^{-7}
Air-start systems connected group	
1 of 2	2×10^{-6}
1 of 3	1×10^{-6}
2 of 3	5×10^{-6}
2 of 4	4×10^{-6}
2 of 5	3×10^{-6}
No corrosion inhibitor group	
1 of 2	6×10^{-6}
1 of 3	4×10^{-6}
2 of 3	1.6×10^{-5}
2 of 4	2×10^{-5}
2 of 5	2×10^{-5}
No fuel tank drain group	
1 of 2	9×10^{-7}
1 of 3	7×10^{-7}
2 of 3	4×10^{-6}
2 of 4	3×10^{-6}
2 of 5	1.4×10^{-6}

Table 9.6.8. (continued)

Diesel generator configuration	Failure rate contribution (h^{-1})
Generic human error	
1 of 2	9×10^{-7}
1 of 3	3×10^{-7}
2 of 3	3×10^{-6}
2 of 4	8×10^{-7}
2 of 5	4×10^{-7}
Above average procedures group	
1 of 2	1×10^{-6}
1 of 3	7×10^{-7}
2 of 3	2×10^{-6}
2 of 4	8×10^{-7}
2 of 5	7×10^{-7}
Average procedures group	
1 of 2	2×10^{-6}
1 of 3	7×10^{-7}
2 of 3	5×10^{-6}
2 of 4	8×10^{-7}
2 of 5	7×10^{-7}
Below average procedures group	
1 of 2	4×10^{-6}
1 of 3	2×10^{-6}
2 of 3	2×10^{-5}
2 of 4	5×10^{-6}
2 of 5	2×10^{-6}

9.7 DERIVATION OF CCF RATE EQUATIONS

The BFR computer program was used to determine failure rates for the diesel generator common cause events (see Sect. 5). These rates depend on the diesel generator success logic. The present version of BFR calculates rates only for failure of all components in a population. Thus, rates calculated by BFR apply only to the one-out-of-two and one-out-of-three success logic configurations. The equations applicable to these two configurations are the following:

$$\lambda(1/2) = \mu p^2 + \omega \tag{9.6.1}$$

and

$$\lambda(1/3) = \mu p^3 + \omega \tag{9.6.2}$$

where

$\lambda(x/y)$ = the CCF rate for a system whose success logic configuration is "x out of y,"
μ = the rate of common-cause shocks,
p = the probability of failure of a single component given that a shock occurs, and
ω = the rate of lethal shocks.

A shock is a human error, hardware failure, or environmental condition that puts a stress on the system.

Similar equations apply to one-of-four and one-of-five success logic configurations as follows:

$$\lambda(1/4) = \mu p^4 + \omega \tag{9.6.3}$$

and

$$\lambda(1/5) = \mu p^5 + \omega \tag{9.6.4}$$

The BFR program calculates CCF rates except for two-of-three, two-of-four, or two-of-five success logic configurations, which are needed for this study. Then three CCF rates can be calculated by the following equations:

$$\lambda(2/3) = 3\mu p^2 q + \mu p^3 + \omega \quad (9.6.5)$$

$$\lambda(2/4) = 4\mu p^3 + \mu p^4 + \omega \quad (9.6.6)$$

$$\lambda(2/5) = 5\mu p^4 q + \mu p^5 = \omega \quad (9.6.7)$$

where

$$q = 1 - p.$$

The BFR output describes the distributions on μ, p, and ω, including the medians. BFR combines the distributions for μ, p, and ω according to the equations above and performs a numerical integration to determine the distribution of the resulting failure rate.

Investigation showed substituting median values of μ, p, and ω into Eqs. (9.6.1) through (9.6.4) underpredicted the median values of the CCF rate calculated by BFR. In some cases the underprediction was as much as 60%. Therefore, it would be inaccurate to use median values of μ, p, q, and ω in Eqs. (9.6.5) through (9.6.7) to estimate CCF rates. Instead, Eqs. (9.6.8) through (9.6.10) were used.

$$\lambda(2/3) = 3q[\lambda(1/2) - \omega] + \lambda(1/3) \quad (9.6.8)$$

$$\lambda(2/4) = 4q[\lambda(1/3) - \omega] + \lambda(1/4) \quad (9.6.9)$$

$$\lambda(2/5) = 5q[\lambda(1/4) - \omega] + \lambda(1/5) \quad (9.6.10)$$

These equations are equivalent to Eqs. (9.6.5) through (9.6.7) if point values are used. If the BFR median results for $\lambda(1/2)$, $\lambda(1/3)$, $\lambda(1/4)$, and $\lambda(1/5)$ are used in Eqs. (9.6.8) through (9.6.10), higher failure rates result than when Eqs. (9.6.5) through (9.6.7) are used. Therefore, Eqs. (9.6.8) through (9.6.10) are used because they are more conservative than Eqs. (9.6.5) through (9.6.7).

9.8 ONSITE BASIC EVENT DATA AND QUANTITATIVE RESULTS

Basic event data used in the fault tree analyses for the 18 plants and 10 generic designs modeled are given in Tables 9.8.1-9.8.28. The failure rates in these tables are the operating failure rates, and the initial unavailabilities are the probabilities that the systems will be unavailable for service when a loss of offsite power occurs. For some systems the operating failure rate is negligible, and this is indicated by an E in the tables. Tables 9.8.29-9.8.55 contain the results of fault tree analyses of 17 plants (Millstone 2 was not included because its onsite and offsite systems were not independent) and 10 generic designs. The undependabilities of the onsite power systems are given for three mission lengths: 0, 10, and 30 h. The undependability for each mission is the probability that the onsite power system will fail to start and run for the time specified. The basic events and cut sets are listed in order of importance; those of lesser importance are not listed (see the Glossary for the definition of basic event and cut set importance).

Table 9.8.1. Arkansas Nuclear One 1, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
SWCCF	1.1×10^{-5}	7	8.0×10^{-5}
DGCCF	8.0×10^{-7}	21	1.4×10^{-4}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	21	8.8×10^{-4}
DG*UD	2.4×10^{-3}	21	2.9×10^{-2}
SW*UD	3.0×10^{-4}	7	2.0×10^{-3}
DC*UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	21	6.1×10^{-5}
SW*TM	ε	7	2.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1 or 2.

