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Risk Evaluation for a Westinghouse PWR, Effects of Fire Protection System Actuation on Safety-Related Equipment

Evaluation of Generic Issue 57

Prepared by
J. Lambright, D. Brosseau, M. Bohn, S. Daniel

Sandia National Laboratories
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Prepared by
J. Lambright, D. Brosseau*, M. Bohn, S. Daniel

Sandia National Laboratories
Albuquerque, NM 87185

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*ERCE, Inc.
7301A Indian School Road, N.E.
Albuquerque, NM 87110

DOCUMENTS IN SERIES

This report is one of a series of reports documenting the technical findings associated with the resolution of Generic Issue 57: Effects of Fire Protection Systems on Safety-Related Equipment.

There are several reports published in association with the resolution of Generic Issue 57. These are:

NUREG/CR-5580, SAND90-1507, Evaluation of Generic Issue 57: Effects of Fire Protection System Actuation on Safety-Related Equipment, Main Report, December 1992.

NUREG/CR-5789, SAND91-1534, Risk Evaluation for a Westinghouse PWR, Effects of Fire Protection System Actuation on Safety-Related Equipment: Evaluation of Generic Issue 57, December 1992.

NUREG/CR-5791, SAND91-1536, Risk Evaluation for a General Electric BWR, Effects of Fire Protection System Actuation on Safety-Related Equipment: Evaluation of Generic Issue 57, December 1992.

NUREG/CR-5790, SAND91-1535, Risk Evaluation for a Babcock & Wilcox Pressurized Water Reactor, Effects of Fire Protection System Actuation on Safety-Related Equipment (Evaluation of Generic Issue 57), September 1992.

NUREG/CR-5906, SAND92-1547, Decision Making Under Uncertainty: An Investigation Into the Application of Formal Decision-Making Methods to Safety Issue Decisions, December 1992.

Letter Report, EGG-NTA-9081, Risk Evaluation of a Westinghouse 4-Loop PWR, Effects of Fire Protection System Actuation on Safety-Related Equipment (Evaluation of Generic Issue 57), Idaho National Engineering Laboratory, December 1991.

Letter Report, Seismic Risk Evaluation for a Pressurized Water Reactor, Effects of Fire Protection System Actuation on Safety-Related Equipment, Sandia National Laboratories, December 1991.

ABSTRACT

Nuclear power plants have experienced actuations of fire protection systems (FPSs) under conditions for which these systems were not intended to actuate, and also have experienced advertent actuations with the presence of a fire. These actuations have often damaged nearby plant equipment.

A review of the impact of past occurrences of both types of such events, a quantification of the risk of FPS actuation, a sensitivity study of the quantification of the risk of FPS actuation and risk calculations in terms of person-REM have been performed. Thirteen different scenarios leading to actuation of fire protection systems due to a variety of causes were identified. A quantification of these thirteen scenarios, where applicable, was performed on a 3-loop Westinghouse Pressurized Water Reactor (PWR). These scenarios ranged from inadvertent actuation caused by human error to hardware failures, and include seismic root causes and seismic/fire interaction. This report estimates the contribution of FPS actuations to core damage frequency and risk.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

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EXECUTIVE SUMMARY

In recent years, fire protection systems (FPSs) in nuclear power plants have actuated at times and under conditions for which they were not intended to actuate, as well as actuating in the presence of a fire, and have often affected and even damaged adjacent plant equipment. To quantify the risk due to this issue, a study was performed which involved: (a) a review of pertinent Licensee Event Reports of industry experience with FPS actuations, (b) a review of Navy experience with FPS actuations, and (c) a quantification of potential scenarios for three commercial nuclear power plants as well as for a set of generically applicable scenarios. This study was conducted as a part of the analysis conducted for resolution of U.S. NRC Generic Issue 57.

In the quantification portion of the study, thirteen different causal mechanisms were identified which could result in fire protection system actuations. A set of criteria was developed for identifying such accident scenarios leading to core damage. These criteria can be applied to probabilistic risk assessment (PRA) vital area analysis for any particular plant in question to identify those accident sequences and cut sets which would lead to core damage (assuming the FPS actuation damages critical equipment in the fire zone affected).

Inasmuch as these scenarios are plant-specific in regard to plant layout and types of fire protection systems present, three plants were selected for the quantification. The criteria developed were applied to two commercial pressurized water reactors (PWRs) and one commercial boiling water reactor (BWR). These plants were selected because each had a detailed PRA and supporting analyses available. This report presents the application of the methodology to a 3-loop Westinghouse PWR.

Using the complete set of accident sequences developed in a previous PRA for the plant, a full set of scenarios based on fire protection system actuations was analyzed. For each accident sequence identified, values for the various parameters involved were chosen, and an estimate of the impact on core damage and risk due to FPS actuation was made. Although an effort was made to use parameter estimates from existing data bases where available, some simplifying assumptions were required due to lack of data.

The risk calculations were performed employing a methodology similar to WASH-1400. An uncertainty analysis was performed for the core damage frequency and risk calculations. The results of the quantification found a total mean contribution to annual core damage frequency of 7.3E-6/ry and total dose of 6.8 person-REM.

1.0 INTRODUCTION

1.1 Scope

Experience in recent years has shown that fire protection systems in nuclear power plants have actuated at times and under conditions for which they were not intended to actuate as well as when intended in the presence of a fire. Since these FPSs are located near the critical equipment they are designed to protect, these actuations have often affected and even caused damage to this adjacent critical plant equipment. On some occasions, the damage has been to safety related equipment, that is, equipment required to ensure the capability to safely shutdown the plant. On other occasions, the damage has been to equipment required for the normal operation of the plant and the reactor was subsequently shutdown. As a consequence, the actuation of fire protection systems represents a potentially important safety issue requiring further study.

In the recently completed Fire Risk Scoping Study (Ref. 1.1), the inadvertent actuation of fire protection systems in commercial United States nuclear power plants was briefly reviewed. Seventy-one events resulting in submission of a Licensee Event Report (LER) were identified during the period from April 1, 1980 to July 14, 1987. The average frequency of occurrence of these inadvertent actuation events was found to be approximately 10 per year.

The Fire Risk Scoping Study was limited in scope and did not attempt to quantify the attendant contribution to core damage frequency (CDF) resulting from the inadvertent actuation of FPS's, primarily because the impact of inadvertent fire protection system actuations was found to be very plant specific. It was concluded that such events could significantly impact the risk at a specific plant only if multiple safety systems could be affected by the inadvertent fire protection system actuation event.

As a follow-on to the Fire Risk Scoping Study, a preliminary study including a scoping quantification of risk due to inadvertent FPS actuation was performed (Ref. 1.2). This study quantified the core damage frequency and risk at one generic PWR. This analysis indicated that the increase in core damage frequency due to inadvertent FPS actuations could range from 10^{-5} to 10^{-4} per reactor year.

The current study, U.S. NRC Generic Issue 57, of which this report is a part, entitled "Effects of Fire Protection System Actuation on Safety-Related Equipment," was begun in 1989. In this study, six main potential causes of inadvertent and advertent actuations of fire protection systems have been identified, as shown on Table 1.1. For the general cases of random and seismic-induced actuations, several potential root causes are also shown.

The objective of this study was to provide a probabilistic basis on which to evaluate the impact on plant core damage frequency and risk of fire protection system actuations. This objective was accomplished by first reviewing past events involving fire protection system actuations. The

Table 1.1

Causes of Potential FPS Actuation

A. Random causes of inadvertent actuation

   Human error (Root Cause 4)

   Hardware failure (Root Cause 6)

   Unknown (Root Cause 13)

B. Actuation induced by fire or by steam pipe break in an adjacent area and smoke/steam spread

   Fire in adjacent zone causing FPS actuation (Root Cause 1)

   Fire-induced FPS actuation (due to fire in adjacent zone) preventing random failure recovery action (Root Cause 2)

   Fire-induced FPS actuation (due to fire in adjacent zone) preventing access for manual fire suppression (Root Cause 3)

   FPS actuation caused by steam release (Root Cause 5)

C. Seismic induced inadvertent actuation

   Dust actuating smoke detectors (Root Cause 7)

   Failure of FPS (e.g., failure of wet pipes, sprinkler heads, etc.) (Root Cause 9)

   Actuation caused by FPS control system relay chatter (Root Cause 8)

D. Seismic induced failure of the FPS, diverting suppression agent from an area where a fire is present (Root Cause 12)

E. Fire external to plant (smoke via ventilation system) (Root Cause 10)

F. Fire present where the FPS is located (Root Cause 11) actuations were then categorized in order to draw some useful conclusions about the causes and effects of these actuations. A quantification of the impacts of such events including sensitivity and uncertainty studies, was performed both in terms of reduction in core damage frequency and risk for the scenarios identified. Finally, risk calculations in terms of person-REM, were performed.

1.2 Methodology

Chapter 3 of NUREG/CR-5580 (Ref. 1.3) presented the overall methodology that is used to evaluate the effects of fire protection system (FPS) actuations on nuclear power plant risk. The objective of the analysis presented in this report is to extend the general methodology to one of a set of representative nuclear plants. In this case, the plant selected is a 3-loop Westinghouse PWR. Using data from industry experience and parametric values used in prior applicable PRA studies, a quantitative assessment of the incremental contribution to core damage frequency due to FPS actuations was performed.

The analysis of the thirteen root causes introduced in Section 3.2 of Reference 1.3 is being applied on a site-specific basis. The actual site being studied is unimportant and will not be named. As the safety significance of FPS actuations is highly plant-specific and is dependent on system inter-dependencies derived from plant event tree and fault tree models, it follows that those models available for the specific plant in question must be used in the analysis. In this case, system models developed as part of the NUREG-1150 study (Ref. 1.4), augmented by site visits, were used as the basis for quantification in this report.

1.3 Organization of the Report

A description of the plant systems and general plant characteristics is provided in Chapter 2. The system descriptions include simplified schematics which depict major system components.

The base case analysis (best estimate) of core damage frequency due to FPS actuations is described in Chapter 3. This analysis addresses all of the root causes presented in Reference 1.3 that apply to this nuclear power plant. This chapter also contains a description of where vital equipment is located throughout the plant, plant fire protection system locations, and an application of the methodology including results in terms of core damage frequency by root cause and by fire zone.

Chapter 4 describes the sensitivity analyses performed and the overall effect on the base case results. These studies are very plant specific, but the issues considered would likely apply to any "typical" Westinghouse PWR. In Chapter 5, the "back end" risk calculations (in terms of offsite person-REM exposure) are described.

1.4 References

1.1 J. A. Lambright, et al., Fire Risk Scoping Study: Investigation of Nuclear Power Plant Fire Risk, Including Previously Unaddressed Issues, NUREG/CR-5088, SAND88-0177, Sandia National Laboratories, November 1988.

1.2 J. C. Romig, et al., Scoping Study of the Potential Impacts of Inadvertent Fire Suppression System Actuations in Commercial Nuclear Power Plants (Letter Report), Sandia National Laboratories, May 1990.

1.3 J. A. Lambright, et al., Evaluation of Generic Issue 57: Effects of Fire Protection System Actuation or Safety-Related Equipment, Main Report, NUREG/CR-5580, SAND91-1507, Sandia National Laboratories, December 1992.

1.4 M. P. Bohn and J. A. Lambright, NUREG/CR-4550, Rev. 1/Vol. 3, Part 3, SAND86-2084, Sandia National Laboratories, December 1990.

2.0 PLANT DESCRIPTION

2.1 Plant, Site and General Characteristics

The PWR studied, which shares its site with a twin unit, is rated at 781 MW. The reactor and generator for both the units were supplied by Westinghouse Electric Corporation. Stone and Webster Engineering Corporation was the Architect/Engineer/Constructor for these plants.

2.2 Description of Plant Systems

This section discusses the system descriptions and system models of the major frontline and support systems identified as important to safety in Reference 2.1. In addition to the event trees discussed in Section 3.2, component fault trees also developed by the internal events analysts were utilized. Use of the same event trees, fault trees, and accident sequences developed during the internal events analysis ensured consistency between these major studies.

The following discussion of the systems includes:

a. A brief functional description of the system with reference to the one-line diagrams that were developed to indicate which components were included in the model;

b. Safety-related success criteria that were applied to the system;

c. Interfaces and safety actuation provisions between the frontline systems and the support systems.

2.2.1 Containment Spray System

The containment spray system (CSS) provides the initial containment pressure reduction following an accident by spraying cool water from the RWST to condense steam in the containment. The CSS is composed of two 100 percent capacity spray injection trains. The CSS has no recirculation or pump cooling capability. Each spray train draws water from the RWST through independent suction lines. Each CSS pump takes suction through a normally open MOV and an in-line filter assembly. Each CSS pump discharges through a pair of normally closed MOVs arranged in parallel and through a check valve to its associated containment spray header. Both CSS pumps also feed a common third spray header (located on the outside of the crane wall) through separate check valves. A simplified schematic of the CSS is shown in Figure 2.1.

The CSS automatically starts on receipt of a Hi-Hi (25 psia) containment pressure signal from the consequence limiting control system (CLCS). The CLCS signals open the pump inlet and outlet valves and start the CSS pumps. An agastat timer in the pump start circuit delays pump start for

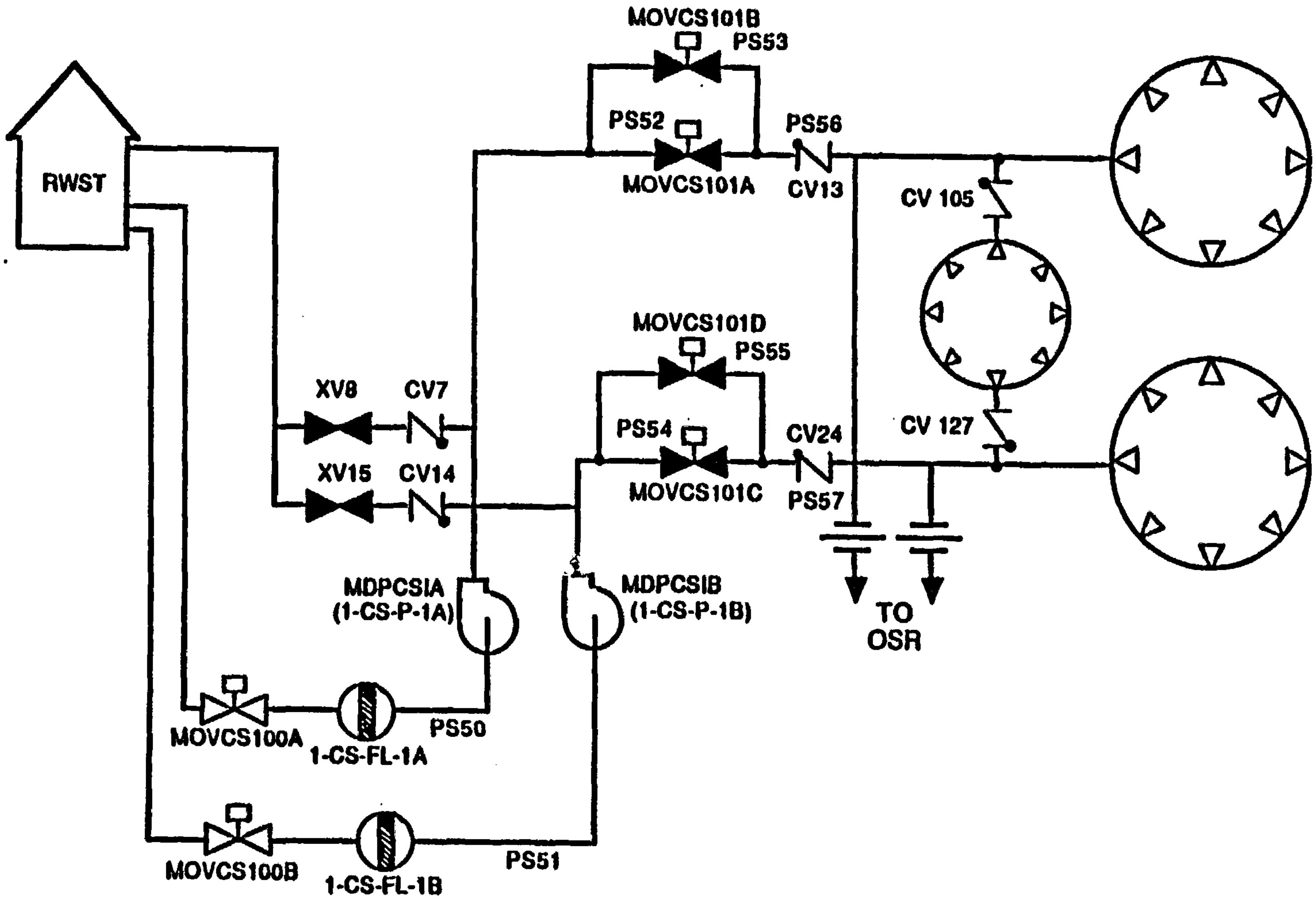


Figure 2.1. Containment Spray System Schematic.

30 seconds after receipt of the signal. The success criterion for the CSS is one of the two CSS trains that provides flow to any one containment spray header.

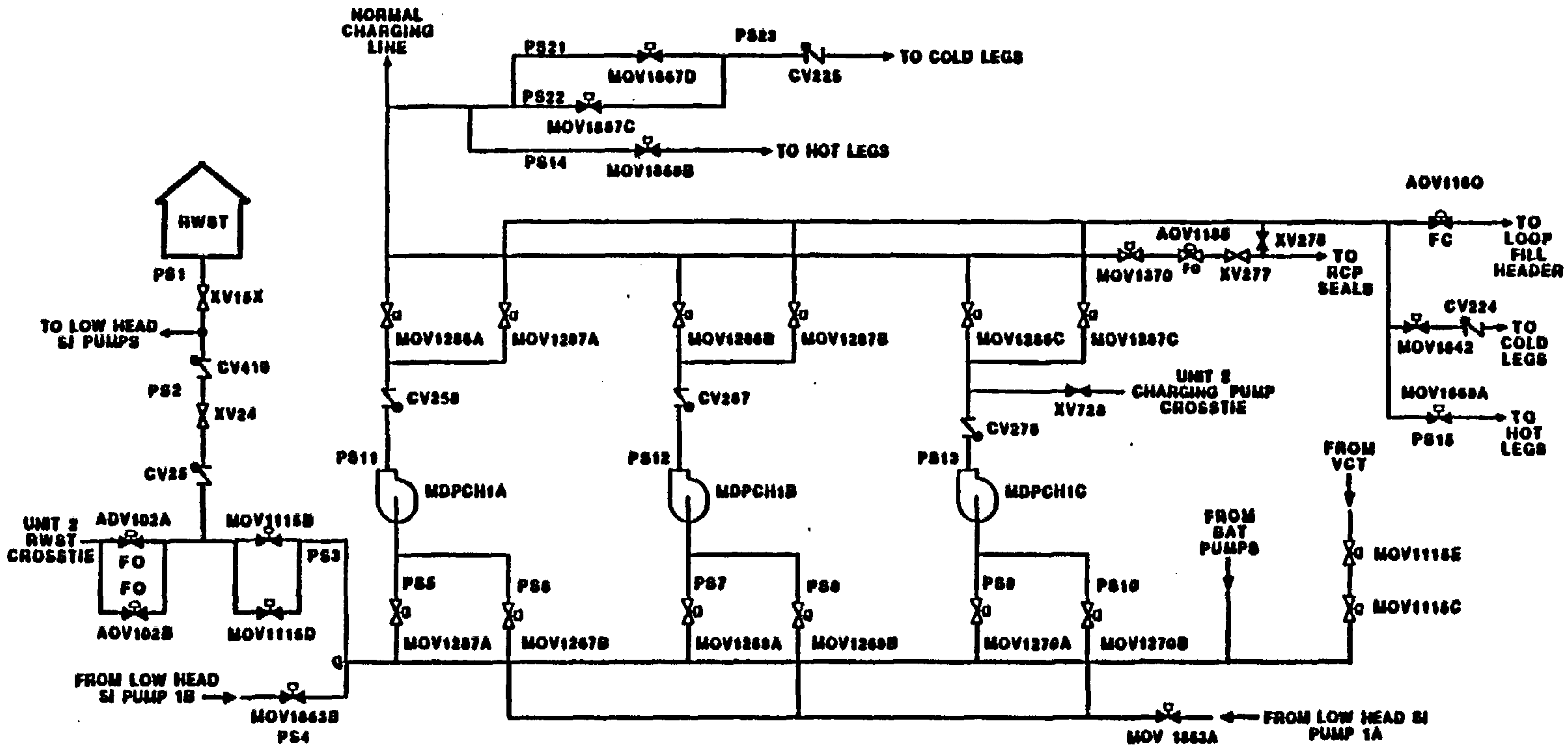
2.2.2 High Pressure Injection/Recirculation System

The charging system provides normal coolant makeup to the RCS and cooling flow to the RCP seals under normal operating conditions. The high pressure injection/recirculation (HPI/HPR) system uses the same charging pumps to provide primary coolant injection and recirculation following an accident, as well as maintaining flow to the RCP seals. The HPI system also functions to deliver boric acid to the RCS from the boric acid transfer system if emergency boration is required. Under normal operating conditions, one of the three charging pumps provides normal RCS makeup and cooling to the RCP seals by taking suction from the volume control tank (VCT) through two MOVs in series.

Upon indication of a loss of RCS coolant or steam line break (i.e., low pressurizer level, high containment pressure, high pressure differential between main steam header and any steam line, or high steam flow with low T_{AVG} or low steam line pressure), the safety injection actuation system (SIAS) initiates emergency coolant injection. The SIAS signals the normal charging line isolation valves to close, the standby charging pumps to start, the valves from the VCT to close, the normally open pump inlet and outlet MOVs to open, and a parallel set of normally closed MOVs to open to provide suction from the RWST. Also on receipt of an SIAS signal, a parallel set of normally closed MOVs open to provide flow from the pump discharge header to the three RCS cold legs. An additional path to the RCS cold legs through a manually operated normally closed MOV is also available. Flow through this line to the RCS is treated as a recovery action. The line to the RCP seals remains open throughout the event. The HPI system may also be used in the "feed and bleed" cooling mode. The only difference in this mode of operation from that discussed above is that an SIAS signal is not necessarily generated so the HPI system must be manually placed in service.

In the recirculation mode of operation, the charging pumps draw suction from the discharge of the low pressure safety injection pumps in the low pressure recirculation (LPR) system. Upon receipt of a low RWST level signal, the recirculation mode transfer (RMT) system signals the charging pump suction valves from the RWST to close and the suction valves from the LPR pump discharges to open.

In the emergency boration mode, the HPI functions as described above with the exception that the boric acid transfer (BAT) pumps deliver boric acid from the BAT tanks to the charging pump suction header. To perform this operation, the operator must switch the normally operating BAT pump to fast speed operation and open the MOV allowing flow into the charging pump suction header. To enhance boric acid addition to the RCS, the emergency procedure calls for the PORVs be opened (to provide pressure reduction). A simplified schematic of the HPI/HPR system, including the relevant portions of the BAT system is presented in Figure 2.2.



NOTE: PIPE SEGMENT (PSXX) REFERS TO PIPING AND COMPONENTS BETWEEN NODES

Figure 2.2. High Pressure Injection/Recirculation System Schematic.

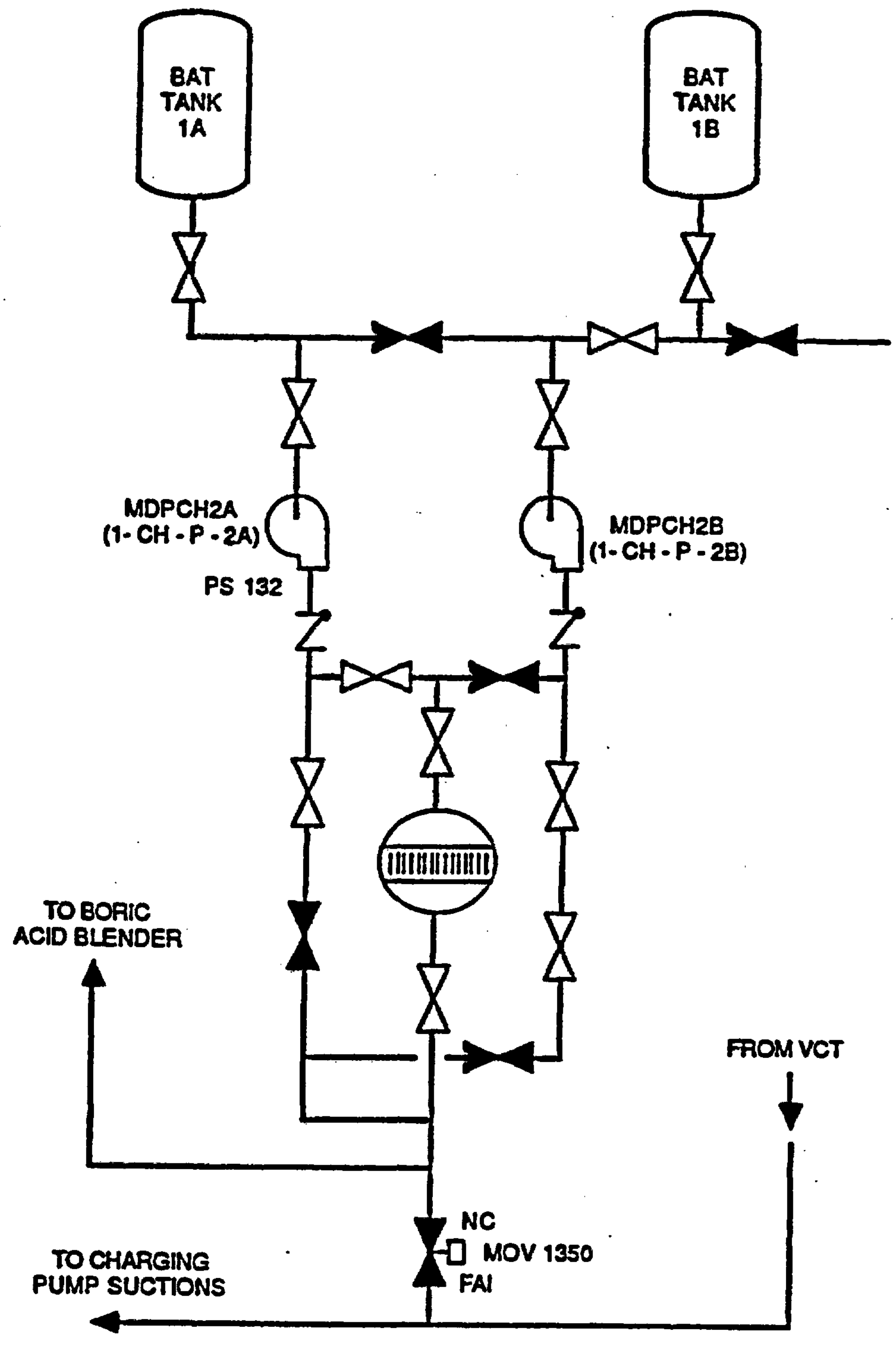


Figure 2.2. High Pressure Injection/Recirculation System Schematic (Concluded).

The success criteria for the HPI modes of operation require flow from any one of three charging pumps to the RCS cold legs in response to a LOCA (automatic actuation), flow from any one of three charging pumps to the RCS cold legs in the "feed and bleed" mode (manual actuation), flow from any one of the three charging pumps to the RCP seals, or flow from any one of three charging pumps to the RCS with flow from one of two BAT pumps operating at fast speed (emergency boration mode). The success criterion for the HPR mode of operation is continued flow from any one of the three charging pumps taking suction from the discharge of the low pressure recirculation system, given successful low pressure system operation.

2.2.3 Accumulator System

The accumulators provide an initial influx of borated water to reflood the reactor core following a large LOCA or a medium LOCA on the upper end of the LOCA size definition. The accumulator system consists of three tanks filled with borated water and pressurized with nitrogen. Each of the accumulators is connected to one of the RCS cold legs by a line containing a normally open MOV and two check valves in series. The check valves serve as isolation valves during normal reactor operation and open to empty the contents of the accumulator when the RCS pressure falls below 650 psig. A simplified schematic of the accumulators is shown in Figure 2.3.

The success criterion for the accumulators following a large LOCA, which assumes a cold leg break, is injection of the contents of the two accumulators associated with the intact cold legs into the RCS. The success criterion for the accumulators following a medium LOCA is injection of the contents of two or more accumulators into the RCS.

2.2.4 Low Pressure Injection/Recirculation System

The low pressure injection recirculation (LPI/LPR) system provides emergency coolant injection and recirculation following a loss of coolant accident when the RCS depressurizes below 300 psig. In addition to the direct recirculation of coolant during the recirculation phase once the RCS is depressurized, the LPR discharge provides the suction source for the HPR system following drainage of the RWST.

The LPI/LPR system is composed of two 100 percent capacity pump trains. The LPI/LPR has no heat removal capability. In the injection mode, the pump trains share a common suction header from the RWST. Each pump draws suction from the header through a normally open MOV, check valve, and locked open manual valve in series. Each pump discharges through a check valve and normally open MOV in series to a common injection header. The injection header contains a locked open MOV and branches to three

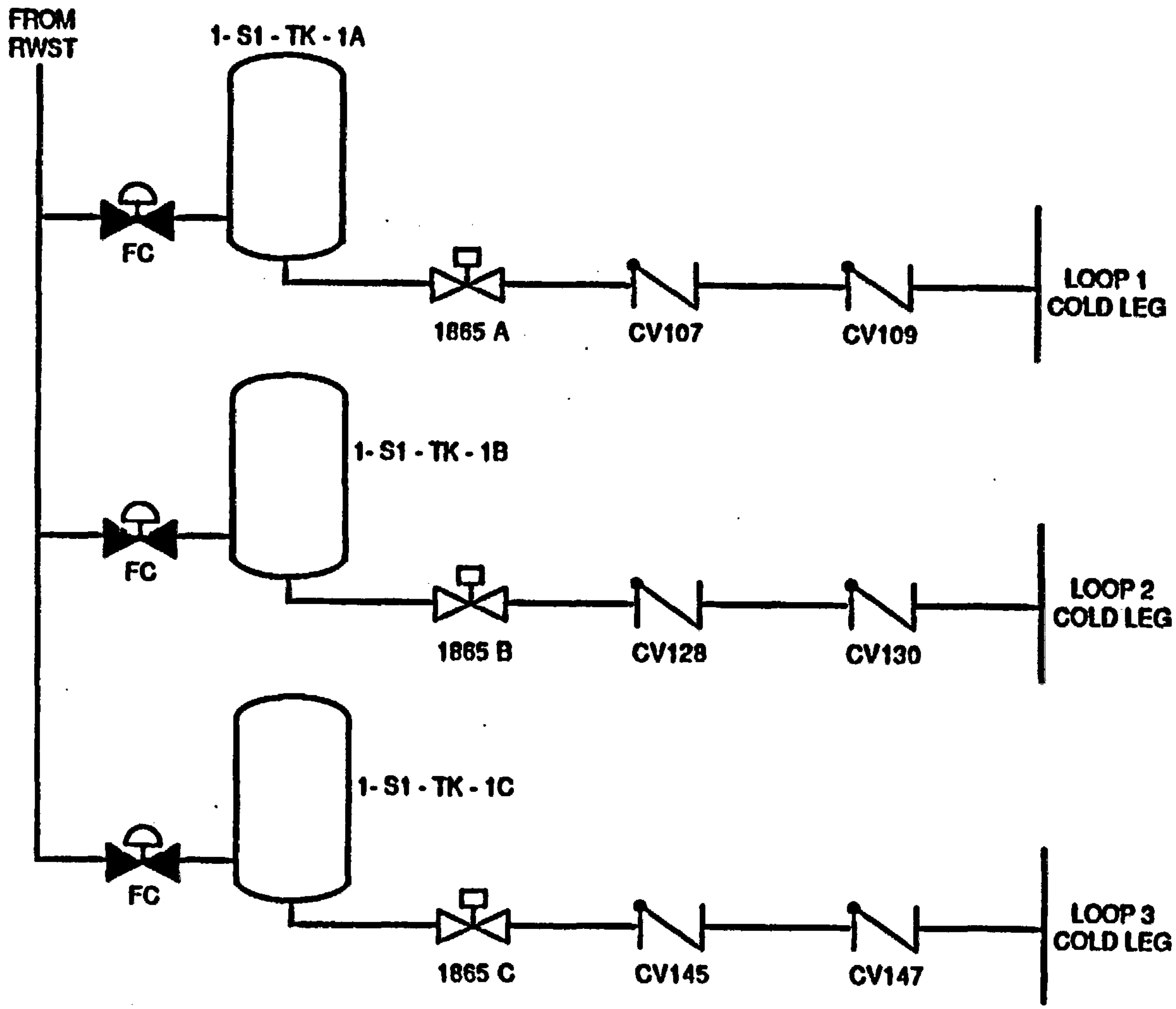


Figure 2.3. Accumulator System Schematic.

separate lines, one to each cold leg. Each of the lines to the cold legs contains two check valves in series to provide isolation from the high pressure RCS.

In the recirculation mode, the pump trains draw suction from the containment sump through a parallel arrangement of suction lines to a common header. Flow from the suction header is drawn through a normally closed MOV and check valve in series. Discharge of the pumps is directed to either the cold legs through the same lines used for injection or to a parallel set of headers which feed the charging pumps, depending on the RCS pressure.

In the hot leg injection mode, system operation is identical to normal recirculation with the exception that the normally open cold leg injection valve must be remote manually closed and one or more normally closed hot leg recirculation valves must be remote manually opened.

Upon indication of a loss of RCS coolant or a main steam line break (i.e., low pressurizer level, high containment pressure, high pressure differential between main steam header and any steam line, or high steam flow with low T_{AVG} or low steam line pressure), the safety injection actuation system (SIAS) initiates LPI operation. The SIAS signals the low pressure pumps to start. All valves are normally aligned to their injection position. If primary system pressure remains above the LPI pump shutoff head, the pumps will discharge to the RWST through two normally open minimum flow recirculation lines until the RCS pressure is sufficiently reduced to allow inflow.

Upon receipt of a low RWST level signal, the recirculation mode transfer system (RMTS) signals the low pressure pump suction valves from the RWST and the valves in the minimum flow recirculation lines to the RWST to close and the suction valves from the containment sump to open. A simplified schematic of the LPI/LPR system is shown in Figure 2.4.

The success criterion for the LPI mode of operation is flow from one or more low pressure pumps to the RCS cold legs in response to a loss of primary coolant inventory. The success criteria for the LPR modes of operation are continued flow from either of the two low pressure pumps to the cold legs and switchover to hot leg recirculation at 16 hours or sufficient flow from either of the two low pressure pumps to the charging pump suction header.

2.2.5 Inside Spray Recirculation System

The inside spray recirculation (ISR) system provides long term containment pressure reduction and containment heat removal following an accident by drawing water from the containment sump and spraying the water into the containment atmosphere. The ISR system is composed of two independent, 100 percent capacity recirculation spray trains. Each spray train draws water from the containment sump through independent suction strainers and lines. The ISR and OSR draw from the same sump, although the sump is compartmentalized and each ISR train has a separate

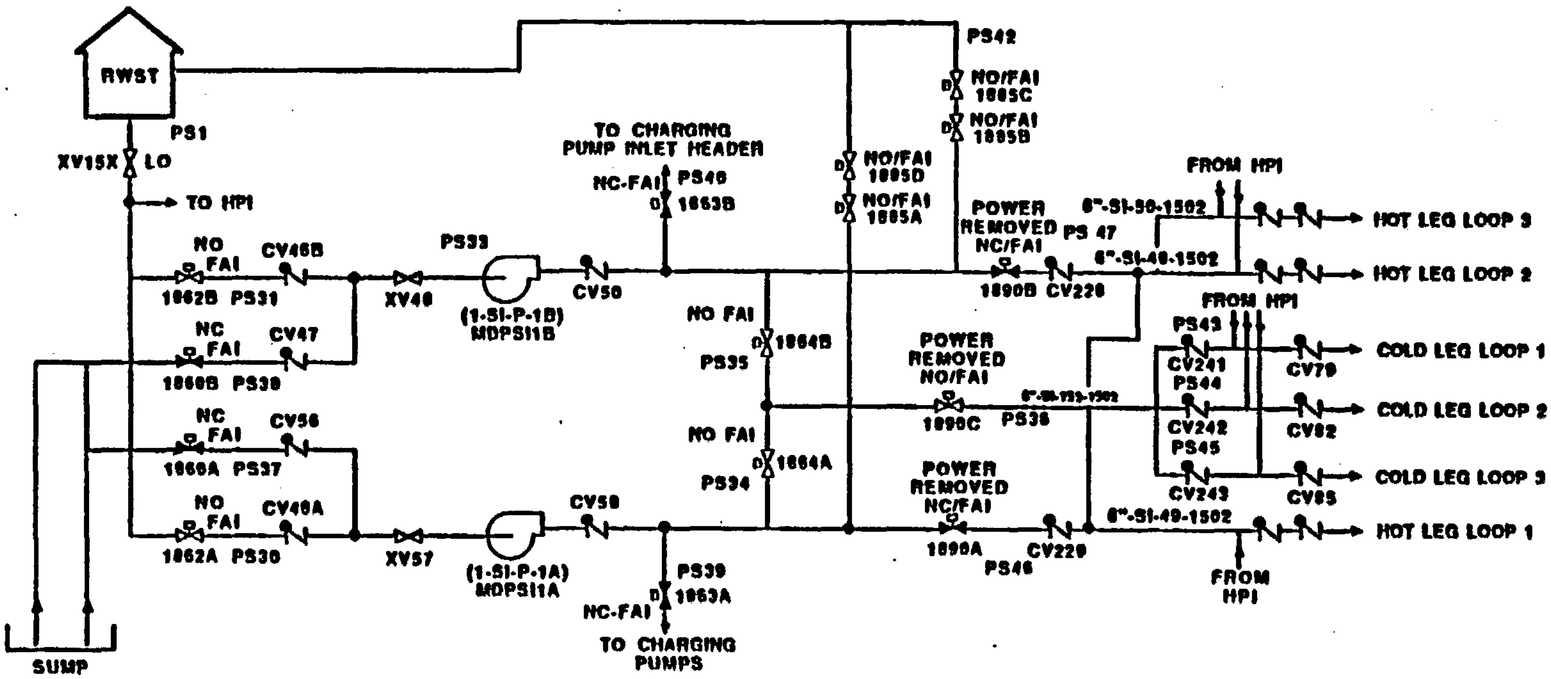


Figure 2.4. Low Pressure Injection/Recirculation System Schematic.

sump compartment. Each ISR system pump discharges to a service water heat exchanger. The cooled water is then directed to an independent spray header. In order to ensure adequate NPSH for the ISR pumps during the initial phases of a LOCA, a recirculation line diverts a small amount of the cooled ISR flow back to the sump, close to the pump inlet. A simplified schematic of the ISR system is shown in Figure 2.5. The ISR system automatically starts on receipt of a Hi-Hi (25 psia) containment pressure signal from the consequence limiting control system (CLCS). The CLCS signals start the ISR pumps. An agastat timer in the pump start circuit delays pump start for two minutes to ensure adequate sump inventory and the correct diesel generator loading sequence in the event of loss of offsite power. The success criterion for the ISR system is that at least one of the two ISR trains provides flow to its containment spray header with service water being supplied to the heat exchanger.

2.2.6 Outside Spray Recirculation System

The outside spray recirculation (OSR) system provides long term containment pressure reduction and containment heat removal following an accident by drawing water from the containment sump and spraying the water into the containment atmosphere.

The OSR system is composed of two independent, 100 percent capacity recirculation spray trains. The spray trains draw water from the containment sump through two parallel suction strainers and lines which are headered together. The OSR and ISR draw from the same sump, although the sump is compartmentalized. Each OSR train has its own separate compartment. Each OSR system pump has an individual suction line from the header with a normally open MOV. Each pump discharges through a normally open MOV, check valve and a service water heat exchanger. The cooled water is then directed to an independent spray header. In order to ensure adequate NPSH for the OSR system pumps during the early phase of a LOCA, a line is provided which diverts a small amount of the cool CSS flow to the sump, close to the pump suction strainers. A simplified schematic of the OSR system is shown in Figure 2.6.

The OSR system automatically starts on receipt of a Hi-Hi (25 psia) containment pressure signal from the consequence limiting control system (CLCS). The CLCS signals start the OSR system pumps and ensure that the pump inlet and discharge valves are open. An agastat timer in the pump start circuit delays pump start for five minutes to ensure adequate sump inventory and the correct diesel generator loading sequence in the event of loss of offsite power. The success criterion for the OSR system is that at least one of the two OSR system trains provides flow to its containment spray header, with service water provided to the heat exchanger.

2.2.7 Auxiliary Feedwater System

The auxiliary feedwater (AFW) system provides feedwater to the steam generators to provide heat removal from the primary system after reactor trip. The AFW system is a three train system, with two electric motor driven pumps and one steam turbine driven pump. Each pump draws suction

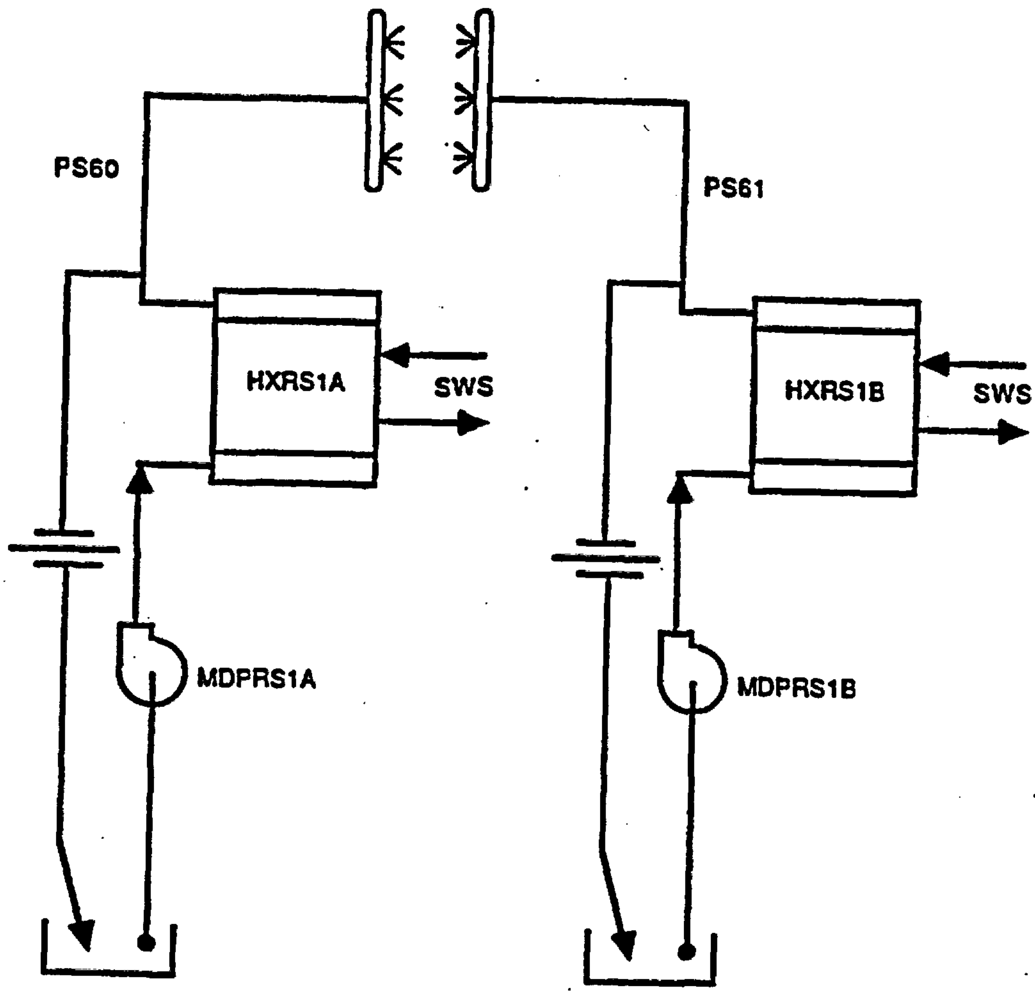


Figure 2.5. Inside Spray Recirculation System Schematic.