Table 9.8.2. Brunswick 1 and 2, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
SWCCF	1.1×10^{-5}	7	8.0×10^{-5}
DGCCF	1.3×10^{-6}	10	1.5×10^{-4}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	10	2.0×10^{-4}
DG*UD	2.4×10^{-3}	10	4.1×10^{-2}
SW#UD	3.0×10^{-4}	7	2.0×10^{-3}
DC#UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	10	1.0×10^{-2}
SW#TM	ε	7	2.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1, 2, 3 or 4.
# = 1 or 2.

Table 9.8.3. Calvert Cliffs 1 and 2, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
SWCCF	1.1×10^{-5}	7	8.0×10^{-5}
DGCCF	1.1×10^{-5}	15	7.0×10^{-4}
BACCF	ε	15	1.0×10^{-6}
DGHEC	ε	15	1.4×10^{-3}
DG*UD	2.4×10^{-3}	15	1.7×10^{-2}
SW#UD	3.0×10^{-4}	7	2.0×10^{-3}
DC#UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	15	1.7×10^{-2}
SW#TM	ε	7	2.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1, 2 or 3.
# = 1 or 2.

Table 9.8.4. Donald C. Cook 2, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
SWCCF	1.1×10^{-5}	7	8.0×10^{-5}
DGCCF	8.0×10^{-7}	14	1.4×10^{-4}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	14	5.2×10^{-4}
DG*UD	2.4×10^{-3}	14	6.8×10^{-2}
SW*UD	3.0×10^{-4}	7	2.0×10^{-3}
DC*UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	14	6.0×10^{-3}
SW*TM	ε	7	2.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1 or 2.

Table 9.8.5. Crystal River 3, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
DGCCF	3.0×10^{-7}	17	5.4×10^{-5}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	17	5.2×10^{-4}
DG*UD	2.4×10^{-3}	17	5.9×10^{-2}
DC*UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	17	1.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1 or 2.

Table 9.8.6. Davis-Besse, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
SWCCF	1.1×10^{-5}	7	8.0×10^{-5}
DGCCF	8.0×10^{-7}	42	1.4×10^{-4}
BACCF	ε	15	1.0×10^{-6}
DGHEC	ε	42	3.4×10^{-4}
DG*UD	2.4×10^{-3}	42	7.6×10^{-2}
SW*UD	3.0×10^{-4}	7	2.0×10^{-3}
DC*UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	42	6.1×10^{-3}
SW*TM	ε	7	2.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1 or 2.

Table 9.8.7. Dresden 2 and 3, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
SWCCF	1.1×10^{-5}	7.0	8.0×10^{-5}
DGCCF	2.3×10^{-6}	6.4	3.7×10^{-4}
BACCF	ε	15.0	1.0×10^{-5}
DGHEC	ε	6.4	3.7×10^{-3}
DG*UD	2.4×10^{-3}	6.4	8.2×10^{-2}
SW#UD	3.0×10^{-4}	7.0	2.0×10^{-3}
DC#UD	1.0×10^{-7}	2.0	1.0×10^{-4}
DG*TM	ε	6.4	4.5×10^{-2}
SW#TM	ε	7.0	2.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1, 2 or 3.
# = 1 or 2.

Table 9.8.8. Joseph M. Farley 1 and 2, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
DGCCF	1.0×10^{-6}	6.3	8.6×10^{-5}
BACCF	ε	15.0	1.0×10^{-6}
DGHEC	ε	6.3	9.5×10^{-5}
DG*UD	2.4×10^{-3}	6.3	4.9×10^{-2}
DC#UD	1.0×10^{-7}	2.0	1.0×10^{-4}
DG*TM	ε	6.3	8.5×10^{-3}

ε = Failure rate is negligibly small.
* = 1, 2, 3, 4 or 5.
# = 1 or 2.

Table 9.8.9. James A. FitzPatrick, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
SWCCF	1.1×10^{-5}	7	8.0×10^{-5}
DGCCF	4.0×10^{-7}	61	3.6×10^{-5}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	61	7.2×10^{-5}
DG*UD	2.4×10^{-3}	61	2.3×10^{-2}
SW#UD	3.0×10^{-4}	7	2.0×10^{-3}
DC#UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	61	2.4×10^{-4}
SW#TM	ε	7	2.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1, 2, 3, or 4.
# = 1 or 2.

Table 9.8.10. Edwin I. Hatch 1 and 2, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
SWCCF	1.1×10^{-5}	7	8.0×10^{-5}
DGCCF	2.1×10^{-5}	92	1.8×10^{-3}
BACCF	ε	15	1.0×10^{-6}
DGHEC	ε	92	1.2×10^{-4}
DG*UD	2.4×10^{-3}	92	4.4×10^{-2}
SW#UD	3.0×10^{-4}	7	2.0×10^{-3}
DC#UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	92	8.5×10^{-3}
SW#TM	ε	7	2.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1, 2, 3, 4, or 5.
# = 1 or 2.

Table 9.8.11. Millstone 1, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
OSCCF	5.0×10^{-7}	8.4	9.0×10^{-5}
BACCF	ε	15.0	1.0×10^{-5}
OSHEC	ε	8.4	1.6×10^{-4}
DGIUD	2.4×10^{-3}	8.4	8.2×10^{-3}
GTIUD	2.4×10^{-3}	16.0	6.8×10^{-2}
GTBUD	1.0×10^{-7}	2.0	1.0×10^{-4}
SW1UD	3.0×10^{-4}	7.0	2.0×10^{-3}
DC#UD	1.0×10^{-7}	2.0	1.0×10^{-4}
DGITM	ε	8.4	1.0×10^{-5}
GTITM	ε	16.0	1.0×10^{-5}
SW1TM	ε	7.0	2.0×10^{-3}

ε = Failure rate is negligibly small.
= 1 or 2.

Table 9.8.12. Millstone 2, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
DC1IE	ε	2	1.0×10^{-3}
SWCCF	1.1×10^{-5}	7	8.0×10^{-5}
DGCCF	2.8×10^{-6}	43	5.0×10^{-4}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	43	8.8×10^{-4}
DG*UD	2.4×10^{-3}	43	1.0×10^{-1}
SW*UD	3.0×10^{-4}	7	2.0×10^{-3}
DC*UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	43	3.5×10^{-2}
SW*TM	ε	7	2.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1 or 2.

Table 9.8.13. Nine Mile Point, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
SWCCF	1.1×10^{-5}	7	8.0×10^{-5}
DGCCF	8.0×10^{-7}	33	1.4×10^{-4}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	33	8.8×10^{-4}
DG*UD	2.4×10^{-3}	33	1.3×10^{-2}
SW*UD	3.0×10^{-4}	7	2.0×10^{-3}
DC*UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	33	2.6×10^{-3}
SW*TM	ε	7	2.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1 or 2.

Table 9.8.14. Peach Bottom 2 and 3, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
SWCCF	1.1×10^{-5}	7	8.0×10^{-5}
DGCCF	5.3×10^{-6}	21	6.0×10^{-4}
BACCF	ε	15	1.0×10^{-6}
DGHEC	ε	21	2.0×10^{-4}
DG*UD	2.4×10^{-3}	21	4.3×10^{-3}
SW#UD	3.0×10^{-4}	7	2.0×10^{-3}
DC#UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	21	1.9×10^{-3}
SW#TM	ε	7	2.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1, 2, 3 or 4.
# = 1 or 2.

Table 9.8.15. St. Lucie, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
DGCCF	3.0×10^{-7}	14	5.4×10^{-5}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	14	8.8×10^{-4}
DG*UD	2.4×10^{-3}	14	6.5×10^{-2}
DC*UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	14	2.5×10^{-3}

ε = Failure rate is negligibly small.
* = 1 or 2.

Table 9.8.16. San Onofre, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
DGCCF	3.0×10^{-7}	4.7	5.4×10^{-5}
BACCF	ε	15.0	1.0×10^{-5}
DGHEC	ε	4.7	5.2×10^{-4}
DG*UD	2.4×10^{-3}	4.7	2.1×10^{-2}
DC*UD	1.0×10^{-7}	2.0	1.0×10^{-4}
DG*TM	ε	4.7	6.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1 or 2.

Table 9.8.17. Turkey Point 3 and 4, basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
DGCCF	3.2×10^{-6}	36	5.8×10^{-4}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	36	5.2×10^{-4}
DG*UD	2.2×10^{-3}	36	3.3×10^{-2}
DC*UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	36	6.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1 or 2.

Table 9.8.18. Yankee (Rowe, Mass.), basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
DGCCF	4.9×10^{-6}	145	5.9×10^{-4}
BACCF	ε	15	5.0×10^{-6}
DGHEC	ε	145	1.2×10^{-4}
DG*UD	2.4×10^{-3}	145	8.2×10^{-3}
DC#UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	145	9.1×10^{-5}

ε = Failure rate is negligibly small.
* = 1, 2, or 3.
# = 1, 2, or 3.

Table 9.8.19. 2 of 5, air-cooled basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
DGCCF	3.0×10^{-7}	20	2.6×10^{-5}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	20	9.5×10^{-5}
DG*UD	2.4×10^{-3}	20	2.5×10^{-2}
DC#UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	20	6.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1, 2, 3, 4, or 5.
# = 1 or 2.

Table 9.8.20. 2 of 5, service-water-cooled basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
SWCCF	1.1×10^{-5}	7	8.0×10^{-5}
DGCCF	1.0×10^{-6}	20	8.6×10^{-5}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	20	9.5×10^{-5}
DG*UD	2.4×10^{-3}	20	2.5×10^{-2}
SW#UD	3.0×10^{-4}	7	2.0×10^{-3}
DC#UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	20	6.0×10^{-3}
SW#TM	ε	7	2.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1, 2, 3, 4, or 5.
# = 1 or 2.

Table 9.8.21. 1 of 3, air-cooled basic event data

Basic event	Failure rate (hr^{-1})	Mean repair time (hr)	Initial unavailability
DGCCF	2.0×10^{-7}	20	2.4×10^{-5}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	20	1.2×10^{-4}
DG*UD	2.4×10^{-3}	20	2.5×10^{-2}
DC*UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	20	6.0×10^{-3}

ε = failure rate is negligibly small
* = 1, 2 or 3.

Table 9.8.22. 1 of 3, service-water-cooled basic event data

Basic event	Failure rate (hr^{-1})	Mean repair time (hr)	Initial unavailability
SWCCF	1.1×10^{-5}	7	8.0×10^{-5}
DGCCF	5.0×10^{-7}	20	6.0×10^{-5}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	20	1.2×10^{-4}
DG*UD	2.4×10^{-3}	20	2.5×10^{-2}
SW#UD	3.0×10^{-4}	7	2.0×10^{-3}
DC#UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	20	6.0×10^{-3}
SW#TM	ε	7	2.0×10^{-3}

ε = failure rate is negligibly small
* = 1, 2, or 3.
# = 1 or 2.

Table 9.8.23. 2 of 4, air-cooled basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
DGCCF	4.0×10^{-7}	20	4.5×10^{-5}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	20	2.0×10^{-4}
DG*UD	2.4×10^{-3}	20	2.5×10^{-2}
DC#UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	20	6.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1, 2, 3 or 4.
# = 1 or 2.

Table 9.8.24. 2 of 4, service-water-cooled basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
SWCCF	1.1×10^{-5}	7	8.0×10^{-5}
DGCCF	1.3×10^{-6}	20	1.5×10^{-4}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	20	2.0×10^{-4}
DG*UD	2.4×10^{-3}	20	2.5×10^{-2}
SW#UD	3.0×10^{-4}	7	2.0×10^{-3}
DC#UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	20	6.0×10^{-3}
SW#TM	ε	7	2.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1, 2, 3, or 4.
# = 1 or 2.

Table 9.8.25. 1 of 2, air-cooled basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
DGCCF	3.0×10^{-7}	20	5.4×10^{-5}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	20	5.2×10^{-4}
DG*UD	2.4×10^{-3}	20	2.5×10^{-2}
DC*UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	20	6.1×10^{-3}

ε = Failure rate is negligibly small.
* = 1 or 2.

Table 9.8.26. 1 of 2, service water-cooled basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
SWCCF	1.1×10^{-5}	7	8.0×10^{-5}
DGCCF	8.0×10^{-7}	20	1.4×10^{-4}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	20	5.2×10^{-4}
DG*UD	2.4×10^{-3}	20	2.5×10^{-2}
SW*UD	3.0×10^{-4}	7	2.0×10^{-3}
DC*UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	20	6.0×10^{-3}
SW*TM	ε	7	2.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1 or 2.

Table 9.8.27. 2 of 3, air-cooled basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
DGCCF	8.0×10^{-7}	20	1.3×10^{-4}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	20	1.3×10^{-3}
DG*UD	2.4×10^{-3}	20	2.5×10^{-2}
DC#UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	20	6.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1, 2, or 3.
# = 1 or 2.