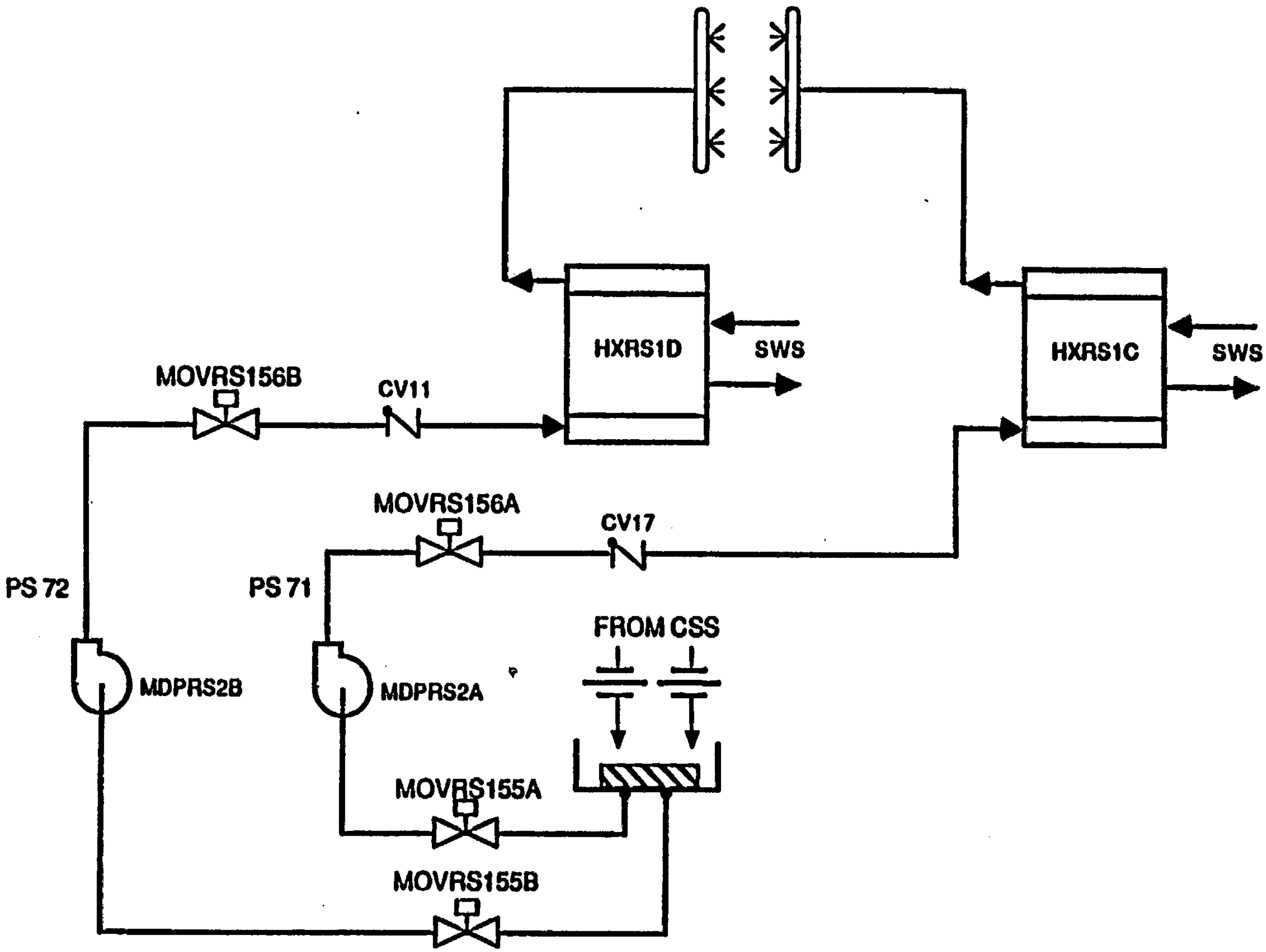


Figure 2.6. Outside Spray Recirculation System Schematic.

through an independent line from the 110,000 gallon condensate storage tank (CST). In addition, a 300,000 gallon CST, a 100,000 gallon emergency makeup tank and the fire main can be used as water supplies for the AFW pumps. Each AFW pump discharges into two parallel headers. Each of these headers can provide auxiliary feedwater flow to any or all of the three steam generators. Flow from each header to any one SG is through a normally open MOV and a locked open valve in series, paralleled with a line from the other header. These lines feed one line containing a check valve which joins the main feedwater line to a steam generator. A simplified schematic of the AFW is shown in Figure 2.7.

The motor driven AFW pumps automatically start on receipt of an SIAS signal, loss of main feedwater, low steam generator level in any steam generator, or loss of offsite power. The turbine driven AFW pump automatically starts on receipt of indication of low steam generator level in two of the three steam generators or undervoltage of any of the three main RCS pumps. These signals also ensure that the system MOVs are in the correct position. The success criterion for the AFW following all events except an ATWS is flow from any one AFW pump to any of the three steam generators.

2.2.8 Primary Pressure Relief System

The primary pressure relief system (PPRS) provides protection from overpressurization of the primary system to ensure that primary integrity is maintained. The PPRS also provides the means to reduce the RCS pressure if necessary.

The PPRS is composed of three code safety relief valves (SRV) and two power operated relief valves (PORVs). The code safety valves were important only for the ATWS analysis. The PORVs provide RCS pressure relief at a set point below the SRVs. The PORVs discharge to the pressurizer relief tank. Each PORV is provided with a motor operated block valve. A simplified schematic of the PPRS is shown in Figure 2.8.

The PORVs automatically open on high RCS pressure or are manually opened at the discretion of the operator. The block valves are normally open unless a PORV is leaking.

The success criterion for the PPRS following a transient event demanding PORV opening is that the PORVs successfully reclose. The success criterion for the PPRS following a transient and failure of the AFWS is that both PORVs successfully open on demand. The success criterion for the PPRS following a small LOCA with failure of the AFWS and for the support system function provided to HPI in the emergency boration mode is that one or more PORVs successfully open on demand.

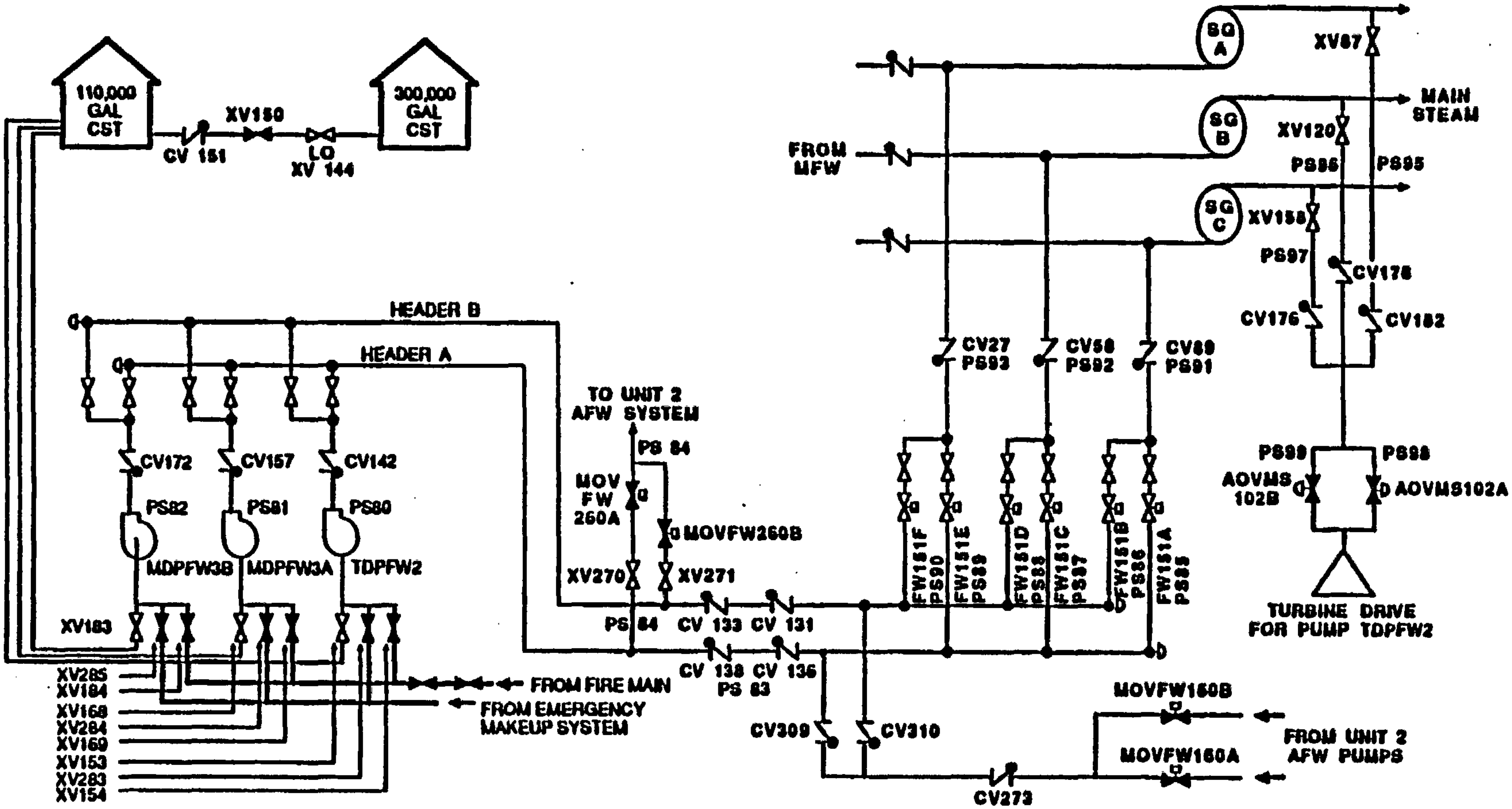


Figure 2.7. Auxiliary Feedwater System Schematic.

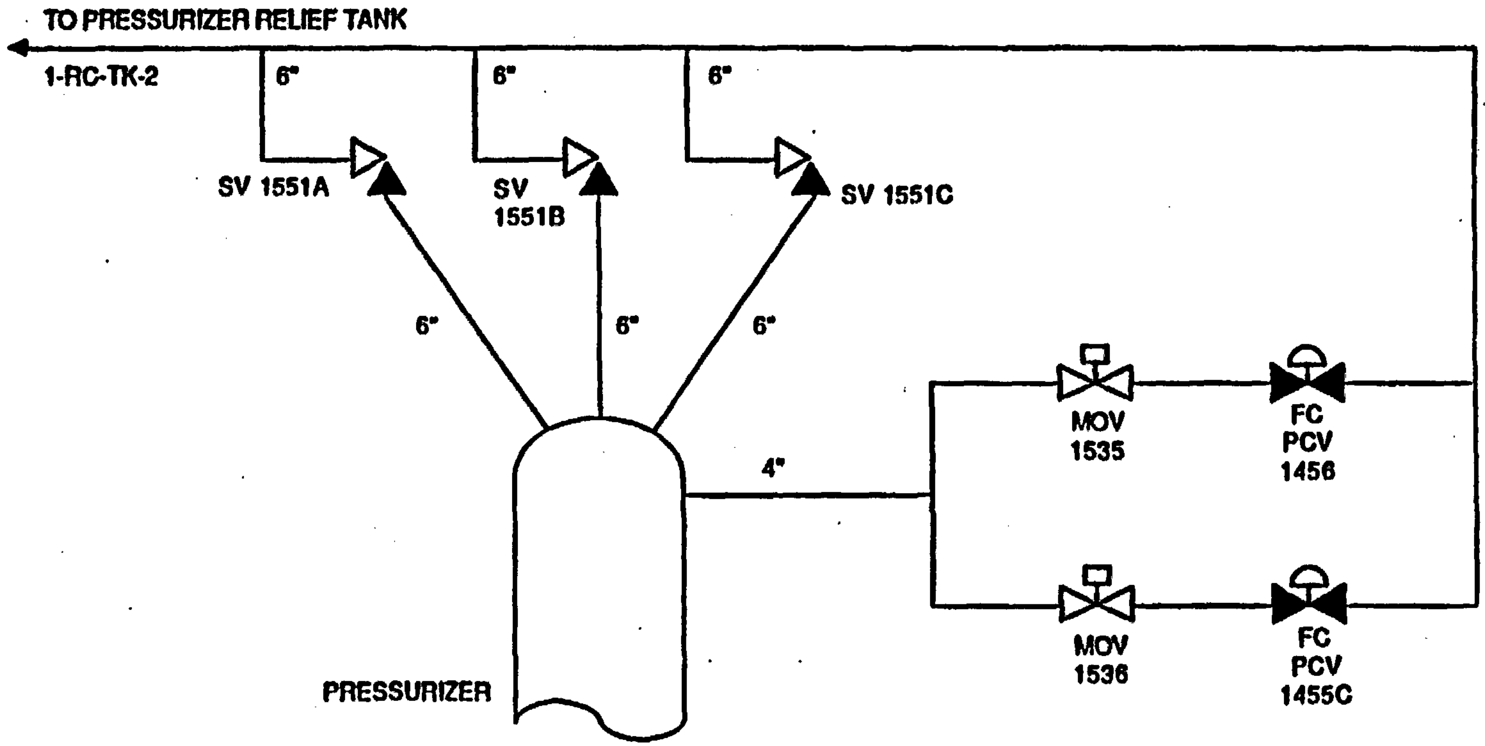


Figure 2.8. Primary Pressure Relief System Schematic.

2.2.9 Power Conversion System

The power conversion system (PCS) can be used to provide feedwater to the steam generators following a transient. The PCS, as modeled in this study, consists of the main feedwater pumps, the condensate pumps, the condensate booster pumps, and the hotwell inventory. Because the plant has electric driven MFW pumps, it is possible to supply feedwater using the MFW system, without having the turbine bypass and steam condensing systems available. The inventory of the hotwell (with the CST as a backup supply) was calculated to be sufficient for all mission times of interest. The feedwater regulating valves will close after a reactor scram, due to plant control logic. The feedwater pumps remain on, and the miniflow valves will open. Feedwater can then be provided to the SGs, through the feedwater regulating valve bypass valve. The success criterion for the PCS are restoration of flow from one or more main feedwater pumps to one or more steam generators.

2.2.10 Charging Pump Cooling System

The charging pump cooling (CPC) system is a support system which provides lube oil cooling and seal cooling to the three charging pumps in the HPI/HPR system.

The CPC system provides two specific cooling functions for the charging pumps, lube oil cooling and seal cooling. The CPC system is composed of two subsystems, the charging pump service water system and the charging pump cooling water system. The charging pump service water system is an open cooling system which provides cooling to the lube oil coolers and to the intermediate seal coolers in the charging pump cooling water system. The charging pump cooling water system is a closed cycle system which provides cooling to the charging pump seal coolers.

The charging pump service water system is composed of two 100 percent capacity pump trains, each providing flow to one intermediate seal cooler and all three charging pump lube oil coolers. Flow is drawn from the condenser inlet lines through independent lines by the charging pump service water pumps. Upstream of each pump are two separate, independent strainer assemblies. Each pump discharges through two check valves. Downstream of the check valves the flow is split with a portion of the flow directed to an intermediate seal cooler and the other portion directed to a common header feeding the lube oil coolers. From this header, flow is directed through the lube oil coolers for the operating charging pumps. Temperature control valves control the flow through the lube oil coolers to prevent overcooling of the lube oil. The service water flow is discharged to the discharge canal.

The charging pump cooling water system is a closed cycle system composed of two 100 percent capacity pump trains, each containing a charging pump cooling water pump and intermediate seal cooler which provide cooling water to the charging pump seal coolers. Each pump draws suction from the outlet of either of the two intermediate seal coolers and discharge to a common header. The common header provides flow to the seal coolers for each charging pump. Two seal coolers in parallel are provided for each charging pump. The discharge of the seal coolers is returned to the intermediate seal coolers where it is cooled by the charging pump service water system. Makeup to the charging pump cooling water system to account for seal leakage is provided by a surge tank which is supplied by the component cooling water system. A simplified schematic of the CPC system is shown in Figure 2.9.

One of the charging pump service water pumps and one of the charging pump cooling water pumps are normally in operation. Upon indication of low discharge pressure of one of the pumps, the parallel pump receives a signal to start. With the exception of the pumps and the lube oil cooler temperature control valves, all other components in the system are manually actuated.

2.2.11 Service Water System

The service water system (SWS), as defined for this analysis, is a support system which provides cooling to the heat exchangers in the ISR system and OSR system. The SWS provides heat removal from the containment following an accident.

The SWS is a gravity flow system. The service water supply to the containment spray heat exchangers consists of two parallel inlet lines which provide SW from the condenser cooling pipes, each through two normally closed MOVs in parallel to individual headers. The headers each provide flow to one ISR and OSR heat exchanger. The two headers are cross connected by two normally open MOVs in series such that flow from either inlet line can be used to cool all four ISR and OSR heat exchangers. Service water flows through each heat exchanger and discharges through a normally open MOV to two headers which flow to the discharge tunnel. A simplified schematic of the SWS is shown in Figure 2.10.

The SWS automatically starts on receipt of a Hi-Hi (25 psia) containment pressure signal from the consequence limiting control system (CLCS). The CLCS signals open the header inlet valves. No other actions are required to place the SWS in service.

2.2.12 Component Cooling Water System

The component cooling water (CCW) system, as defined for this analysis, includes only that portion of the CCW system required to provide cooling water to the RCS pump thermal barriers. The CCW system is composed of two CCW pumps in parallel and two CCW heat exchangers. The CCW system is a closed cycle system. The CCW pumps take suction from the return line from the RCS pump thermal barriers and are headered together at their discharges. The header feeds the two CCW heat exchangers arranged in parallel. The discharge of the heat exchangers is delivered to the thermal barriers. After cooling of the thermal barriers, the flow is returned to the CCW pump suction. Makeup to the CCW system is

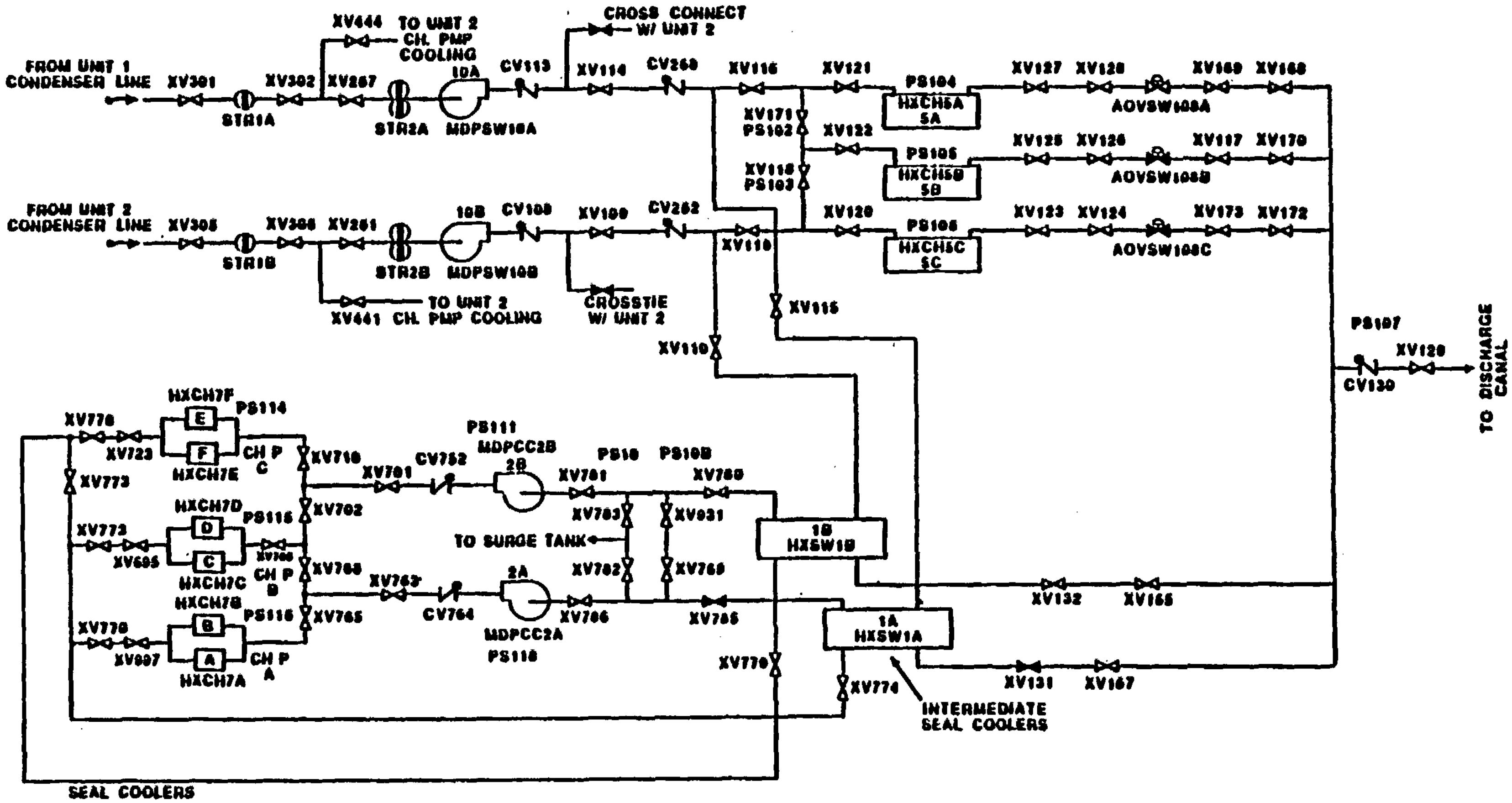


Figure 2.9. Charging Pump Cooling System Schematic.