Table 9.8.28. 2 of 3, service-water-cooled basic event data

Basic event	Failure rate (h^{-1})	Mean repair time (h)	Initial unavailability
SWCCF	1.1×10^{-5}	7	8.0×10^{-5}
DGCCF	2.3×10^{-6}	20	3.7×10^{-4}
BACCF	ε	15	1.0×10^{-5}
DGHEC	ε	20	1.3×10^{-3}
DG*UD	2.4×10^{-3}	20	2.5×10^{-2}
SW#UD	3.0×10^{-4}	7	2.0×10^{-3}
DC#UD	1.0×10^{-7}	2	1.0×10^{-4}
DG*TM	ε	20	6.0×10^{-3}
SW#TM	ε	7	2.0×10^{-3}

ε = Failure rate is negligibly small.
* = 1, 2, or 3.
# = 1 or 2.

Table 9.8.29. Arkansas Nuclear One 1, onsite results

T = 0 h	Undependability = 2.2×10^{-3}	T = 10 h	Undependability = 4.3×10^{-3}	T = 30 h	Undependability = 9.2×10^{-3}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DG1UD, DG2UD	0.44	DG1UD, DG2UD	0.64	DG1UD, DG2UD	0.76
DGHEC	0.40	DGHEC	0.21	DGHEC	0.10
DGCCF	0.06	SW1UD, SW2UD	0.05	SW1UD, SW2UD	0.07
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DGHEC	0.40	DG1UD, DG2UD	0.57	DG1UD, DG2UD	0.69
DG1UD, DG2UD	0.38	DGHEC	0.21	DGHEC	0.10
DGCCF	0.06	DG1UD, SW2UD	0.05	DG1UD, SW2UD	0.06
		SW1UD, DG2UD	0.05	SW1UD, DG2UD	0.06

Table 9.8.30. Brunswick 1 and 2, onsite results

T = 0 h	Undependability = 1.7×10^{-3}	T = 10 h	Undependability = 3.1×10^{-3}	T = 30 h	Undependability = 5.0×10^{-3}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DG1UD, DG2UD, DG3UD, DG4UD	0.28	DG1UD, DG2UD, DG3UD, DG4UD	0.32	DG1UD, DG2UD, DG3UD, DG4UD	0.32
SW1UD, SW2UD	0.13	SW1UD, SW2UD	0.18	SW1UD, SW2UD	0.23
DGHEC	0.12				
SW1TM, SW2TM	0.1	SW1TM, SW2TM	0.07	SWCCF	0.90
DGCCF	0.09	DGHEC	0.06		
		SWCCF	0.06		
		DGCCF	0.05		
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DGHEC	0.12	DG2UD, SW1UD	0.08	DG2UD, SW1UD	0.10
DGCCF	0.09	DG1UD, SW2UD	0.08	DG1UD, SW2UD	0.10
		DG4UD, SW1UD	0.08	DG3UD, SW2UD	0.10
		DG3UD, SW2UD	0.08	DG4UD, SW1UD	0.10
		DGHEC	0.06	SWCCF	0.90
		SWCCF	0.06	DG1UD, DG2UD, DG3UD	0.05
		DGCCF	0.05		
		DG1UD, DG2UD, DG3UD	0.05	DG1UD, DG2UD, DG4UD	0.05
		DG1UD, DG2UD, DG4UD	0.05	DG2UD, DG3UD DG4UD	0.05
		DG2UD, DG3UD, DG4UD	0.05	DG1UD, DG3UD, DG4UD	0.05
		DG1UD, DG3UD, DG4UD	0.05		

Table 9.8.31. Calvert Cliffs 1 and 2, onsite results

T = 0 h	Undependability = 5×10^{-3}	T = 10 h	Undependability = 1.1×10^{-2}	T = 30 h	Undependability = 2.3×10^{-2}
Basic Event	**Importance**	**Basic Event**	**Importance**	**Basic Event**	**Importance**
DGHEC	0.27				
DG3UD	0.25	DG3UD	0.38	DG3UD	0.48
DG1UD and DG2UD	0.23	DG1UD and DG2UD	0.37	DG1UD and DG2UD	0.46
DGCCF	0.13	DGHEC	0.13	DG3TM	0.081
DG3TM	0.12	DG3TM	0.12	DG1TM and DG2TM	0.077
DG1TM and DG2TM	0.12	DG2TM and DG1TM	0.11	DGHEC	0.061
		DGCCF	0.073		
Cut Set	**Importance**	**Cut Set**	**Importance**	**Cut Set**	**Importance**
DGHEC	0.27	DGHEC	0.13	DG1UD, DG2UD	0.18
DGCCF	0.13	DG1UD, DG2UD	0.12	DG1UD, DG3UD	0.18
DG2UD, DG1TM	0.055	DG1UD, DG3UD	0.12	DG2UD, DG3UD	0.18
DG3UD, DG1TM	0.055	DG2UD, DG3UD	0.12	DGHEC	0.061
DG1UD, DG2TM	0.055	DGCCF	0.073		
DG3UD, DG2TM	0.055	DG2UD, DG1TM	0.053		
DG1UD, DG3TM	0.055	DG3UD, DG1TM	0.053		
DG2UD, DG3TM	0.055	DG1UD, DG2TM	0.053		
DG1UD, DG2UD	0.055	DG3UD, DG2TM	0.053		
DG1UD, DG3UD	0.055	DG1UD, DG3TM	0.053		
DG2UD, DG3UD	0.055	DG2UD, DG3TM	0.053		

Table 9.8.32. Donald C. Cook 2, onsite results

T = 0 h	Undependability = 6.8×10^{-3}	T = 10 h	Undependability = 1.0×10^{-2}	T = 30 h	Undependability = 1.6×10^{-2}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DG1UD, DG2UD	0.78	DG1UD, DG2UD	0.81	DG1UD, DG2UD	0.83
DGHEC	0.08	DG1TM, DG2TM	0.05	SW1UD, SW2UD	0.05
DG1TM, DG2TM	0.06	DGHEC	0.05		
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DG1UD, DG2UD	0.68	DG1UD, DG2UD	0.71	DG1UD, DG2UD	0.73
DGHEC	0.08	DGHEC	0.05		
DG1TM, DG2UD	0.06	DG1TM, DG2UD	0.05		
DG2TM, DG1UD	0.06	DG2TM, DG1UD	0.05		