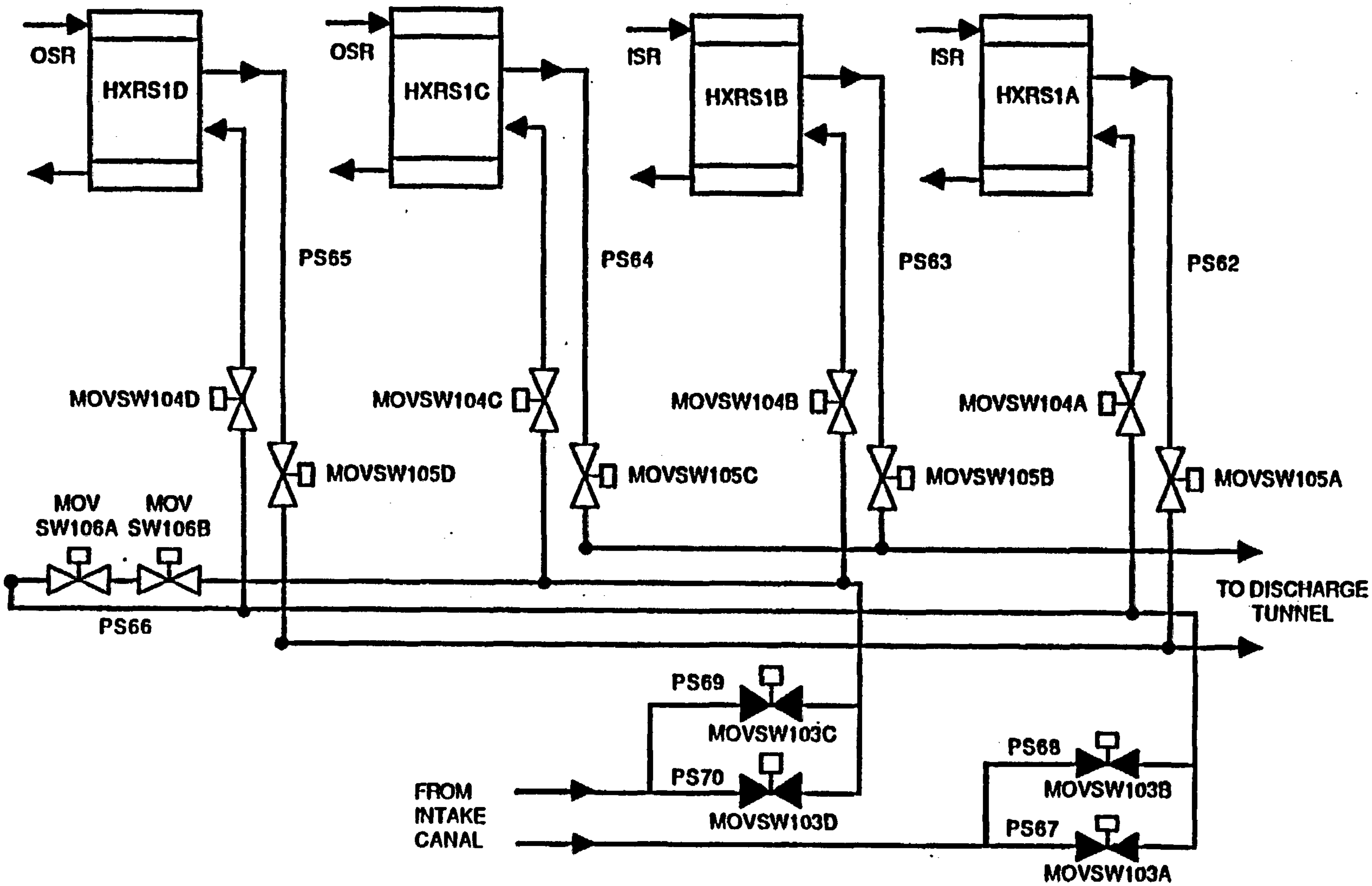


Figure 2.10. Service Water System Schematic.

provided from a surge tank in the system. A simplified schematic of the portions of the CCW system required for thermal barrier cooling is shown in Figure 2.11.

One CCW pump and heat exchanger are normally in operation. In the event of failure of either component, the parallel component is manually placed in service. Following a loss of offsite power, the stub buses powering the CCW pumps are shed from the emergency buses and must be manually reconnected to restore power to the CCW pumps. The throttle valve on the thermal barrier cooling water outlet closes on loss of instrument air or receipt of a CLCS Hi-Hi signal, resulting in loss of flow to the thermal barriers. The success criterion for the CCW system is that continued CCW flow is provided to the RCS pump thermal barriers following reactor shutdown.

2.2.13 Emergency Power System

The emergency power system (EPS) provides AC and DC power to safety-related components following reactor scram. The EPS consists of two 4160 V AC buses, four 480 V AC buses, four 120 V AC vital instrumentation buses, two 125 V DC buses, one dedicated and one shared diesel generator, and their associated motor control centers, breakers, transformers, chargers, inverters, and batteries.

Each 4160 V AC bus is normally powered from offsite power sources. On loss of offsite power the breakers open and the diesel generators start and their associated breakers close to load the diesels on the emergency buses. The plant has three diesel generators, one dedicated to each unit and a third swing diesel generator shared by the units. The dedicated diesel at Unit 1 is attached to the 1H 4160 V AC bus while the swing diesel can be connected to the 1J 4160 V AC bus. In the event that the swing diesel is demanded by both units, the diesel will be aligned to the unit at which an SIAS or CLCS Hi-Hi exists. If signals exist at both units, the diesel will be aligned to the unit whose breaker closes first. Each diesel is a self-contained, self-cooled unit with its own battery for starting power. The 4160 V AC buses provide power to the large pumps such as the high pressure injection pumps, the stub buses which each power one CCW and residual heat removal pump and are shed on undervoltage on the main bus, and the 480 V AC buses through transformers.

The following description applies to the 1H related buses. Since the 1H and 1J related buses are symmetrical, the description is equally applicable to the 1J related buses with the appropriate changes to the designators.

The 1H 4160 V AC bus feeds two 480 V AC buses (1H and 1H-1) through transformers. The 1H 480 V AC bus is primarily used to power pumps such as the A train low pressure injection pump. The 1H-1 480 V AC bus feeds two motor control centers (MCCs), MCC 1H1-1 and 1H1-2, which provide power to a multitude of MOVs and small pumps such as the charging pump cooling water pumps. MCC 1H1-1 also provides power to two battery chargers used to charge DC battery A, and to the 1-I 120 V AC vital instrumentation by DC bus 1A through an inverter.

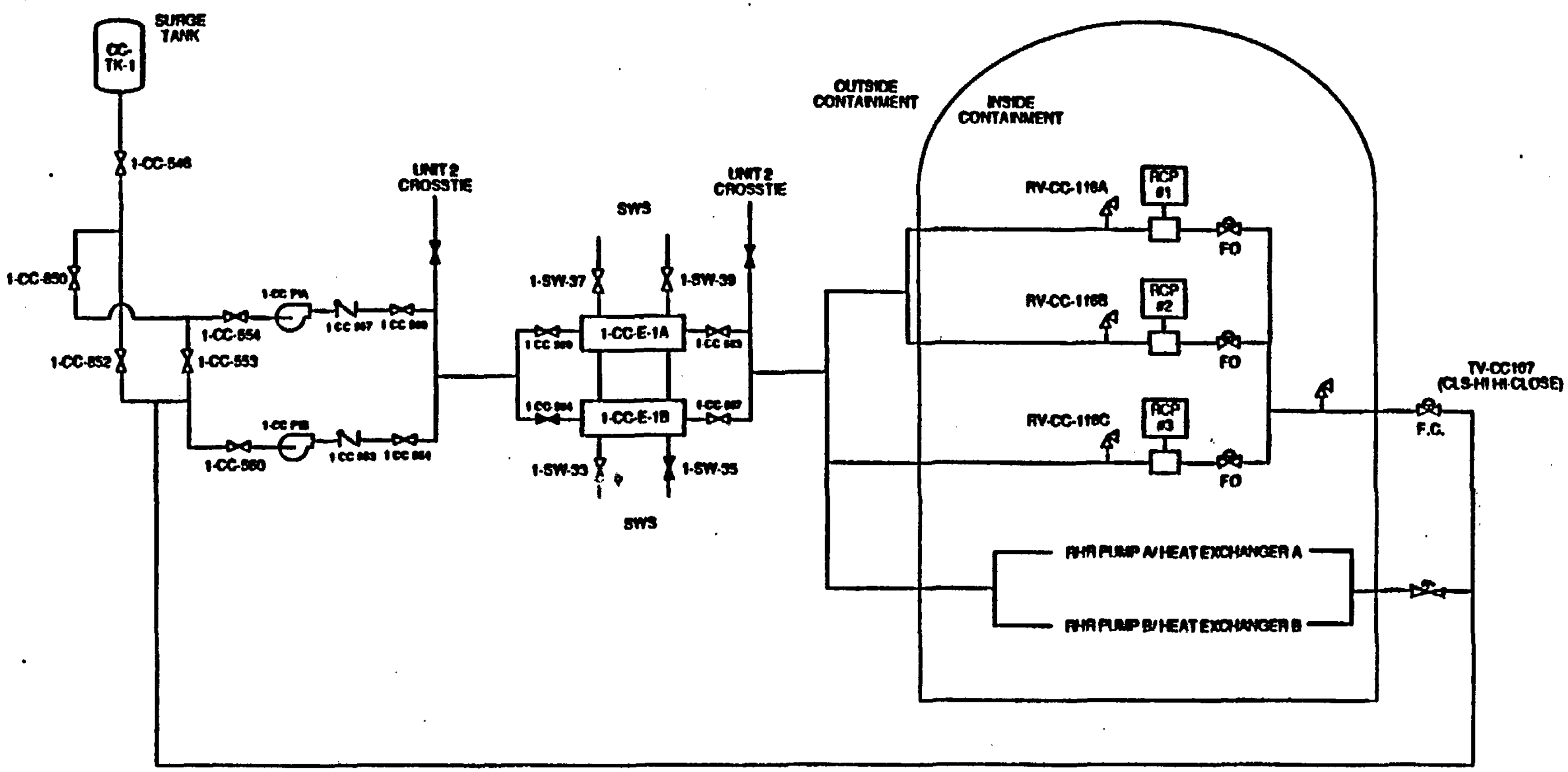


Figure 2.11. Component Cooling Water System Schematic.

The 1A 125 V DC bus provides control power to the switchgear for the pumps powered from the 1H buses. The 1A 125 V DC bus is powered from a 480 V AC bus, as noted above, and in the event of loss of the AC power source is powered from DC battery A. A simplified electrical diagram of the EPS is included in Figure 2.12.

2.2.14 Safety Injection Actuation System

The safety injection actuation system (SIAS) automatically initiates the high and low pressure injection systems following an indication of the need for primary coolant makeup. The SIAS is composed of two independent trains used to automatically actuate the low and high pressure injection systems and the motor driven AFW pumps. The signals which actuate SIAS are shown in Figure 2.13.

2.2.15 Consequence Limiting Control System

The consequence limiting control system (CLCS) automatically actuates the containment safeguards systems following receipt of an indication of Hi-Hi (25 psia) containment pressure. The CLCS is composed of four containment pressure sensors, each feeding a signal comparator. The output of each signal comparator is input into two separate three-out-of-four logic trains. These logic trains automatically actuate the containment safeguards system components. A simplified CLCS logic diagram is shown in Figure 2.14.

2.2.16 Recirculation Mode Transfer System

The recirculation mode transfer (RMT) system automatically initiates the switchover of the suction of the low pressure injection pumps from the RWST to the containment sump and the suction of the high pressure injection pumps from the RWST to the low pressure injection pump discharges on low RWST level. The RMT system is composed of four independent RWST level sensors, each feeding two separate two-out-of-four relay matrices. These two relay matrices automatically actuate the components required to perform the switchover to the recirculation mode of the low and high pressure systems. A simplified RMT system logic diagram is shown in Figure 2.15.

2.2.17 Residual Heat Removal System

The residual heat removal (RHR) system provides shutdown cooling when the reactor coolant system (RCS) depressurizes below 450 psig and cools below 350°F. The RHR is a front line system (although nonsafety grade) designed to provide long-term decay heat removal. The following sections provide a physical description of the RHR system and identify the interfaces and dependencies of the RHR system with other front line and support systems. A simplified RHR system schematic is shown in Figure 2.16.

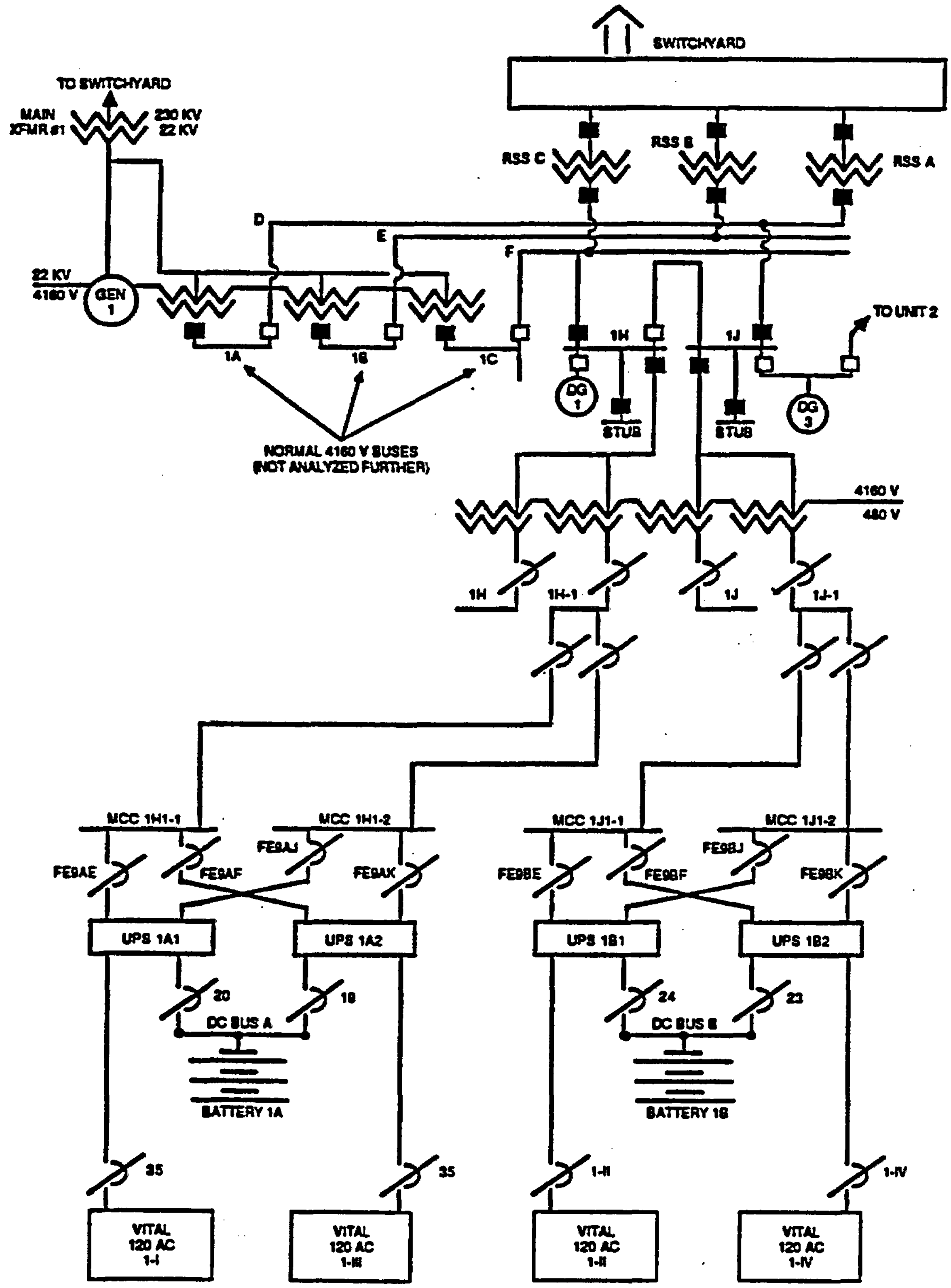


Figure 2.12. Emergency Power System Schematic.

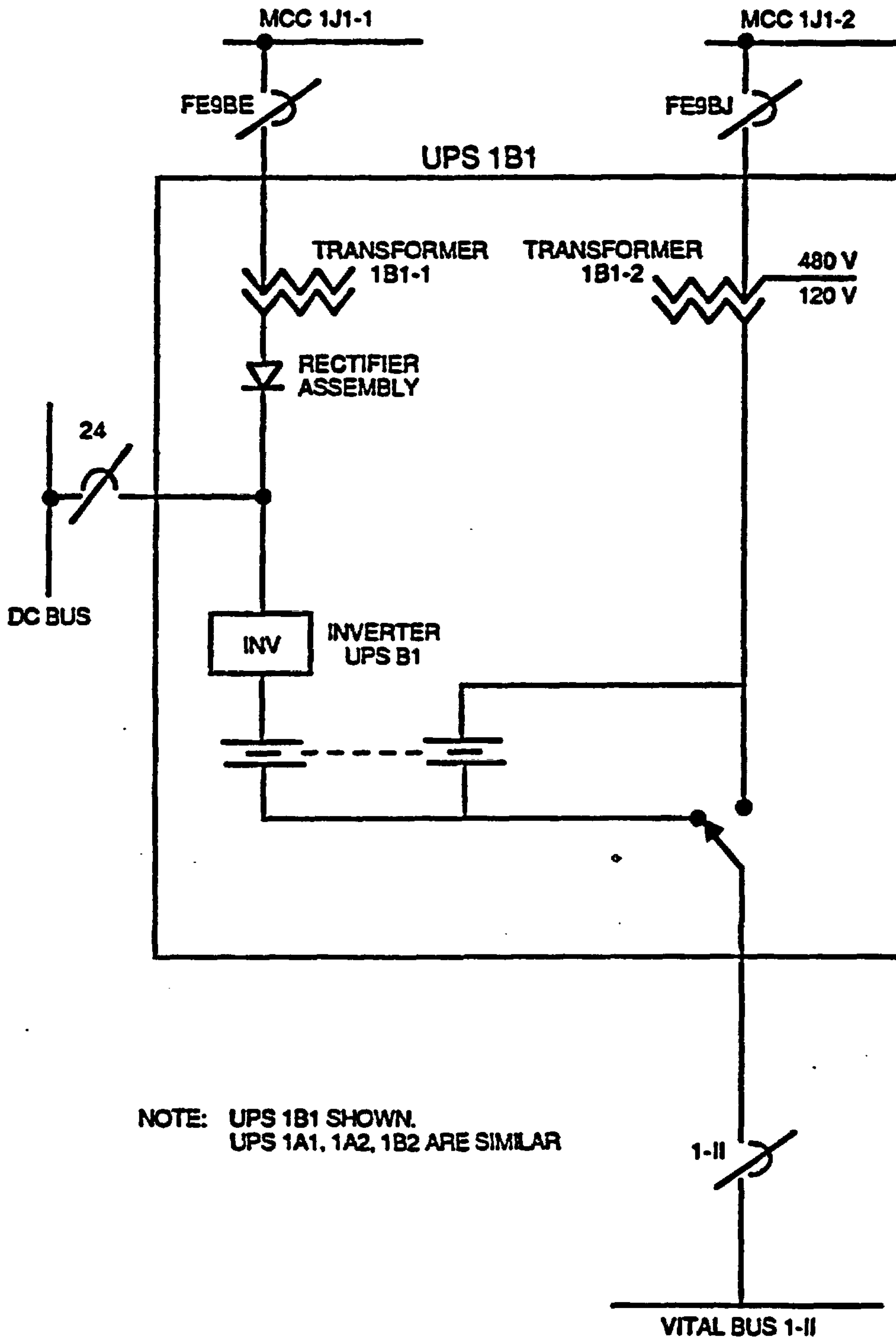


Figure 2.12. Emergency Power System Schematic (Concluded).