Table 9.8.33. Crystal River 3, onsite results

T = 0 h	Undependability = 4.2×10^{-3}	T = 10 h	Undependability = 6.8×10^{-3}	T = 30 h	Undependability = 1.1×10^{-2}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DG1UD, DG2UD	0.85	DG1UD, DG2UD	0.9	DG1UD, DG2UD	0.94
DGHEC	0.12	DGHEC	0.08		
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DG1UD, DG2UD	0.83	DG1UD, DG2UD	0.89	DG1UD, DG2UD	0.93
DGHEC	0.12	DGHEC	0.08		

Table 9.8.34. Davis-Besse, onsite results

T = 0 h	Undependability = 7.9×10^{-3}	T = 10 h	Undependability = 1.3×10^{-2}	T = 30 h	Undependability = 2.2×10^{-2}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DG1UD, DG2UD	0.83	DG1UD, DG2UD	0.84	DG1UD, DG2UD	0.86
DG1TM, DG2TM	0.06	DG1TM, DG2TM	0.05	SW1UD, SW2UD	0.05
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DG1UD, DG2UD	0.73	DG1UD, DG2UD	0.75	DG1UD, DG2UD	0.77
DG2UD, DG1TM	0.06				
DG1UD, DG2TM	0.06				

Table 9.8.35. Dresden 2 & 3, onsite results

T = 0 h	Undependability = 4.8 x 10^{-2}	T = 10 h	Undependability = 6.0 x 10^{-2}	T = 30 h	Undependability 6.7 x 10^{-2}
Basic Event	**Importance**	**Basic Event**	**Importance**	**Basic Event**	**Importance**
DG3UD	0.45	DG3UD	0.45	DG3UD	0.48
DG1UD, DG2UD	0.44	DG1UD, DG2UD	0.45	DG1UD, DG2UD	0.46
DG3TM	0.16	DG3TM	0.15	DG3TM	0.13
DG1TM, DG2TM	0.16	DG1TM, DG2TM	0.14	DG1TM, DG2TM	0.13
DGHEC	0.08	DGHEC	0.06	DGHEC	0.06
Cut Set	**Importance**	**Cut Set**	**Importance**	**Cut Set**	**Importance**
DG1UD, DG2UD	0.14	DG1UD, DG2UD	0.15	DG1UD, DG2UD	0.16
DG1UD, DG3UD	0.14	DG1UD, DG3UD	0.15	DG1UD, DG3UD	0.16
DG2UD, DG3UD	0.14	DG2UD, DG3UD	0.15	DG2UD, DG3UD	0.16
DGHEC	0.08	DG1TM, DG2UD	0.07	DG1TM, DG2UD	0.07
DG1TM, DG2UD	0.08	DG1TM, DG3UD	0.07	DG1TM, DG3UD	0.07
DG1TM, DG3UD	0.08	DG2TM, DG1UD	0.07	DG2TM, DG1UD	0.07
DG2TM, DG1UD	0.08	DG2TM, DG3UD	0.07	DG2TM, DG3UD	0.07
DG2TM, DG3UD	0.08	DG3TM, DG2UD	0.07	DG3TM, DG1UD	0.07
DG3TM, DG1UD	0.08	DG3TM, DG1UD	0.07	DG3TM, DG2UD	0.07
DG3TM, DG2UD	0.08	DGHEC	0.06	DGHEC	0.06

Table 9.8.36. Joseph M. Farley, onsite results

T = 0 h	Undependability = 2.4 x 10^{-4}	T = 10 h	Undependability = 2.8 x 10^{-4}	T = 30 h	Undependability = 3.1 x 10^{-4}
Basic Event	**Importance**	**Basic Event**	**Importance**	**Basic Event**	**Importance**
DGHEC	0.39	DGCCF	0.34	DGCCF	0.38
DGCCF	0.35	DGHEC	0.34	DGHEC	0.31
DG2UD, DG4UD	0.16	DG2UD, DG4UD	0.22	DG2UD, DG4UD	0.21
DG1UD, DG3UD, DG5UD	0.15	DG1UD, DG3UD, DG5UD	0.20	DG1UD, DG3UD, DG5UD	0.20
Cut Set	**Importance**	**Cut Set**	**Importance**	**Cut Set**	**Importance**
DGHEC	0.39	DGCCF	0.34	DGCCF	0.38
DGCCF	0.35	DGHEC	0.34	DGHEC	0.31

Table 9.8.37. James A. FitzPatrick, onsite results

T = 0 h	Undependability = 2.2×10^{-4}	T = 10 h	Undependability = 3.7×10^{-4}	T = 30 h	Undependability = 7.4×10^{-4}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
SWCCF	0.37	SWCCF	0.52	SWCCF	0.57
DGHEC	0.33	DGHEC	0.19	SW1UD, SW2UD	0.12
DGCCF	0.17	DGCCF	0.11	DG1UD, DG2UD, DG3UD, DG4UD	0.12
		SW1UD, SW2UD	0.09	DGHEC	0.10
				DGCCF	0.07
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
SWCCF	0.37	SWCCF	0.52	SWCCF	0.57
DGHEC	0.33	DGHEC	0.19	DGHEC	0.10
DGCCF	0.17	DGCCF	0.11	BACCF	0.07
				DG1UD, DG2UD, DG3UD, DG4UD	0.06
				SW1UD, SW2UD	0.06
				DG1UD, DG3UD, SW2UD	0.05
				SW1UD, DG2UD, DG4UD	0.05

Table 9.8.38. Edwin I. Hatch 1 and 2, onsite results

T = 0 h	Undependability = 2.5×10^{-3}	T = 10 h	Undependability = 3.5×10^{-3}	T = 30 h	Undependability = 6.1×10^{-3}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DGCCF	0.73	DGCCF	0.58	DGCCF	0.4
SW1UD	0.09	SW1UD	0.2	SW1UD	0.31
DG2UD, DG4UD	0.08	DG2UD, DG4UD	0.15	DG2UD, DG4UD	0.24
SW1TM	0.07	SW1TM	0.07	DG1UD, DG3UD, DG5UD	0.11
DGHEC	0.05	SWCCF	0.06	SWCCF	0.07
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DGCCF	0.73	DGCCF	0.58	DGCCF	0.4
DGHEC	0.05	DG2UD, SW1UD	0.08	DG2UD, SW1UD	0.14
		DG4UD, SW1UD	0.08	DG4UD, SW1UD	0.14
		SWCCF	0.06	SWCCF	0.07

Table 9.8.39. Millstone 1, onsite results

T = 0 h	Undependability = 1.1×10^{-3}	T = 10 h	Undependability = 3.1×10^{-3}	T = 30 h	Undependability = 6.6×10^{-3}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
GT1UD	0.76	GT1UD	0.91	GT1UD	0.96
DG1UD	0.51	DG1UD	0.74	DG1UD	0.82
OSHEC	0.15	SW1UD	0.12	SW1UD	0.11
SW1UD	0.12	SW1TM	0.052		
SW1TM	0.12	OSHEC	0.051		
OSCCF	0.082				
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
GT1UD, DG1UD	0.51	GT1UD, DG1UD	0.74	GT1UD, DG1UD	0.82
OSHEC	0.15	GT1UD, SW1UD	0.12	GT1UD, SW1UD	0.11
SW1TM, GT1UD	0.12	GT1UD, SW1TM	0.052		
GT1UD, SW1UD	0.11	OSCCF	0.051		
OSCCF	0.082				

Table 9.8.40. Nine Mile Point, onsite results

T = 0 h	Undependability = 1.5×10^{-3}	T = 10 h	Undependability = 3.1×10^{-3}	T = 30 h	Undependability = 8.2×10^{-3}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DGHEC	0.60	DG1UD, DG2UD	0.49	DG1UD, DG2UD	0.72
DG1UD, DG2UD	0.17	DGHEC	0.29	DGHEC	0.11
DGCCF	0.10	SWCCF	0.06	SW1UD, SW2UD	0.07
SWCCF	0.05	SW1UD, SW2UD	0.06	SWCCF	0.05
		DGCCF	0.05		
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DGHEC	0.60	DG2UD, DG1UD	0.40	DG2UD, DG1UD	0.63
DG2UD, DG1UD	0.11	DGHEC	0.29	DGHEC	0.11
DGCCF	0.10	SWCCF	0.06	DG2UD, SW1UD	0.06
SWCCF	0.05	DGCCF	0.05	SW2UD, DG1UD	0.06
				SWCCF	0.05

Table 9.8.41. Peach Bottom 2 and 3, onsite results

T = 0 h	Undependability = 9.8×10^{-4}	T = 10 h	Undependability = 1.7×10^{-3}	T = 30 h	Undependability = 3.9×10^{-3}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DGCCF	0.61	DGCCF	0.38	DG1UD, DG2UD, DG3UD and DG4UD	0.24
DGHEC	0.20	SW1UD and SW2UD	0.14	SW1UD and SW2UD	0.22
SWCCF	0.08	DGHEC	0.12	DGCCF	0.20
		SWCCF	0.11	SWCCF	0.11
		DG1UD, DG2UD, DG3UD, DG4UD	0.11	DGHEC	0.05
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DGCCF	0.61	DGCCF	0.38	DGCCF	0.20
DGHEC	0.20	DGHEC	0.12	SWCCF	0.11
SWCCF	0.08	SWCCF	0.11	DG1UD, SW2UD	0.10
		DG1UD, SW2UD	0.06	DG2UD, SW1UD	0.10
		DG2UD, SW1UD	0.06	DG3UD, SW2UD	0.10
		DG3UD, SW2UD	0.06	DG4UD, SW1UD	0.10
		DG4UD, SW1UD	0.06	DGHEC	0.05

Table 9.8.42. St. Lucie, onsite results

T = 0 h	Undependability = 5.5×10^{-3}	T = 10 h	Undependability = 8.3×10^{-3}	T = 30 h	Undependability = 1.2×10^{-2}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DG1UD, DG2UD	0.80	DG1UD, DG2UD	0.86	DG1UD, DG2UD	0.9
DGHEC	0.16	DGHEC	0.11	DGHEC	0.07
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DG1UD, DG2UD	0.77	DG1UD, DG2UD	0.83	DG1UD, DG2UD	0.88
DGHEC	0.16	DGHEC	0.11	DGHEC	0.07

Table 9.8.43. San Onofre, onsite results

T = 0 h	Undependability = 1.3 x 10^{-3}	T = 10 h	Undependability = 2.1 x 10^{-3}	T = 30 h	Undependability = 3.3 x 10^{-3}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DG1UD, DG2UD	0.44	DG1UD, DG2UD	0.64	DG1UD, DG2UD	0.76
DGHEC	0.41	DGHEC	0.24	DGHEC	0.16
DG1TM, DG2TM	0.10	DG1TM, DG2TM	0.09	DG1TM, DG2TM	0.06
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DGHEC	0.41	DG1UD, DG2UD	0.55	DG1UD, DG2UD	0.70
DG1UD, DG2UD	0.34	DGHEC	0.24	DGHEC	0.16
DG1TM, DG2UD	0.10	DG1TM, DG2UD	0.09	DG1TM, DG2UD	0.06
DG2TM, DG1UD	0.10	DG2TM, DG1UD	0.09	DG2TM, DG1UD	0.06

Table 9.8.44. Turkey Point 3 & 4, onsite results

T = 0 h	Undependability = 2.6 x 10^{-3}	T = 10 h	Undependability = 4.8 x 10^{-3}	T = 30 h	Undependability = 1.0 x 10^{-2}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DG1UD, DG2UD	0.50	DG1UD, DG2UD	0.69	DG1UD, DG2UD	0.83
DGCCF	0.22	DGCCF	0.13	DGCCF	0.07
DGHEC	0.20	DGHEC	0.11	DGHEC	0.05
DG1TM, DG2TM	0.08	DG1TM, DG2M	0.07	DG1TM, DG2TM	0.05
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DG1UD, DG2UD	0.42	DG1UD, DG2UD	0.62	DG1UD, DG2UD	0.79
DGCCF	0.22	DGCCF	0.13	DGCCF	0.07
DGHEC	0.20	DGHEC	0.11	DGHEC	0.05
DG1TM, DG2UD	0.08	DG1TM, DG2UD	0.07	DG1TM, DG2UD	0.05
DG2TM, DG1UD	0.08	DG2TM, DG1UD	0.07	DG2TM, DG1UD	0.05

Table 9.8.45. Yankee (Rowe, Mass.) onsite results

T = 0 h	Undependability = 7.2 x 10^{-4}	T = 10 h	Undependability = 8.0 x 10^{-4}	T = 30 h	Undependability = 1.3 x 10^{-3}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DGCCF	0.82	DGCCF	0.80	DGCCF	0.57
DGHEC	0.17	DGHEC	0.15	DG1UD, DG2UD and DG3UD	0.33
				DGHEC	0.09
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DGCCF	0.82	DGCCF	0.80	DGCCF	0.57
DGHEC	0.17	DGHEC	0.15	DG1UD, DG2UD, DG3UD	0.33
				DGHEC	0.09