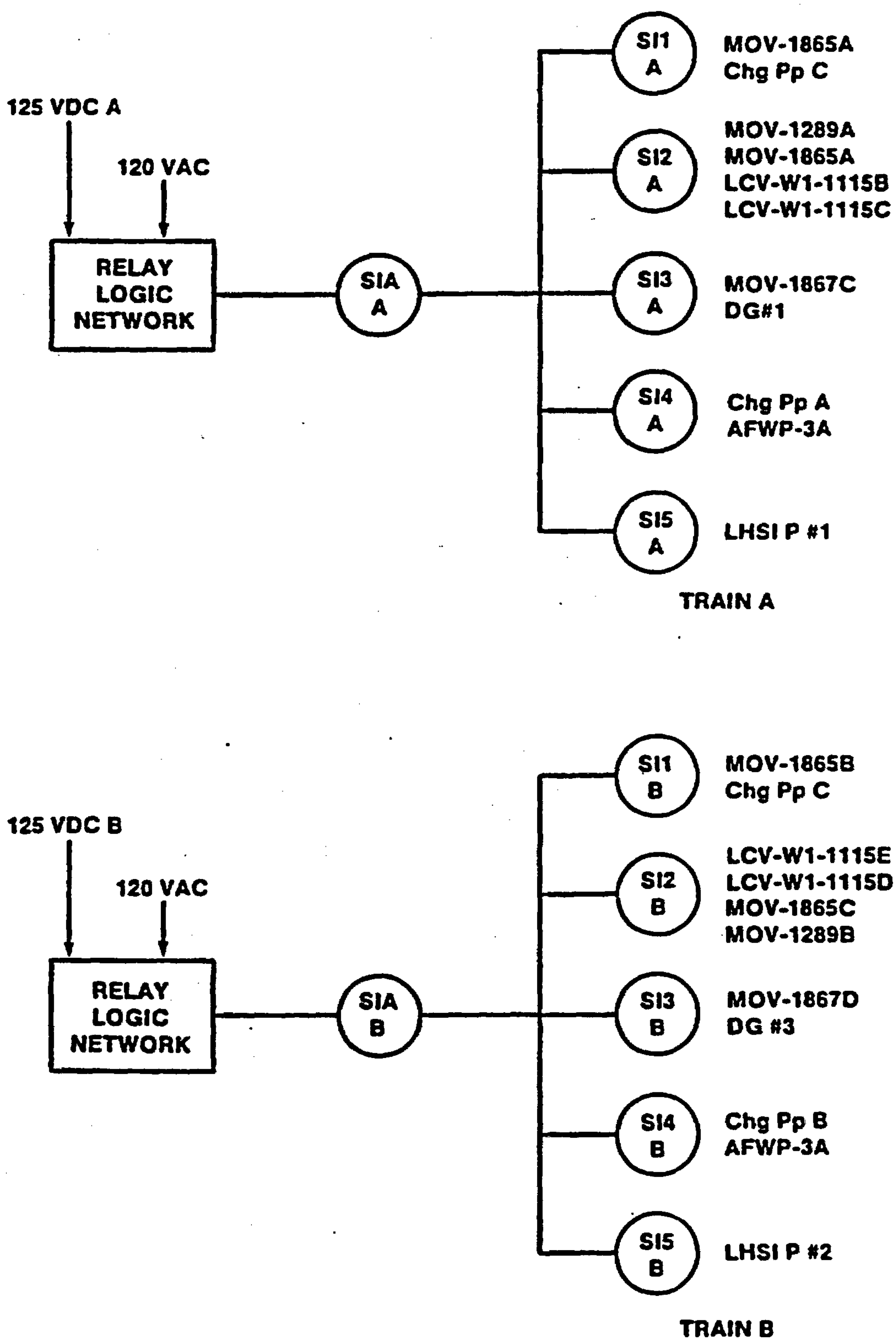


Figure 2.13. Safety Injection Actuation System Diagram.

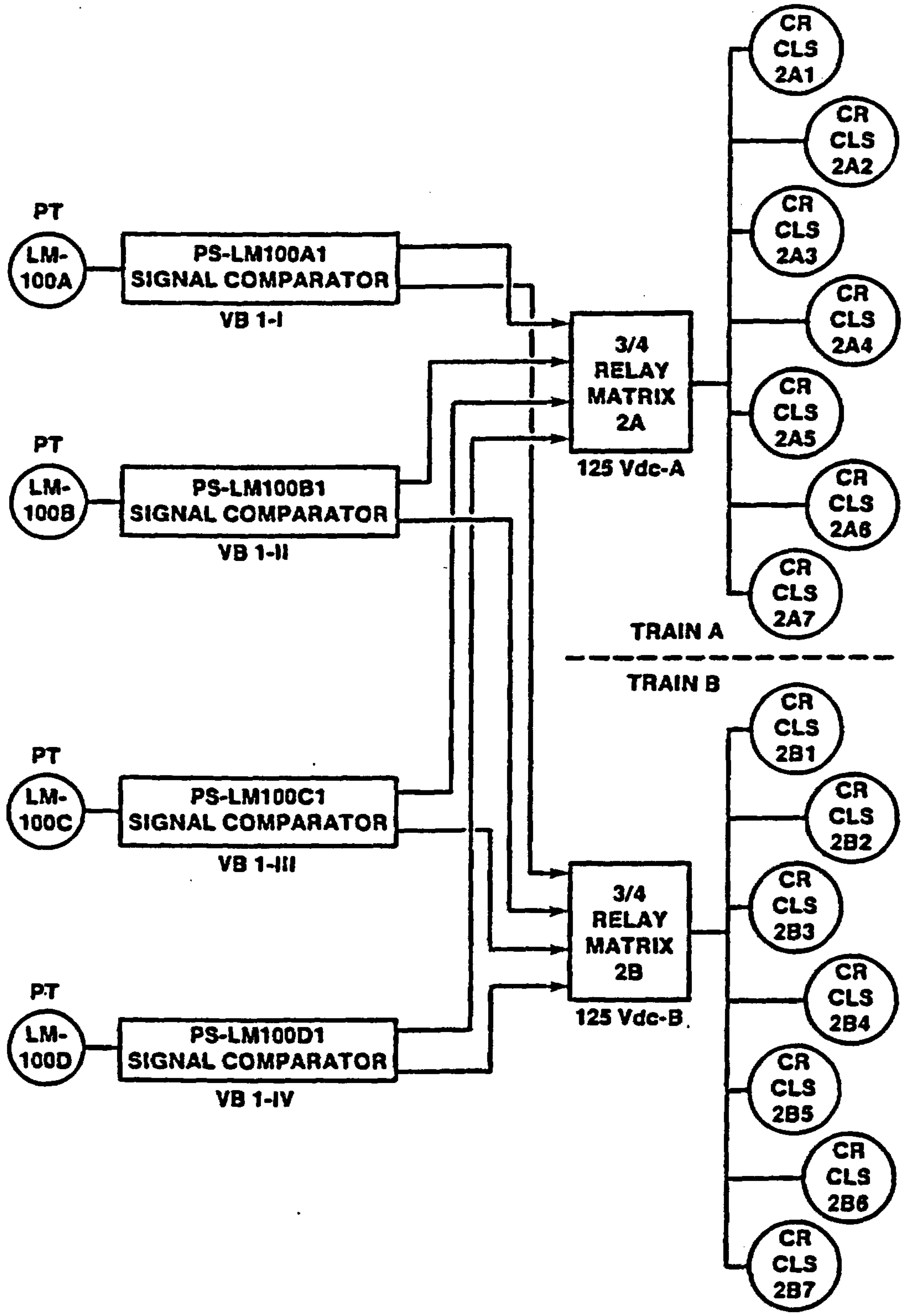


Figure 2.14. Consequence Limiting Control System Logic Diagram.

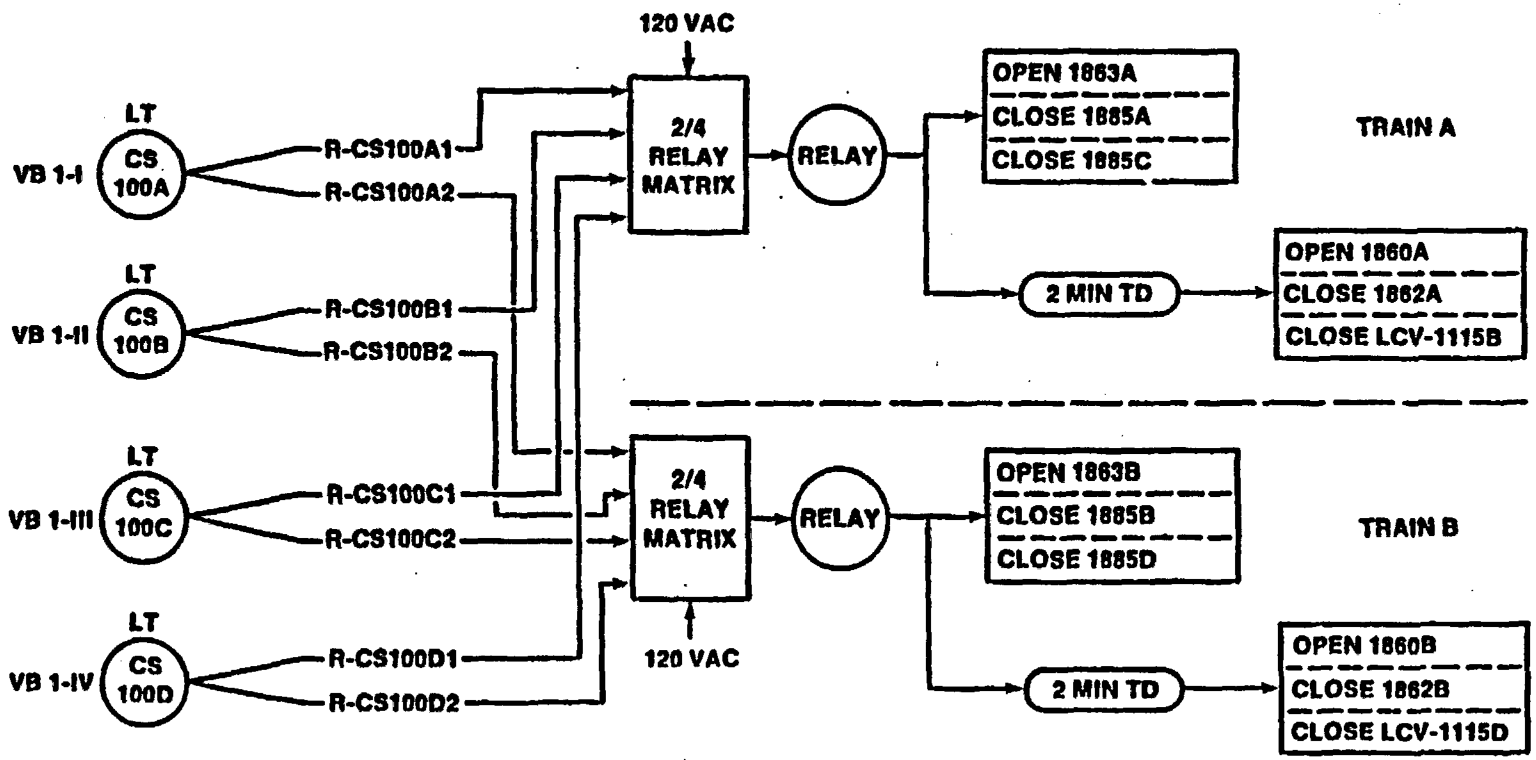


Figure 2.15. Recirculation Mode Transfer System Logic Diagram.

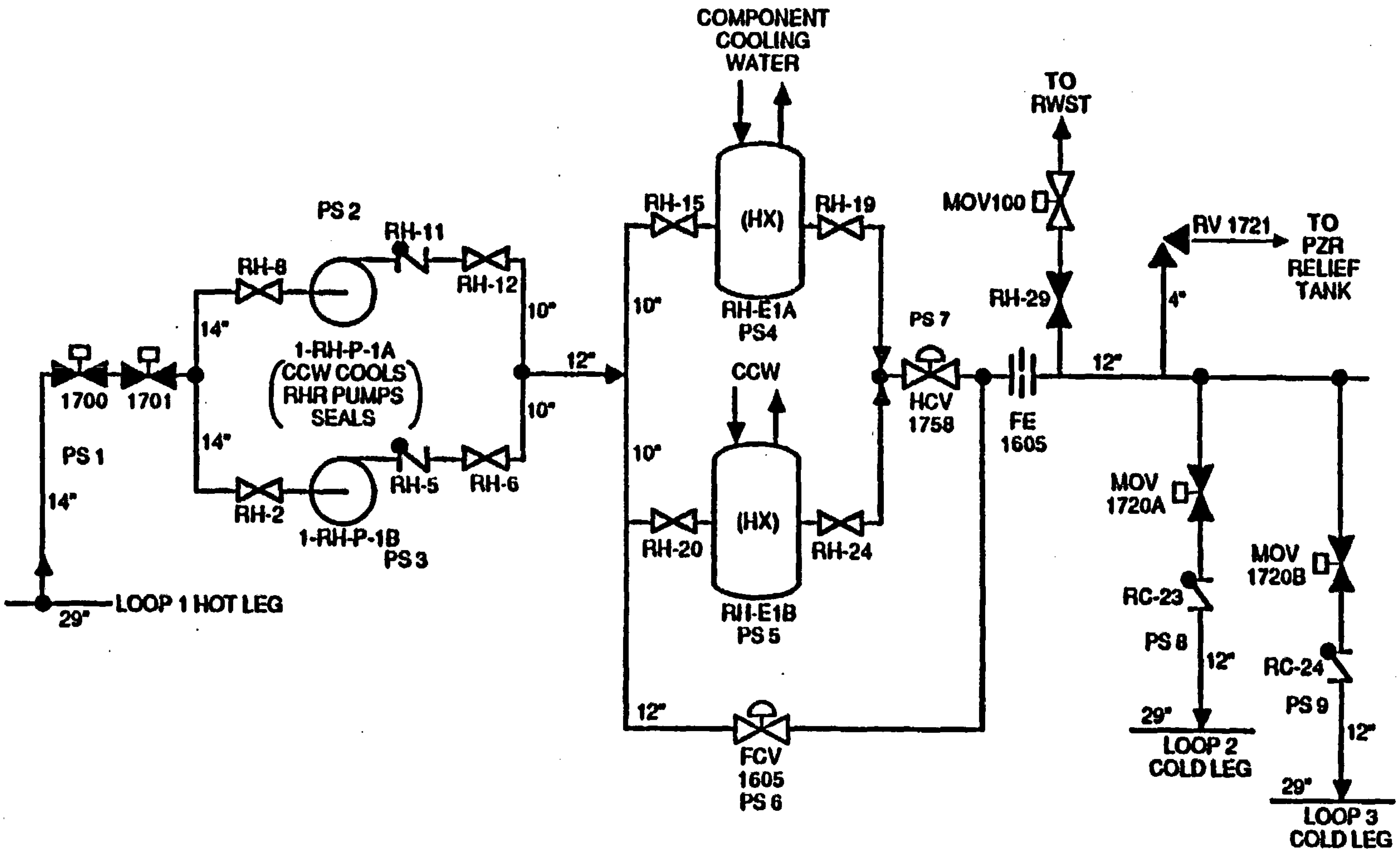


Figure 2.16. Residual Heat Removal System Schematic.

The RHR system is composed of two pumps and two RHR heat exchangers in parallel. The RHR pumps take suction from the RCS loop 1 hot leg through two normally shut motor operated valves (MOVs) and a manual isolation valve. The discharge of the pumps is headered together and feeds two heat exchangers arranged in parallel. The RHR pumps and heat exchangers are cooled by the component cooling water system (CCW). An air operated valve (AOV) controls bypass flow around the heat exchangers, another controls flow through the heat exchangers. The two AOVs work together to control the cooldown rate of the RCS. The discharge of the flow control valves feeds into the SI/accumulator piping and is delivered to the RCS loop 2 and loop 3 cold legs. Each path has a normally shut MOV isolating the RHR from the high pressure RCS during normal plant operations. Makeup to the RHR system is provided by the RCS.

The RHR is manually initiated. An interlock prevents opening the RHR isolation MOVs until RCS pressure is below 450 psig. One RHR pump and heat exchanger are normally in operation. In the event of failure of either component, the parallel component is manually placed in service. Following a loss of offsite power, the stub buses powering the RHR pumps are shed from the emergency buses and must be manually reconnected to restore power to the RHR pumps.

2.3 References

2.1 M. P. Bohn and J. A. Lambright, NUREG/CR-4550, SAND86-2084, Rev. 1, Vol. 3, Part 4, Sandia National Laboratories, October, 1989.

3.0 ROOT CAUSE ANALYSES

3.1 Introduction

This chapter describes the quantification and resulting contributions to core damage frequency (CDF) for the root cause scenarios. For the PWR being studied, a detailed fire PRA and supporting analyses were available as part of the NRC-sponsored NUREG-1150 program studies (Ref. 3.1). Plant-specific data analysis was performed as part of internal events analysis (Ref. 3.2) and these results are utilized wherever applicable. In this study, detailed analysis of the propagation of smoke within each room was performed taking into account the actual location of critical equipment in the room, and a plant-specific evaluation of the number and type of fire barriers in each zone was made.

For this analysis, the configuration of equipment and fire protection systems at the plant were reviewed. The potential root causes of FPS actuations that could lead to core damage were identified. Based on the knowledge of the FPS configuration, a quantification of potential core damage sequences was performed.

3.2 Procedure

The initial phase of the analysis consisted of reviewing the plant configuration. This was accomplished primarily by reviewing the plant 10CFR50 Appendix R submittal (Ref. 3.3). From this submittal, information was obtained on the overall plant layout, the individual plant Fire Zones, the particular types of FPS and fire detectors installed, and the critical equipment required for safe shutdown. This information was used to determine those critical areas of interest for further study. Using this information, a vital area analysis was performed. A listing of all Fire Zones which resulted from the vital area analysis and which also have either automatically or manually actuated fixed fire protection systems are given in Table 3.1. Nine critical Fire Zones were identified.

These zones are listed in Table 3.2 along with the type of FPS, type of detectors, FPS actuation scheme, and critical equipment in the Fire Zone. Figure 3.1 gives a general plant layout drawing. Figures 3.2 through 3.7 are simplified illustrations of these critical Fire Zones.

In several instances, the Appendix R information was supplemented by phone calls to plant personnel as well as a detailed plant walkdown. Details on the locations of the equipment were obtained from Reference 3.3.

The Appendix R submittal was also used, along with a plant walkdown, to determine the penetrations into each of the critical Fire Zones. Table 3.3 lists these Fire Zones and the doors and cable penetration that connect them to other Fire Zones.

An additional document utilized was the Internal Events PRA for the PWR studied (Ref. 3.2). The internal events report provided additional information on the plant safe shutdown equipment and system models.

Table 3.1

Fire Zones and Designators

Fire Zone Number	Fire Zone Name
Fire Zone 1, 2	Cable Vault/Tunnels
Fire Zone 3, 4	Emergency Switchgear Rooms
Fire Zone 6, 7, 8	Diesel Generator Rooms
Fire Zone 17	Auxiliary Building
Fire Zone 31	Turbine Building

This report also described safety-significant recovery actions from random failures. These recovery actions were then analyzed for the possibility that FPS actuations could prevent them from being performed (Root Cause 2). Generic fire data (Ref. 3.4) developed to support the NUREG-1150 fire analyses provided frequencies of fires in the different areas, probabilities of Fire Zone barrier failures (smoke and heat spread), and the fire PRA provided estimated times to damage critical equipment from fires in the different zones.

A detailed analysis of the plant ventilation systems was performed. This analysis included a thorough review of system descriptions as well as ventilation drawings. Once this review was completed, a plant walkdown was performed to verify the review and clear up questions that resulted from the review process. For this plant, smoke detectors are used for indication purposes only. Therefore, Root Causes 1, 3, 7, and 10 (fire induced actuation due to smoke spread, fire-induced FPS actuation preventing fire-fighting access, FPS actuation due to dust in a seismic event, and external plant fires) were screened from further analysis.

The diesel generator room ventilation system is manually actuated. Given a seismic event that demands the diesel generators due to a loss-of-offsite power, the room cooling configuration is assumed to remain as-is even though the manual-fixed CO_2 system may be actuated. This configuration is considered to be atypical, but for the purposes of this study was analyzed as-is.