Table 9.8.46. 2 of 5, air-cooled, onsite results

T = 0 h	Undependability = 1.4 x 10^{-4}	T = 10 h	Undependability = 1.6 x 10^{-4}	T = 30 h	Undependability = 2.3 x 10^{-4}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DGHEC	0.67	DGHEC	0.58	DGHEC	0.41
DGCCF	0.18	DGCCF	0.18	DG2UD and DG4UD	0.29
BACCF	0.07	DG2UD, DG4UD	0.12	DG1UD, DG3UD, and DG5UD	0.28
		DG1UD, DG3UD, DG5UD	0.1	DGCCF	0.15
		BACCF	0.06		
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DGHEC	0.67	DGHEC	0.58	DGHEC	0.41
DGCCF	0.18	DGCCF	0.18	DGCCF	0.15
BACCF	0.07	BACCF	0.06	DG1UD, DG2UD, DG3UD, DG4UD	0.06
				DG1UD, DG2UD, DG3UD, DG5UD	0.06
				DG1UD, DG2UD, DG4UD, DG5UD	0.06
				DG1UD, DG3UD, DG4UD, DG5UD	0.06
				DG2UD, DG3UD, DG4UD, DG5UD	0.06

Table 9.8.47. 2 of 5, service water-cooled, onsite results

T = 0 h	Undependability = 5.3×10^{-4}	T = 10 h	Undependability = 1.1×10^{-3}	T = 30 h	Undependability = 2.2×10^{-3}
Basic Event	**Importance**	**Basic Event**	**Importance**	**Basic Event**	**Importance**
SW1UD	0.25	SW1UD	0.42	SW1UD	0.54
DG2UD, DG4UD	0.2	DG2UD, DG4UD	0.26	DG2UD, DG4UD	0.31
SW1TM	0.2	SWCCF	0.18	SWCCF	0.19
DGHEC	0.18	SW1TM	0.15	SW1TM	0.08
DGCCF	0.16	DGCCF	0.09	SW2UD	0.06
SWCCF	0.15	DGHEC	0.09	DG1UD, DG3UD, and DG5UD	0.06
				DGCCF	0.05
Cut Set	**Importance**	**Cut Set**	**Importance**	**Cut Set**	**Importance**
DGHEC	0.18	SWCCF	0.18	DG2UD, SW1UD	0.24
DGCCF	0.16	DG2UD, SW1UD	0.18	DG4UD, SW1UD	0.24
SWCCF	0.15	DG4UD, SW1UD	0.18	SWCCF	0.19
DG2UD, SW1UD	0.10	DGCCF	0.09	DGCCF	0.05
DG4UD, SW1UD	0.10	DGHEC	0.09		
DG2UD, SW1TM	0.10	DG2UD, SW1TM	0.07		
DG4UD, SW1TM	0.10	DG4UD, SW1TM	0.07		

Table 9.8.48. 1 of 3, air-cooled, onsite resuts

T = 0 h	Undependability = 1.8×10^{-4}	T = 10 h	Undependability = 2.7×10^{-4}	T = 30 h	Undependability = 5.0×10^{-4}
Basic Event	**Importance**	**Basic Event**	**Importance**	**Basic Event**	**Importance**
DGHEC	0.66	DGHEC	0.45	DG1UD, DG2UD	0.65
DGCCF	0.13	DG1UD, DG2UD	0.38	DG3UD	0.65
DG1UD, DG2UD	0.13	DG3UD	0.38	DGHEC	0.24
DG3UD	0.13	DGCCF	0.10	DGCCF	0.06
BACCF	0.06				
Cut Set	**Importance**	**Cut Set**	**Importance**	**Cut Set**	**Importance**
DGHEC	0.66	DGHEC	0.45	DG1UD, DG2UD, DG3UD	0.57
DGCCF	0.13	DG1UD, DG2UD, DG3UD	0.30	DGHEC	0.23
DG1UD, DG2UD, DG3UD	0.09	DGCCF	0.10	DGCCF	0.07
BACCF	0.06				

Table 9.8.49. 1 of 3, service water-cooled, onsite results

T = 0 h	Undependability = 3.0×10^{-4}	T = 10 h	Undependability = 5.3×10^{-4}	T = 30 h	Undependability = 1.1×10^{-3}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DGHEC	0.39	SWCCF	0.36	SWCCF	0.40
SWCCF	0.26	DGHEC	0.23	DG3UD	0.35
DGCCF	0.2	DG3UD	0.22	DG1UD, DG2UD	0.33
DG3UD	0.09	DG1UD, DG2UD	0.20	DGHEC	0.11
DG1UD, DG2UD	0.08	DGCCF	0.12	DGCCF	0.07
				SW1UD, SW2UD	0.06
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DGHEC	0.39	SWCCF	0.36	SWCCF	0.40
SWCCF	0.26	DGHEC	0.23	DG1UD, DG2UD, DG3UD	0.27
DGCCF	0.2	DG1UD, DG2UD, DG3UD	0.15	DGHEC	0.11
DG1UD, DG2UD, DG3UD	0.05	DGCCF	0.12	DGCCF	0.07

Table 9.8.50. 2 of 4, air-cooled, onsite results

T = 0 h	Undependability = 3.7×10^{-4}	T = 10 h	Undependability = 7.1×10^{-4}	T = 30 h	Undependability = 1.7×10^{-3}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DGHEC	0.53	DG1UD, DG2UD, DG3UD, DG4UD	0.42	DG1UD, DG2UD, DG3UD, DG4UD	0.59
DG1UD, DG2UD, DG3UD, DG4UD	0.19	DGHEC	0.28	DGHEC	0.12
DGCCF	0.12	DGCCF	0.07		
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DGHEC	0.53	DGHEC	0.28	DG1UD, DG2UD, DG3UD	0.17
DGCCF	0.12	DG1UD, DG2UD, DG3UD	0.11	DG1UD, DG2UD, DG4UD	0.17
		DG1UD, DG2UD, DG4UD	0.11	DG1UD, DG3UD, DG4UD	0.17
		DG1UD, DG3UD, DG4UD	0.11	DG2UD, DG3UD, DG4UD	0.17
		DG2UD, DG3UD, DG4UD	0.11	DGHEC	0.12
		DGCCF	0.07		