3.2.1 General Transients Caused By FPS Actuation or Fires

Using the sequences and cut sets obtained from the vital area analysis performed as part of the NUREG-1150 fire PRA, the various sequences leading to core damage were developed. Based on the original plant fire PRA, six general transient sequences which lead to core damage were considered. The general transient event tree from which these are taken is shown in Figure 3.8. No LOSP transient or pipe break LOCA caused

Table 3.2

Fire Protection Systems
and Safe Shutdown Equipment by Fire Zone

Fire Zone	Suppression System	Safe Shutdown Equipment
Fire Zone 1 (Unit 1 Cable Vault and Tunnel)	Automatic CO_2 activated by 6 heat detectors (with a backup manual actuation switch in Emergency Switchgear Room); manually actuated deluge (manual actuation involves turning valve handle) and manually actuated dry-pipe sprinkler system (having fusible links in sprinkler heads); also 8 ionization-type smoke detectors	Numerous cables for power, control, and instrumentation Motor control centers Cables for charging pumps (no. 1A, 1B, 1C) Cables for charging pump cooling water pumps (no. 2A, 2B) Cables for component cooling water pumps (no. 1A, 1B) Cables for AFW pumps (no. 2, 3A, 3B) Cables for containment spray pumps (no. 1A, 1B) Cables for low pressure safety injection pumps (no. 1A, 1B) Cables for inside and outside spray recirculation pumps (no. 1A, 1B, 2A, 2B) Cables for residual heat removal pumps (no. 1A, 1B) AC power circuit breakers (no. FE9BJ, FE9BK)
Fire Zone 2 (Unit 2 Cable Vault and Tunnel)	Automatic CO_2 activated by 6 heat detectors (with a backup manual actuation switch in Emergency Switchgear Room); manually actuated deluge (manual actuation involves turning valve handle) and manually actuated dry-pipe sprinkler system (having fusible links in sprinkler heads); also 8 ionization-type smoke detectors	Cables and controls for AFW cross-connect valve to Unit 1 Numerous cables for power, control, and instrumentation Motor control centers

Table 3.2

Fire Protection Systems
and Safe Shutdown Equipment by Fire Zone (Continued)

Fire Zone	Suppression System	Safe Shutdown Equipment
Fire Zone 3 (Unit 1 Emergency Switchgear Room)	Halon system manually actuated either locally or from Control Room panel no. 2; also, 10 ionization-type smoke detectors (Halon supply is 10 gas bottles designed to empty all their contents)	Cables Cables and controls for charging pumps (no. 1A, 1B, 1C) Cables and controls for charging pump cooling water pumps (no. 2A, 2B) Cables and controls for component cooling water pumps (no. 1A, 1B) Cables and controls for charging pump service water pumps (no. 10A, 10B) Cables and controls for AFW pumps (no. 2, 3A, 3B) Cables and controls for containment spray pumps (no. 1A, 1B) Cables and controls for low pressure safety injection pumps (no. 1A, 1B) Cables and controls for inside and outside spray recirculation pumps (no. 1A, 1B, 2A, 2B) Cables and controls for residual heat removal pumps (no. 1A, 1B) Numerous switchgear and relay racks for safe shutdown equipment Unit 1 auxiliary shutdown panel Several vital AC and DC power busses and associated circuit breakers Vital DC to AC inverters and rectifiers (no. 1-III, UPS-1, and UPS-2) Several vital AC transformers Vital AC buss feeders from diesel generators

Table 3.2

Fire Protection Systems
and Safe Shutdown Equipment by Fire Zone (Continued)

Fire Zone	Suppression System	Safe Shutdown Equipment
		DC battery output and charger circuits Emergency communications system (repeater)
Fire Zone 4 (Unit 2 Emergency Switchgear Room)	Halon system manually actuated either locally or from Control Room panel No. 2; also, 12 ionization-type smoke detectors (Halon supply is 10 gas bottles designed to empty all their contents)	Cables and controls for AFW cross-connect valve to Unit 1 Numerous switchgear and relay racks for Unit 2 safe shutdown equipment Unit 2 auxiliary shutdown panel cables Emergency communications system (repeater)
Fire Zone 6 (Emergency Diesel Generator Rm No. 1)	Manually actuated low-pressure CO_2 system (actuation switches are outside door and in Control Room on panel no. 1); also, 2 heat detectors	Diesel generator no. 1 Related switchgear and MCC cabinets
Fire Zone 7 (Emergency Diesel Generator Rm No. 2)	Manually actuated low-pressure CO_2 system (actuation switches are outside door and in Control Room on panel no. 1); also, 2 heat detectors	Diesel generator no. 2 Related switchgear and MCC cabinets
Fire Zone 8 (Emergency Diesel Generator Rm No. 3)	Manually actuated low-pressure CO_2 system (actuation switches are outside door and in Control Room on both panels no. 1 and 2); also, 2 heat detectors	Diesel generator no. 3 Related switchgear and MCC cabinets
Fire Zone 17 (Auxiliary Building)	3 charcoal ventilation filters at 45 ft level, 2 of which have manually actuated low-pressure CO_2 systems (switches are next to filters and in Control Room on panel no. 2), and 1 of which has a	6 charging pumps (no. 1A, 1B, 1C, plus Unit 2) 4 charging pump-component cooling water pumps (no. 2A and 2B plus Unit 2) 4 component cooling water pumps (no. 1A

Table 3.2

Fire Protection Systems
and Safe Shutdown Equipment by Fire Zone (Continued)

Fire Zone	Suppression System	Safe Shutdown Equipment
	manually actuated deluge (switch is next to filter); all 3 charcoal filter banks have heat detectors and the building has 38 ceiling-mounted ionization-type smoke detectors and 7 duct-mounted smoke detectors	and 1B plus Unit 2) Associated cables and valves for above pumps (especially MOVs 1115B, 1115C, 1115D, 1115E, 1350, 1867C, 1867D) Cables for indications at the remote monitoring panel Piping for charging pump service water Ventilation for Auxiliary Bldg. (charcoal filters) Emergency communications system (repeater) Boric acid transfer pump no. CH2A
Fire Zone 31 (Turbine Building)	Heat detector-actuated deluge system near lube oil components; automatic sprinklers in several areas including the corridors outside the Control Room and the Emergency Switchgear Rooms; automatic CO_2 systems actuated by heat detectors in Normal Switchgear Rooms, Cable Spreading Rooms, and general turbine area; also, several ionization-type smoke detectors	Cables for charging pump service water pumps (no. 10A, 10B) Piping for charging pump service water system Cables and controls for AFW motor-driven pumps (no. 3A, 3B) Cables and controls for containment spray pumps (no. 1A) Cables and controls for low-pressure safety injection pump (no. 1A) Cables and controls for outside spray recirculation pump (no. 2A) Cables and controls for residual heat removal pump (no. 1A) Several main steam valves (solenoid operated) Circulating and service water motor-operated valves

Table 3.2

Fire Protection Systems
and Safe Shutdown Equipment by Fire Zone (Concluded)

Fire Zone	Suppression System	Safe Shutdown Equipment
		Auxiliary steam system Motor-operated valves on the inlet and outlet of each condenser Remote monitoring panels Emergency communications system (repeater)

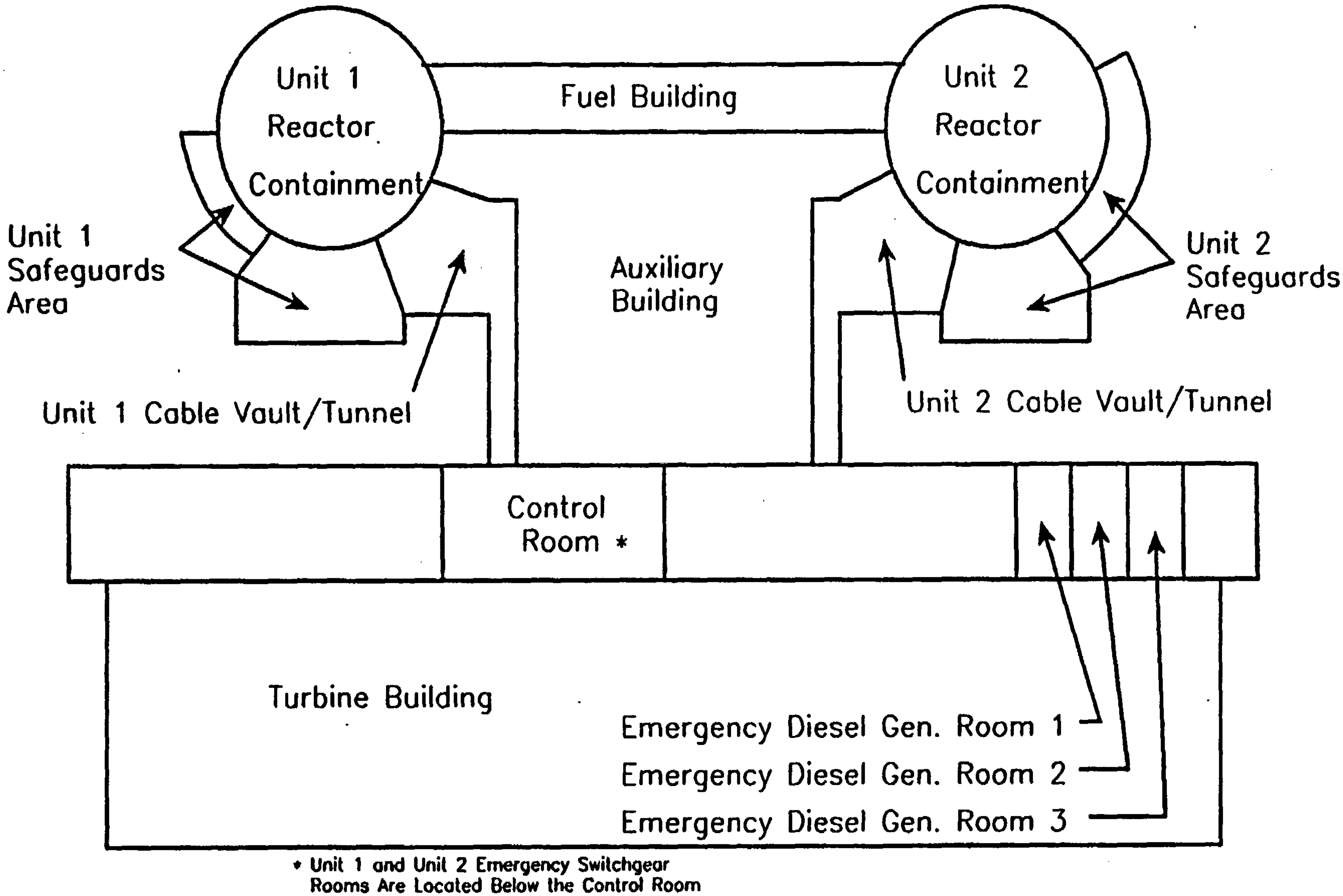


Figure 3.1. Plant Layout.

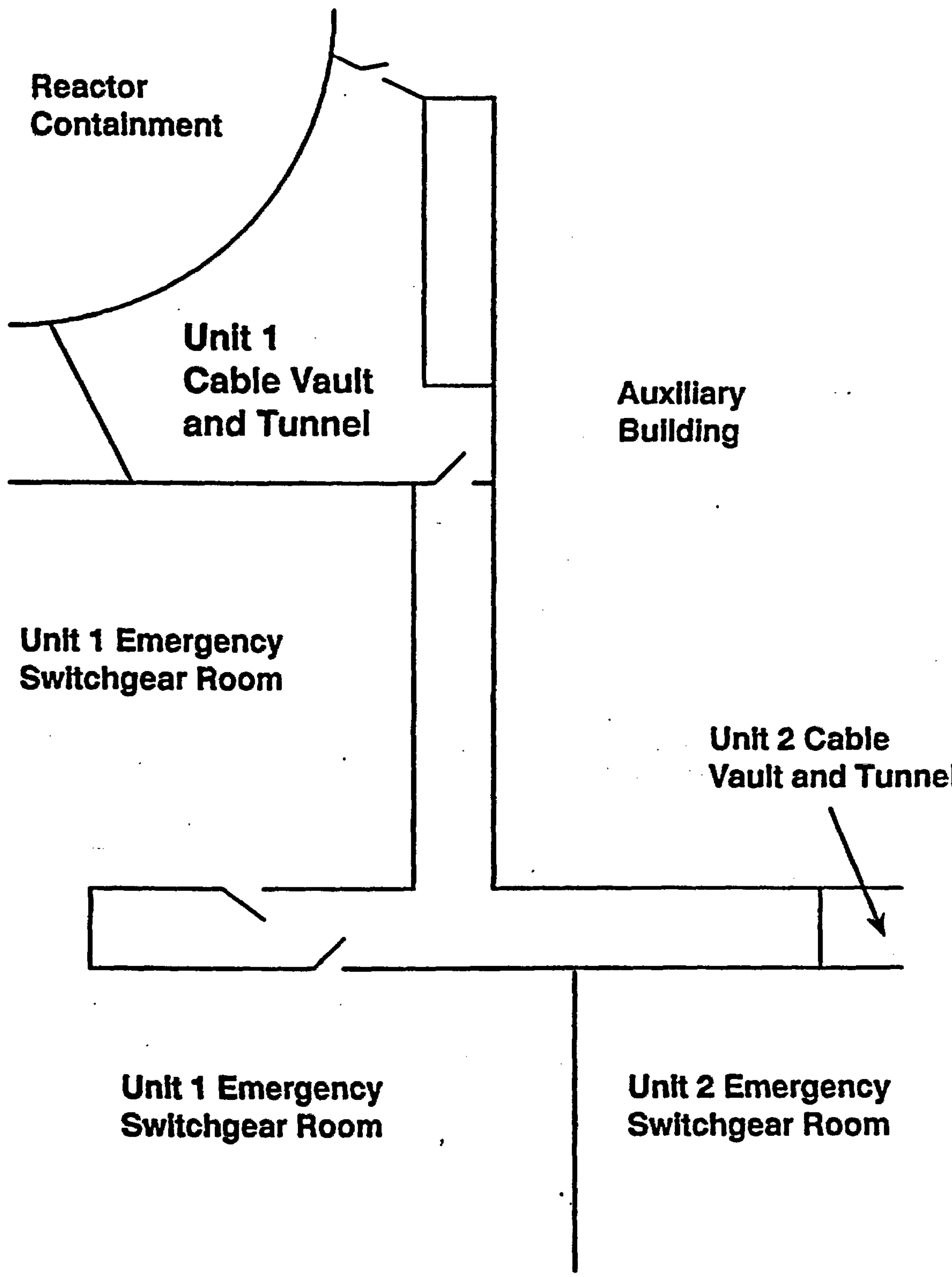


Figure 3.2. Cable Vault and Tunnel (Fire Zone 1).

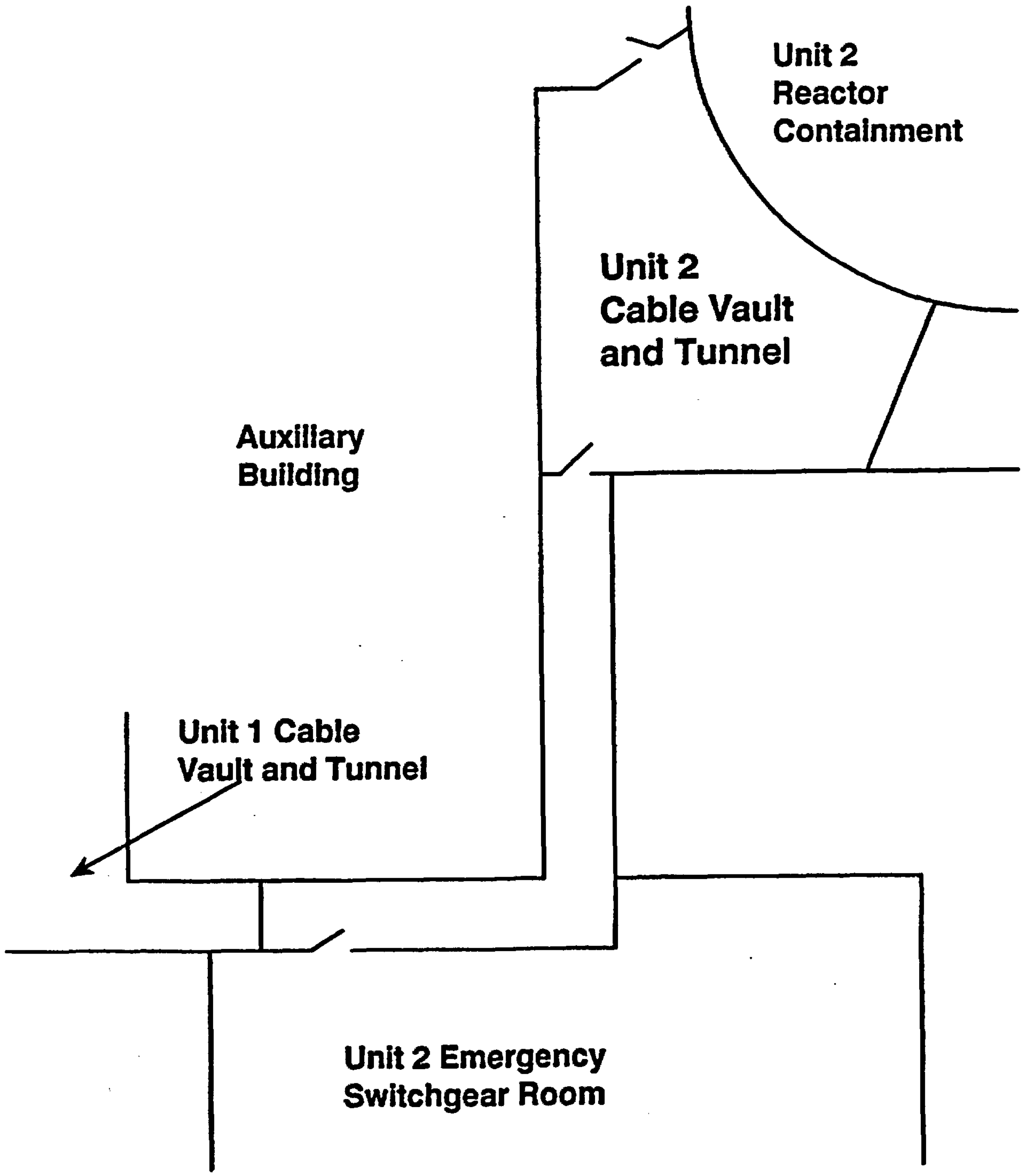


Figure 3.3. Cable Vault and Tunnel (Fire Zone 2).

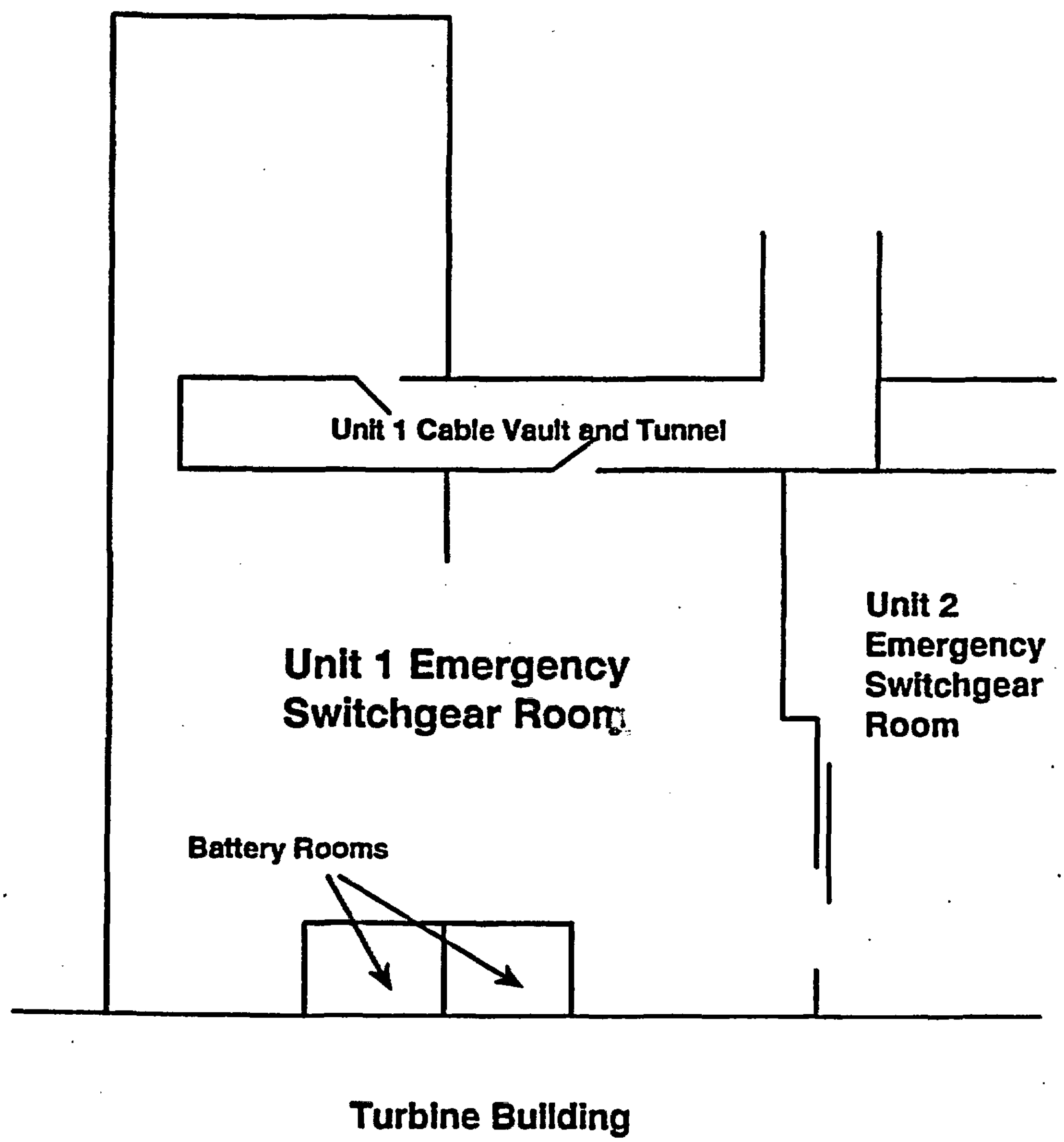


Figure 3.4. Unit 1 Emergency Switchgear Room (Fire Zone 3).

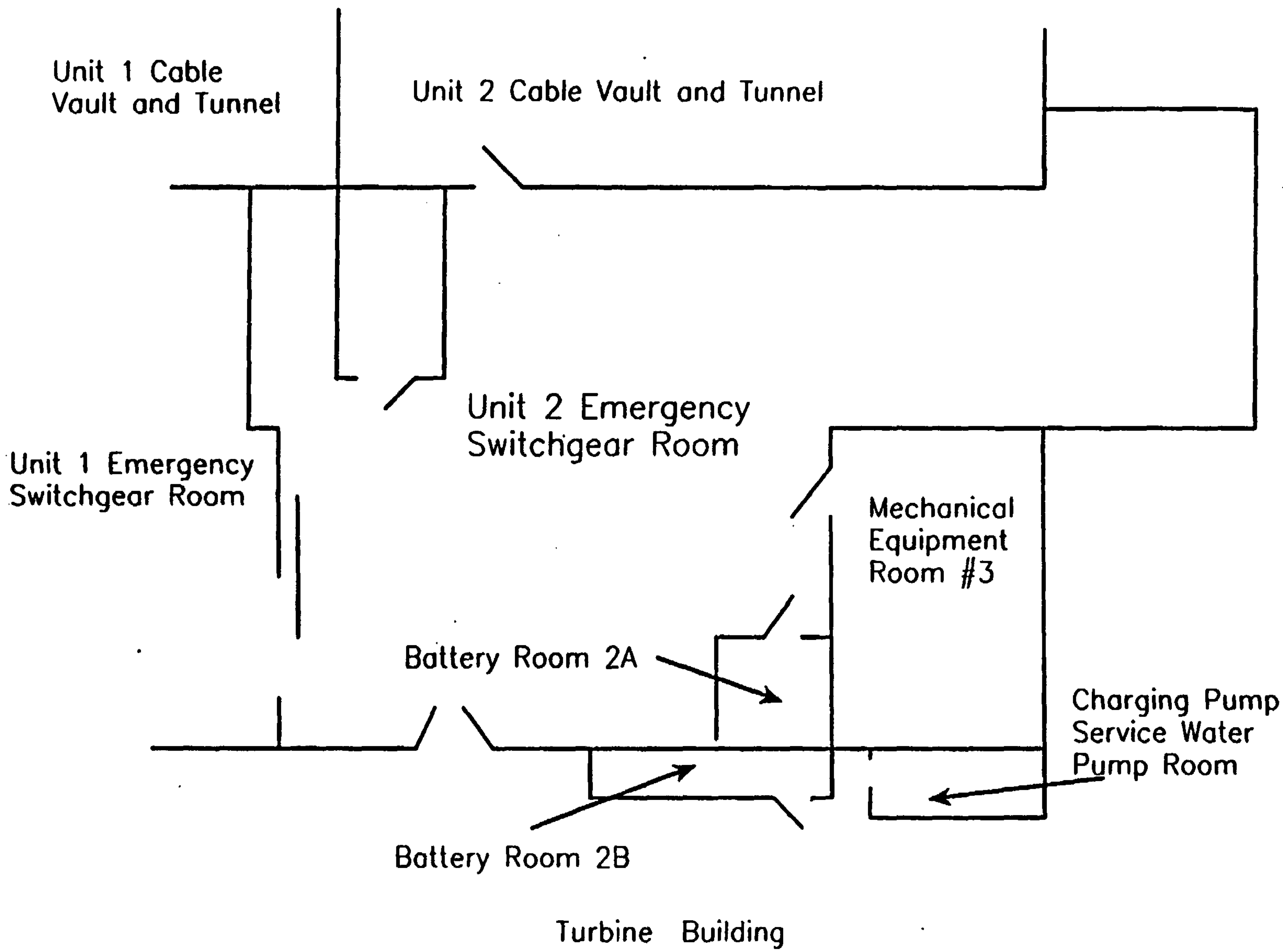


Figure 3.5. Unit 2 Emergency Switchgear Room (Fire Zone 4).

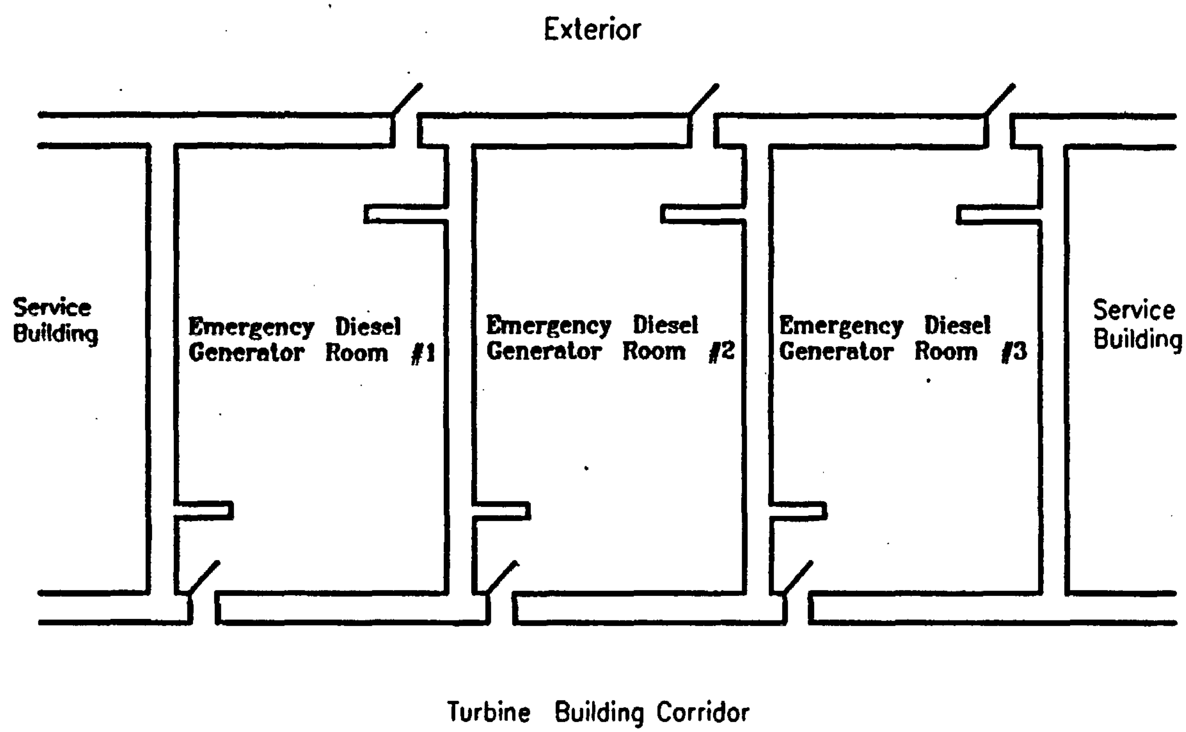


Figure 3.6. Emergency Diesel Generator Rooms (Fire Zones 6, 7, and 8).

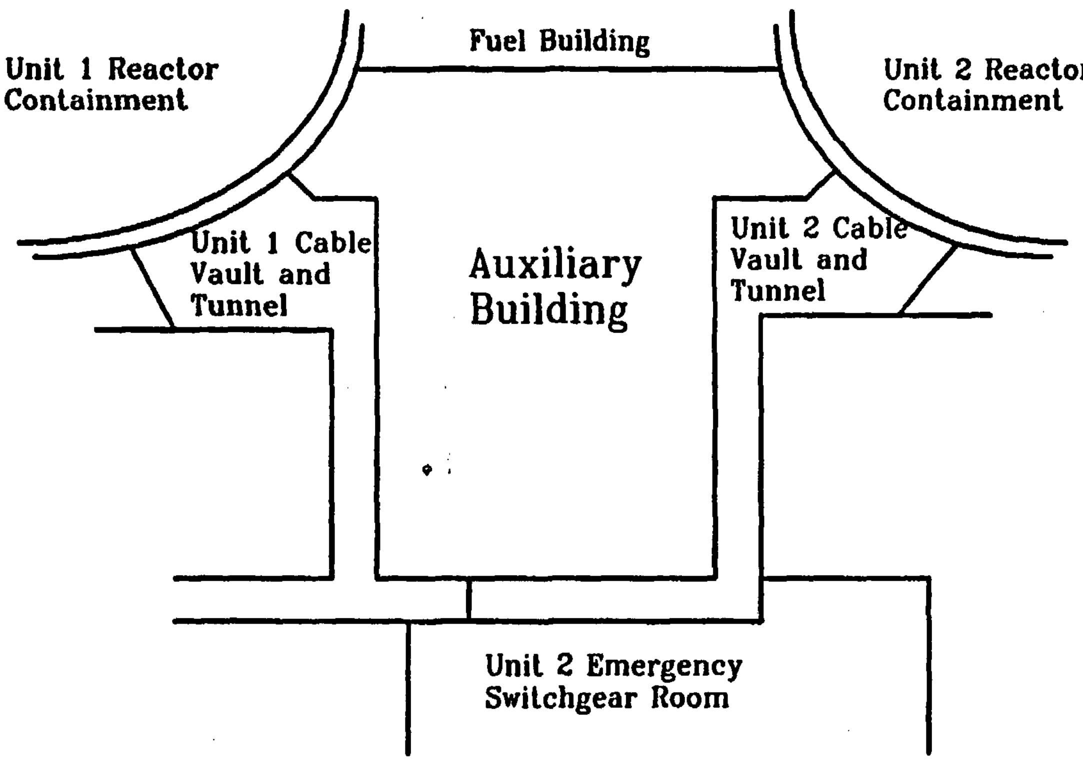


Figure 3.7. Auxiliary Building (Fire Zone 17).

Table 3.3

Plant Fire Zone Penetrations
and Adjacencies

Fire Area	Penetration	Connected Areas
FZ-1 (Unit 1 Cable Vault and Tunnel)	Doors	FZ-3, FZ-17
	Cables	FZ-2, FZ-3, FZ-5, FZ-17, FZ-19
FZ-2 (Unit 2 Cable Vault and Tunnel)	Doors	FZ-4, FZ-17
	Cables	FZ-1, FZ-4, FZ-5, FZ-17, FZ-20
FZ-3 (Unit 1 Emerg. Switchgear Room)	Doors	FZ-1, FZ-4
	Cables	FZ-1, FZ-5, FZ-4, FZ-31
FZ-4 (Unit 2 Emerg. Switchgear Room)	Doors	FZ-2, FZ-3, FZ-5, FZ-31, FZ-45
	Cables	FZ-2, FZ-3, FZ-5, FZ-31
FZ-6 (Diesel Generator Room No. 1)	Doors	FZ-31, Outside
	Cables	FZ-7, FZ-31
FZ-7 (Diesel Generator Room No. 2)	Doors	FZ-31, Outside
	Cables	FZ-6, FZ-8
FZ-8 (Diesel Generator Room No. 3)	Doors	FZ-31, Outside
	Cables	FZ-7, FZ-31
FZ-17 (Auxiliary Building)	Doors	FZ-1, FZ-2, FZ-31, Outside
	Cables	FZ-1, FZ-2
FZ-31 (Turbine Building)	Doors	FZ-4, FZ-5, FZ-6, FZ-8, FZ-12, FZ-17, FZ-54, Outside
	Cables	FZ-3, FZ-4, FZ-5, FZ-6, FZ-7, FZ-8, FZ-45, FZ-46, FZ-47

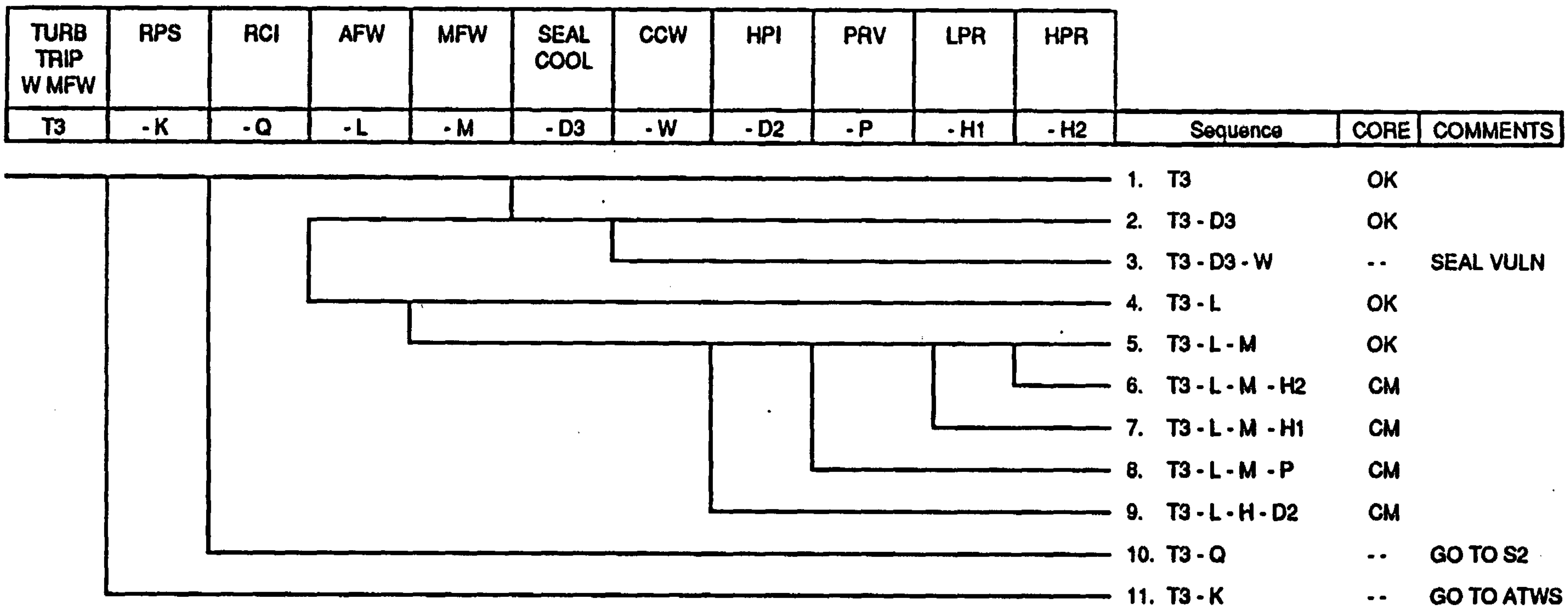


Figure 3.8. General Transient Event Tree.

directly by an FPS actuation or a fire alone was considered to be credible. Table 3.4 summarizes the transient sequences analyzed.

Sequence 3 is a transient with successful manual or automatic scram in which both HPI and CCW are failed which leads directly to a seal LOCA. Sequences 6 and 7 are transients in which both the AFW and MFW systems fail and long-term heat removal fails due to either a failure of the LPR or HPR systems. Sequences 12 and 13 also have failure of both the AFW and MFW systems, but in this case feed and bleed is failed either due to a failure of the HPI or PRV systems. Finally, sequence 14 is a transient with a stuck open relief valve and failure to provide core inventory makeup due to failure of the HPI system.

These sequences were analyzed for their applicability to the FPS actuation root cause scenarios as described in Section 3 of Reference 3.5. These criteria were applied to each cut set in the vital area analysis core damage sequences which were developed in the fire PRA performed as part of the NUREG-1150 program. In this process, many cut sets and several sequences were screened from further consideration. The sequences and cut sets that remained were grouped according to the thirteen root causes described in Section 3 of Reference 3.5.

3.2.2 LOSP Transients Due To Seismic Events

The loss of offsite power event tree used for this study is given in Figure 3.9. A total of six sequences leading to core damage are shown on this tree, and these sequences are listed in Table 3.5.

Sequence 3 is a LOSP with failure of both HPI and CCW systems which leads directly to a seal LOCA. In both sequences 5 and 6, the AFW system fails with long-term decay heat removal also failed due to loss of either the LPR or HPR systems. Sequences 7 and 8 have short-term heat removal failed due to failure of the AFW system and failure of feed and bleed. Finally, in sequence 9 a stuck open relief valve occurs with failure of core inventory makeup due to loss of the HPI system.

A plant walkdown was conducted to determine plant specific fragilities for all FPSs. Insights gained from the Loma Prieta earthquake (Ref. 3.5, Appendix C) were utilized where applicable. It was found that mechanical failure of a FPS (Root Cause 9) could be eliminated from further consideration based on this walkdown. The vital area analysis revealed that all critical plant safety equipment was protected by either Halon or CO_2 FPSs. In both cases, system piping does not contain any fire protection agent. Therefore, piping failures would not directly lead to agent release. For both systems mechanically-induced repositioning of an admission valve is the only plausible release mechanism for Root Cause 9. However, this type of failure mode is of sufficiently low probability ($<10^{-4}$) that Root Cause 9 scenarios could be screened from further consideration.

Since no vital area analysis had been performed for the LOSP sequences in the original PRA, one was performed as part of this study.

Table 3.4

General Transient Accident Sequences Analyzed

Sequence 3	T_3D_3W (Seal LOCA)
Sequence 6	T_3LMH_2
Sequence 7	T_3LMH_1
Sequence 8	T_3LMP
Sequence 9	T_3LMD_2
Sequence 10	T_3QD_1 (Stuck open relief valve)

Safety Systems Nomenclature

Q	Stuck-open PORV
D_1	High pressure injection (HPI)
D_2	Same as HPI
D_3	High pressure injection for seal cooling
H_1	High pressure recirculation (HPR-LH)
H_2	Low pressure recirculation (LPR-HH)
L	Auxiliary feedwater system (AFWS)
M	Main feedwater (MFW)
P	Block valves and PORV system (both valves required) (PPS1)
W	Component cooling water system (CCW)

In this process it was found that sequences 5, 7, and 8 were negligible based on random failure probabilities. The remaining three sequences were quantified for Root Causes 8 and 12 as described in Section 3.2.3.

3.2.3 Quantification

3.2.3.1 Quantification of Random and Fire-Induced Actuation Scenarios

The occurrence of a random FPS actuation, or an actuation in the presence of a fire in a nuclear power plant, can result in a plant transient caused either by the operator manually tripping the plant or the plant automatically tripping as a result of the actuation itself. The purpose of this study is to quantify the impact on risk of

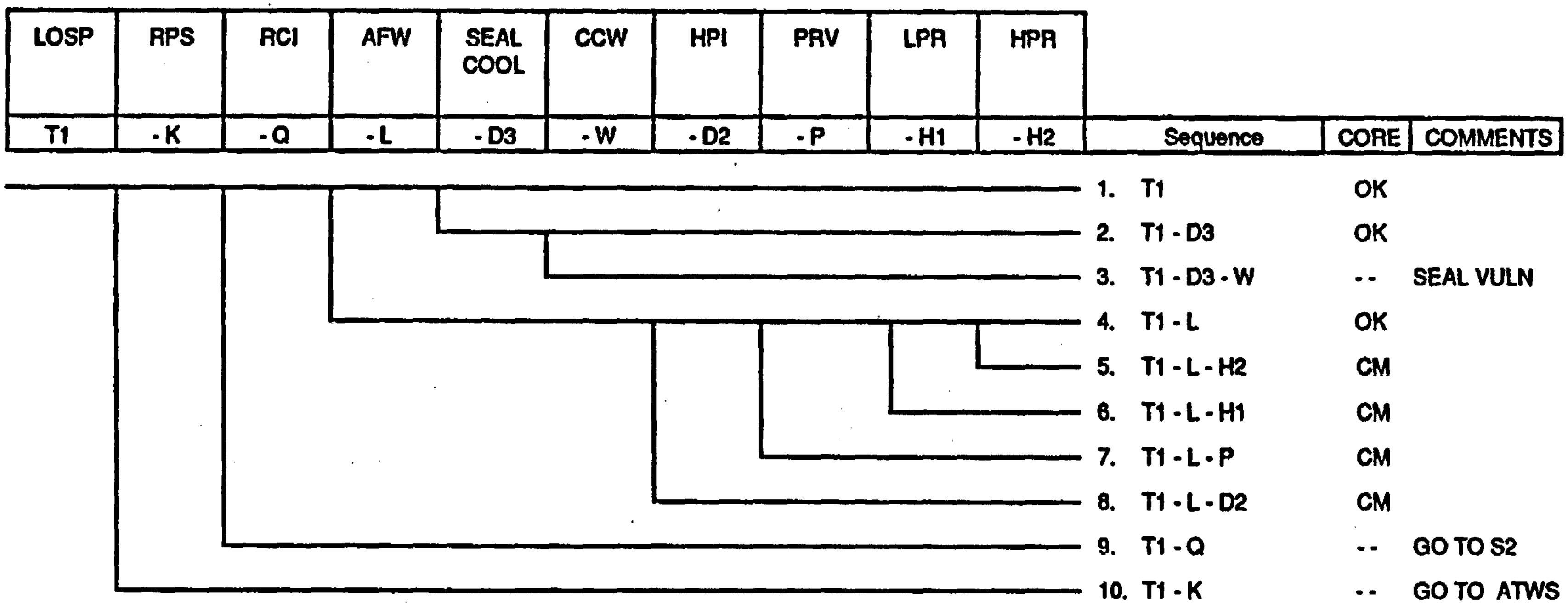


Figure 3.9. LOSP Event Tree.

Table 3.5

Loss of Offsite Power Transient Sequences

Sequence 3	T_1D_3W (Seal LOCA)
Sequence 5	T_1LH_2
Sequence 6	T_1LH_1
Sequence 7	T_1LP
Sequence 8	T_1LD_2
Sequence 9	T_1QD_1 (Stuck-open PORV)

*Refer to Table 3.4 for event descriptions.

inadvertent and advertent actuations of the FPS. The values chosen for the various parameters utilized in the calculation of the core damage frequency are best estimate values based on historical data. When little data existed, best estimate probability assignments were made based on plant walkdowns and engineering judgement. The specific equations utilized in the calculation of the core damage frequency contribution from each root cause can be found in Section 3 of Reference 3.5. Table 3.6 summarizes the fire frequencies used for each Fire Zone. The fire frequencies were taken from the NUREG-1150 study and are based on Bayesian updating to make the data plant specific. Table 3.7 presents fire frequencies of areas adjacent to the Fire Zones which appeared in the vital area analysis. Note that it is often necessary to ratio the overall building fire occurrence frequency down to reflect the fact that fires in only a small subset of the building can cause the postulated smoke spread to adjacent areas. This is called "partitioning" and is based on both analyst judgement and sensitivity calculations using a fire growth computer code CCFM.VENTS (Ref. 3.6). For this study, partitioning of the fire frequencies for the larger Fire Zones was performed wherever applicable. For example, in the turbine building this reduced the fire frequency by an order of magnitude for all areas. Thus, the frequencies in the table are not directly additive. The plant walkdown also revealed no potential sources of combustion and consequently was eliminated from the analysis.