Table 9.8.51. 2 of 4, service water-cooled, onsite results

T = 0 h	Undependability = 1.0×10^{-3}	T = 10 h	Undependability = 2.2×10^{-3}	T = 30 h	Undependability = 4.8×10^{-3}
Basic Event	**Importance**	**Basic Event**	**Importance**	**Basic Event**	**Importance**
DGHEC	0.20	DG1UD, DG2UD, DG3UD, DG4UD	0.26	DG1UD, DG2UD, DG3UD, DG4UD	0.33
DG1UD, DG2UD, DG3UD, DG4UD	0.17	SW1UD, SW2UD	0.20	SW1UD, SW2UD	0.24
DGCCF	0.15	DGHEC	0.09	SWCCF	0.09
SW1UD, SW2UD	0.13	SWCCF	0.09		
SW1TM, SW2TM	0.10	DGCCF	0.07		
SWCCF	0.08	SW1TM, SW2TM	0.07		
Cut Set	**Importance**	**Cut Set**	**Importance**	**Cut Set**	**Importance**
DGHEC	0.20	DGHEC	0.09	DG1UD, SW2UD	0.11
DGCCF	0.15	SWCCF	0.09	DG2UD, SW1UD	0.11
SWCCF	0.08	DG1UD, SW2UD	0.09	DG3UD, SW2UD	0.11
DG1UD, SW2UD	0.05	DG2UD, SW1UD	0.09	DG4UD, SW1UD	0.11
DG2UD, SW1UD	0.05	DG3UD, SW2UD	0.09	SWCCF	0.09
DG3UD, SW2UD	0.05	DG4UD, SW1UD	0.09	DG1UD, DG2UD, DG3UD	0.06
DG4UD, SW1UD	0.05	DGCCF	0.07	DG1UD, DG2UD, DG4UD	0.06
DG1UD, SW2TM	0.05			DG1UD, DG3UD, DG4UD	0.06
DG2UD, SW1TM	0.05			DG2UD, DG3UD, DG4UD	0.06
DG3UD, SW2TM	0.05				
DG4UD, SW1TM	0.05				

Table 9.8.52. 1 of 2, air-cooled, onsite results

T = 0 h	Undependability = 1.5×10^{-3}	T = 10 h	Undependability = 3.2×10^{-3}	T = 30 h	Undependability = 7.0×10^{-3}
Basic Event	**Importance**	**Basic Event**	**Importance**	**Basic Event**	**Importance**
DG1UD, DG2UD	0.53	DG1UD, DG2UD	0.73	DG1UD, DG2UD	0.86
DGHEC	0.34	DGHEC	0.16	DGHEC	0.07
DG1TM, DG2TM	0.10	DG1TM, DG2TM	0.08	DG1TM, DG2TM	0.05
Cut Set	**Importance**	**Cut Set**	**Importance**	**Cut Set**	**Importance**
DG1UD, DG2UD	0.41	DG1UD, DG2UD	0.65	DG1UD, DG2UD	0.81
DGHEC	0.34	DGHEC	0.16	DGHEC	0.07
DG1TM, DG2UD	0.10	DG1TM, DG2UD	0.08	DG1TM, DG2UD	0.05
DG2TM, DG1UD	0.10	DG2TM, DG1UD	0.08	DG2TM, DG1UD	0.05

Table 9.8.53. 1 of 2, service-water-cooled, onsite results

T = 0 h	Undependability = 1.9×10^{-3}	T = 10 h	Undependability = 4.1×10^{-3}	T = 30 h	Undependability = 8.9×10^{-3}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DG1UD, DG2UD	0.46	DG1UD, DG2UD	0.63	DG1UD, DG2UD	0.75
DGHEC	0.27	DGHEC	0.13	SW2UD, SW1UD	0.07
DG1TM, DG2TM	0.09	DG1TM, DG2TM	0.07	DGHEC	0.06
DGCCF	0.07	SW1UD, SW2UD	0.06		
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DG1UD, DG2UD	0.33	DG1UD, DG2UD	0.50	DG1UD, DG2UD	0.64
DGHEC	0.27	DGHEC	0.13	DGHEC	0.06
DG1TM, DG2UD	0.08	DG1TM, DG2UD	0.07	DG1UD, SW2UD	0.06
DG2TM, DG1UD	0.08	DG2TM, DG1UD	0.07	DG2UD, SW1UD	0.06
DGCCF	0.08				

Table 9.8.54. 2 of 3, air-cooled, onsite results

T = 0 h	Undependability = 4.2×10^{-3}	T = 10 h	Undependability = 9.2×10^{-3}	T = 30 h	Undependability = 2.1×10^{-2}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DG3UD	0.37	DG3UD	0.50	DG3UD	0.58
DG1UD, DG2UD	0.37	DG1UD, DG2UD	0.50	DG1UD, DG2UD	0.58
DGHEC	0.31	DGHEC	0.14	DGHEC	0.06
DG3TM	0.07	DG3TM	0.06		
DG1TM, DG2TM	0.07	DG1TM, DG2TM	0.06		
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DGHEC	0.31	DG1UD, DG2UD	0.22	DG1UD, DG2UD	0.27
DG1UD, DG2UD	0.15	DG1UD, DG3UD	0.22	DG1UD, DG3UD	0.27
DG1UD, DG3UD	0.15	DG2UD, DG3UD	0.22	DG2UD, DG3UD	0.27
DG2UD, DG3UD	0.15	DGHEC	0.14	DGHEC	0.06

Table 9.8.55. 2 of 3, service water-cooled, onsite results

T = 0 h	Undependability = 5.0×10^{-3}	T = 10 h	Undependability = 1.1×10^{-2}	T = 30 h	Undependability = 2.4×10^{-2}
Basic Event	Importance	Basic Event	Importance	Basic Event	Importance
DG3UD	0.35	DG3UD	0.48	DG3UD	0.55
DG1UD, DG2UD	0.33	DG1UD, DG2UD	0.45	DG1UD, DG2UD	0.53
DGHEC	0.26	DGHEC	0.12	DGHEC	0.05
DGCCF	0.07	DG3TM	0.05		
DG3TM	0.07	DG1TM, DG2TM	0.05		
DG1TM, DG2TM	0.06				
Cut Set	Importance	Cut Set	Importance	Cut Set	Importance
DGHEC	0.26	DG1UD, DG2UD	0.19	DG1UD, DG2UD	0.24
DG1UD, DG2UD	0.12	DG1UD, DG3UD	0.19	DG1UD, DG3UD	0.24
DG1UD, DG3UD	0.12	DG2UD, DG3UD	0.19	DG2UD, DG3UD	0.24
DG2UD, DG3UD	0.12	DGHEC	0.12	DGHEC	0.05
DGCCF	0.07				

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