3.2.3.2 Quantification of Seismically-Induced FPS Actuations

A site-specific seismic analysis was performed on the FPSs for the plant analyzed in this report. When a seismic event occurs, a loss of offsite power is highly likely due to the failure of ceramic insulators in the switchyard. Thus, the seismic sequences which must be considered are those where offsite power is assumed to be lost. Once the vital area analysis has been performed for the LOSP sequences, one can quantify them in a similar fashion as was done for the random and fire induced FPS actuation scenarios. The one significant difference is that the accident sequences evaluated are conditional on the plant site seismic curve (a function of peak ground acceleration) and as such must be

Table 3.6

Fire Frequencies Corresponding to Plant Fire Zones

Fire Zone	Fire Frequency (per reactor year)
Cable Vault and Tunnel (Fire Zones 1 and 2)	2.68E-3
Emergency Switchgear Room (Fire Zones 3 and 4)	2.97E-3
Control Room (Fire Zone 5)	4.40E-3
Emergency Diesel Generator Room (Fire Zones 6, 7, and 8)	2.31E-2
Auxiliary Building (Fire Zone 17)	6.38E-2
Safeguards Zone (Fire Zones 19 and 20)	1.77E-2
Turbine Building (Fire Zone 31)	3.21E-2
Mechanical Equipment Room No. 3 (Fire Zone 45)	3.71E-3
Charging Pump Service Water Pump Room (Fire Zone 54)	3.71E-3

integrated over the seismic hazard curve. For the seismic sequences considered in this analysis the damage is a result of seismic events above the safe shutdown earthquake (SSE). For the base case analysis of the seismic sequences the Lawrence Livermore National Laboratory (LLNL) hazard curves were utilized (Ref. 3.7). In Chapter 4, a sensitivity study is performed comparing the CDF contribution from the seismic root causes utilizing the LLNL and the Electric Power Research Institute (EPRI) hazard curves (Reference 3.8).

3.3 Results of Quantification

The results of the quantification for the fire and random failure-induced root causes are presented in Table 3.8. Tables 3.9 and 3.10 present the results for the quantification of Root Causes 8 and 12. These results are mean values of their associated distribution.

Table 3.7

Fire Frequencies in Adjacent Zones

		Fire Zone of Interest				
		FZ-1		FZ-2		FZ-3
Adjacent Zones	FZ-2	2.68E-3	FZ-1	2.68E-3	FZ-1	2.68E-3
	FZ-3	2.97E-3	FZ-4	2.97E-3	FZ-4	2.97E-3
	FZ-5*	4.40E-4	FZ-5*	4.40E-4	FZ-5*	4.40E-4
	FZ-17	6.39E-2	FZ-17	6.39E-2	FZ-31	3.21E-2
	FZ-19	1.77E-2	FZ-20	1.77E-2		
		Fire Zone of Interest				
		FZ-4		FZ-17		FZ-31
Adjacent Zones	FZ-2	2.68E-3	FZ-1	2.68E-3	FZ-3	2.97E-3
	FZ-3	2.97E-3	FZ-2	2.68E-3	FZ-4	2.97E-3
	FZ-5*	4.40E-3	FZ-31	3.21E-2	FZ-5*	4.40E-4
	FZ-31	3.21E-2			FZ-6	2.31E-2
	FZ-45	3.71E-3			FZ-7	2.31E-2
					FZ-8	2.31E-2
					FZ-12	2.97E-3
					FZ-17	6.39E-2
					FZ-45	3.71E-3
					FZ-54	3.71E-3
		Fire Zone of Interest				
		FZ-6		FZ-8		
Adjacent Zones	FZ-7	2.31E-2	FZ-7	2.31E-2		
	FZ-31	3.21E-2	FZ-31	3.21E-2		

*The control room (FZ-5) had its fire frequency lowered by one order of magnitude to allow credit for quick suppression of fire.

Credit for operator recovery was given where allowable for all non-seismic root causes. These recovery values were assigned consistently with those probabilities in the internal events analysis. The only modification to that rule is for recovery actions that had to take place in the presence of a fire or FPS actuation. For these cases, Reference 3.9 was used for guidance.

Table 3.8

Core Damage Frequencies for General Transient (Seal LOCA) Sequence 3 (Per Reactor Year)

Root Cause	Fire Zone 1	Fire Zone 3	Total
1	---	---	
2	---	---	
3	---	---	
4	3.0E-7	1.1E-6	1.4E-6
5	5.9E-8	1.1E-6	1.1E-6
6	3.9E-7	1.7E-6	2.1E-6
10	---	---	---
11	1.7E-7	2.5E-7	4.2E-7
13	3.0E-7	2.7E-7	5.7E-7
Totals	1.2E-6	4.4E-6	5.6E-6

Table 3.9

Frequencies for FPS Root Cause 8

Sequence		Frequency (per reactor year)
T_1-9		2.5E-7
T_1-5		1.0E-8
	Total	2.6E-7

Table 3.10

Frequencies for FPS Root Cause 12

Sequence		Frequency (per reactor year)
T_1-3		1.4E-6
	Total	1.4E-6

The Root Cause 8 scenario leads to the actuation of the CO_2 system in the diesel generator rooms due to relay chatter in a seismic event. Operator recovery of the diesel generators was allowed since 5 hours were available before battery depletion during a station blackout. The specific recovery actions that need to be performed are venting of at least one diesel generator room and then starting that diesel generator. Recovery action probability for this scenario was assigned based upon Reference 3.6.

Recovery was also given for seismic Root Cause Scenario 12. In this case, the recovery action that is performed is the cross-connection of the Unit #2 HPI system to either prevent a seal LOCA from occuring or to provide makeup if the seal LOCA has already occurred.

Appendix A presents the uncertainty calculations as well as each cut set for the seismic and non-seismic root causes. Additionally, each basic event probability value is given in Appendix A. The details concerning the development of these probability assignments can be found in Section 3 of Reference 3.5.

3.3.1 Root Cause 1--Fire-Induced FPS Actuation Due to Smoke Spread

This plant uses smoke detectors for indication purposes only. Therefore, no actuation of any FPS due to smoke was postulated. Thus, this root cause is not applicable plant under consideration.

3.3.2 Root Cause 2--Fire-Induced FPS Actuation Preventing Recovery

For this root cause, all cut sets could be screened either because the random failures were recoverable or there was no connectivity between the zone where the fire occurred and the zone where the recovery action took place. Therefore, this root cause was found not be applicable for this plant.

The criteria for allowing credit for recovery for random failures was applied consistently with internal events analysis (Ref. 3.2). Thus, if recovery was not allowed for instance for a mechanical failure of a check valve, it was also not considered here. Most random failures were eliminated based on this criteria. Secondly, if random failure recovery was allowed by the internal events analysis, a determination was made in which Fire Zone(s) the recovery action(s) occurred. For the recoverable random failures it was found that none occurred in Fire Zones where FPS actuation would either hinder the action or prevent access to the zone.

3.3.3 Root Cause 3--Fire-Induced FPS Actuation Preventing Fire-Fighting Access

This root cause was found not to be applicable. It was found that smoke spread could not actuate FPSs in adjacent zones.

3.3.4 Root Cause 4--FPS Actuation Caused by Human Error

Here, an incremental increase in core damage frequency of 1.4E-6/yr was found. The dominant contributor was Sequence 3 which is a simultaneous failure of the HPI and CCW systems, which results in a seal LOCA and failure of early emergency coolant injection. The contributing fire zones are the Unit 1 cable vault/tunnel and emergency switchgear rooms. In these areas, there is sufficient equipment which, if failed, results in failure of both the HPI and the CCW systems.

Recovery was allowed consistent with the fire PRA. Credit was given for cross connections to the Unit 2 HPI to either prevent a seal LOCA or mitigate its effect if it has already occurred.

3.3.5 Root Cause 5--FPS Actuation Caused by Pipe Break

The incremental increase in core damage frequency for this root cause was found to be 1.1E-6/yr. It again arises due to inadvertent FPS actuations in the emergency switchgear room and the cable vault/tunnel giving rise to Sequence 3 as described previously. These inadvertent actuations are caused by steam line breaks in the turbine building. All other sequences and fire zones are negligible contributors to core damage frequency.

At this plant, two such events have occurred. In each case, FPS actuation either occurred due to water intrusion into a controller or due to operator error.

For the case of the cable vault/tunnel, the steam must penetrate through the wall between the turbine building and emergency switchgear room and actuate either of two controllers in the emergency switchgear room. The probability for barrier failure was assessed to be 0.1. In the most recent steam line break (turbine building), steam is known to have penetrated the applicable barrier but did not cause CO_2 system actuation.

The controllers for the manual Halon system (emergency switchgear room) are located in the turbine building. This system has been actuated for both steam line breaks that have occurred. Therefore, the probability of actuation given a turbine building steam line break has been assigned a probability of 1.0.

3.3.6 Root Cause 6--FPS Actuation Caused by Hardware Failures in FPS

The incremental increase in core damage frequency for this root cause was found to be 2.1E-6/yr. It again arises primarily due to inadvertent FPS actuations in the cable vault/tunnel giving rise to Sequence 3 as described previously. As was the case for Root Cause 4, credit was given for operators cross connecting the Unit 2 HPI.

3.3.7 Root Cause 7--Dust-Triggered FPS Actuations in Seismic Events

As noted earlier, the plant under consideration does not utilize automatic fire protection systems which could be actuated by dust raised during a seismic event. (Certain fire zones do have either ionization or smoke detectors, but they are not used to actuate any of the fire protection systems.) Hence, this root cause was not applicable for the plant under consideration.

3.3.8 Root Cause 8--Relay Chatter FPS Actuations in Seismic Events

The core damage frequency incremental increase associated with this root cause was found to be 2.6E-7/ry. Sequences T_1-9 and T_1-5, described in Section 3.2.2 (T_1-9 & T_1-5) contributed roughly 97 and 3 percent, respectively to the Root Cause 8 core damage frequency contribution.

3.3.9 Root Cause 9--FPS Actuations Due To Seismic Failures of FPS

This root cause was found not to be applicable for this plant. This result was based on seismic fragility evaluation and a comprehensive a plant walkdown. See Section 3.2.2 for more details.

3.3.10 Root Cause 10--External Plant Fires Causing FPS Actuations

This root cause was screened from further analysis as described in Section 3.2. It should be noted, however, that this PWR site does have a fairly thick wooded area in close proximity to the buildings, and that external fires are a real possibility.

3.3.11 Root Cause 11--Advertent Actuation of a Suppression System

For this scenario to occur, actuation of the FPS has to be in the same fire zone as the fire. Critical damage must occur either as a combination of fire-related effects and FPS agent release or due to FPS agent release alone. Two fire zones leading to transient Sequence 3 contribute 4.2E-7/ry to core damage frequency. The cable vault/tunnel contributes 1.7E-7/ry while the emergency switchgear room contributes 2.5E-7/ry. As was the case for Root Causes 4 and 6, credit for operator recovery was given for Sequence 3.

3.3.12 Root Cause 12--Seismic/Fire Interaction

The incremental increase in core damage frequency for this root cause was found to be 1.4E-6/ry. This scenario arises from a seismically-induced fire in the cable vault/tunnel. This fire fails cabling for both the HPI and CCW systems leading to a seal LOCA sequence (T_1-3).

The fire occurs due to a tipping or sliding failure of either of two vital energized motor control centers which are located in close proximity to the HPI and CCW cabling. Diversion of fire suppressant is caused by failure of the CO_2 tank and/or its outlet piping. A plant specific fragility evaluation was performed both for the CO_2 tank and the vital motor control centers.

3.3.13 Root Cause 13--FPS Actuation Due to Unknown Causes

The incremental increase in core damage frequency for this root cause was found to be 5.7E-7/yr. It again arises primarily due to inadvertent actuations in the cable vault/tunnel and emergency switchgear room giving rise to Sequence 3. Credit was given for operator recovery as before.

3.4 Summary

As described above, of the thirteen root cause scenarios postulated to lead to core damage resulting from actuation of this plant's fire protection systems, six were found not to be applicable (fire-induced FPS actuation due to smoke spread, FPS actuation preventing manual fire-fighting and operator recovery of random failures, FPS actuation due to dust raised in a seismic event, external plant fires, and seismically-induced FPS mechanical failure).

The seven remaining root cause scenarios led to an increase in core damage frequency with the following distribution:

Mean	7.3E-6
Median	4.2E-6
5th%	5.9E-7
95th%	2.6E-5.

The dominant contributors to this total were Root Causes 6, 12, 4, and 5 which are inadvertent actuations due to human error, seismic/fire interaction, inadvertent actuation due to hardware failure and steam pipe break. These scenarios contributed 82 percent to the total.

Advertent actuation of an FPS (Root Cause 11) contributed 4.2E-7/yr and also was found to lead to a seal LOCA. Inadvertent actuation due to unknown causes (Root Cause 13) contributed nine percent to the overall core damage frequency. Finally, core damage due to seismic Root Cause 8 contributed four percent.

It must be noted that this was a plant-specific analysis. Others plants of the same type might have core damage frequency contributions from Root Causes 1, 2, 3, 7, 9, and 10 which were not applicable to this site. Also, these results are highly dependent on the plant-specific equipment and cable locations.

3.5 References

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4.0 SENSITIVITY STUDIES

The results in Chapter 3 represent a base case analysis that used the parameter value estimates presented in Reference 4.1. As discussed there, several of the parameter values are thought to be more uncertain than other estimates. In particular, the values taken for the probability of a fire given tipping or sliding failure of an energized motor control center or bus, the probability of cable damage from the FPS actuation, the probability of Halon damage to equipment and the probability of barrier failure were best estimate values but with less data for justification of assignment. This section describes sensitivity studies in which four of the more uncertain estimates are varied (i.e., the probability of a fire given tipping or sliding failure of an energized electrical cabinet, the probability of FPS damage to cables, the probability of Halon damage to equipment and the probability of barrier failure). Additionally, a sensitivity study is presented comparing the CDF contribution from the seismic root causes utilizing the LLNL and the EPRI hazard curves (Ref. 4.2). Table 4.1 summarizes the results of these studies and also presents a sixth sensitivity study which is a combination of all five sensitivity studies. Descriptions of each sensitivity study are presented below.

Calculations for the sensitivity studies of core damage frequency and risk are accomplished by the use of the top event matrix analysis code TEMAC (Ref. 4.3) and the latin hypercube sampling code (Ref. 4.4).

4.1 Sensitivity Study 1--Comparison of CDF Utilizing the LLNL and EPRI Seismic Hazard Curves

At this time, both sets of hazard curves are viewed by the USNRC as being equally credible. As such, calculations of the seismic core damage frequencies can be made for both sets of hazard curves and the results viewed as a measure of methodological uncertainty in the hazard curve development process.

In the base case analysis, the LLNL seismic hazard curves were utilized to calculate the CDF contribution for each of the applicable seismic root causes (8 and 12) to be consistent with the NUREG-1150 studies. As a point of comparison, the CDF contribution from the seismic root causes were also calculated using the EPRI seismic hazard curves. All other values were kept the same as in the base case study. The results are presented in Table 4.2. Figures 4.1 and 4.2 present the LLNL hazard curves and the EPRI hazard curves, respectively.

4.2 Sensitivity Study 2--Decrease in the Probability of a Fire Given Tipping or Sliding Failure of an Energized Motor Control Center

For the base case analysis, the probability of a fire given the tipping or sliding failure of an electrical cabinet was assigned a value of 0.5. This value was based on engineering judgement and takes into account industrial earthquake experiences of a similar nature. However, the actual probability may be less than the base case value.

Table 4.1

Summary of Sensitivity Results
in Terms of Core Damage Frequency (Per Reactor Year)**

Root Cause	Base Case	Study 1 EPRI Hazard Curves	Study 2 Decrease in Probability of a Seismic Fire	Study 3 Reduced CO_2 Damage to Cable
1.	Not applicable for plant under consideration.			
2.	Not applicable for plant under consideration.			
3.	Not applicable for plant under consideration.			
4.	1.4E-6	N/A*	N/A	1.2E-6
5.	1.1E-6	N/A	N/A	1.1E-6
6.	2.1E-6	N/A	N/A	1.8E-6
7.	Not applicable for plant under consideration.			
8.	2.6E-7	3.2E-8	N/A	2.5E-7
9.	Not applicable for plant under consideration.			
10.	Not applicable for plant under consideration.			
11.	4.2E-7	N/A	N/A	3.0E-7
12.	1.4E-6	2.0E-7	2.8E-7	N/A*
13.	5.7E-7	N/A	N/A	3.3E-7
Total	7.3E-6	5.9E-6	6.2E-6	6.4E-6

* All entries listed as N/A were not requantified from the base case. Therefore, the total for each sensitivity study can be obtained by using the base case frequency for these entries.

** All entries in this table represent mean values of uncertainty analysis results given in Appendix A.

Table 4.1 (Concluded)

Summary of Sensitivity Results
in Terms of Core Damage Frequency (Per Reactor Year)**

Root Cause	Base Case	Study 4 Barrier Failure = .01	Study 5 No Halon Damage	Study 6 All Combined
1.	Not applicable for plant under consideration.			
2.	Not applicable for plant under consideration.			
3.	Not applicable for plant under consideration.			
4.	1.4E-6	N/A	3.0E-7	6.0E-8
5.	1.1E-6	1.1E-6	5.9E-8	1.2E-8
6.	2.1E-6	N/A	3.9E-7	8.0E-8
7.	Not applicable for plant under consideration.			
8.	2.6E-7	N/A	N/A	3.2E-8
9.	Not applicable for plant under consideration.			
10.	Not applicable for plant under consideration.			
11.	4.2E-7	N/A	1.7E-7	3.4E-8
12.	1.4E-6	N/A	N/A	4.0E-8
13.	5.7E-7	N/A	3.0E-7	6.0E-8
Total	7.3E-6	7.3E-6	2.9E-6	3.2E-7

* All entries listed as N/A were not requantified from the base case. Therefore, the total for each sensitivity study can be obtained by using the base case frequency for these entries.

** All entries in this table represent mean values of uncertainty analysis results given in Appendix A.

Table 4.2

Core Damage Frequencies for Sensitivity Study 1
EPRI Seismic Hazard Curves (Per Reactor Year)*

Root Cause	Sequence			Total
	T_1-3	T_1-5	T_1-9	
1	---	---	---	
2	---	---	---	
3	---	---	---	
4	---	---	---	
5	---	---	---	
6	---	---	---	
7	---	---	---	
8	---	<1.0E-8	3.2E-8	
9	---	---	---	
10	---	---	---	
11	---	---	---	
12	2.0E-7	---	---	
13	---	---	---	
Totals	2.0E-7	<1.0E-8	3.2E-8	2.3E-7

* All entries in this table are mean values.

Consequently, for this sensitivity study, the probability of a fire given the tipping or sliding failure of an energized motor control center was reduced by a factor of 5. All other numerical values were kept the same as in the base case. The accident sequence cut sets were requantified to determine a new value of the incremental increase in core damage frequency. Since this study involves seismic/fire interaction, the only Root Cause affected is Root Cause 12.

The requantified contribution to the core damage frequency is presented in Table 4.3.

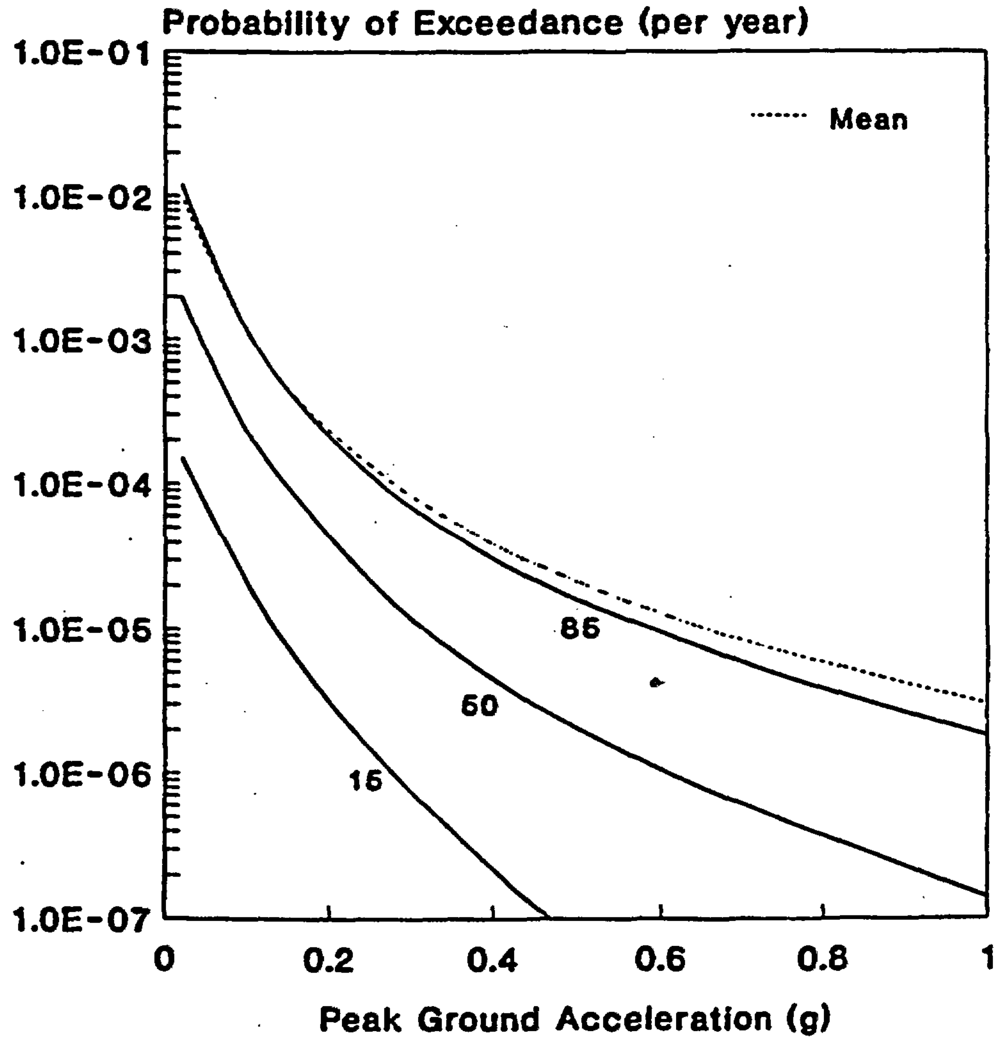

Figure 4.1. LLNL Hazard Curve: Mean, Median, 15th and 85th Percentile Curves.

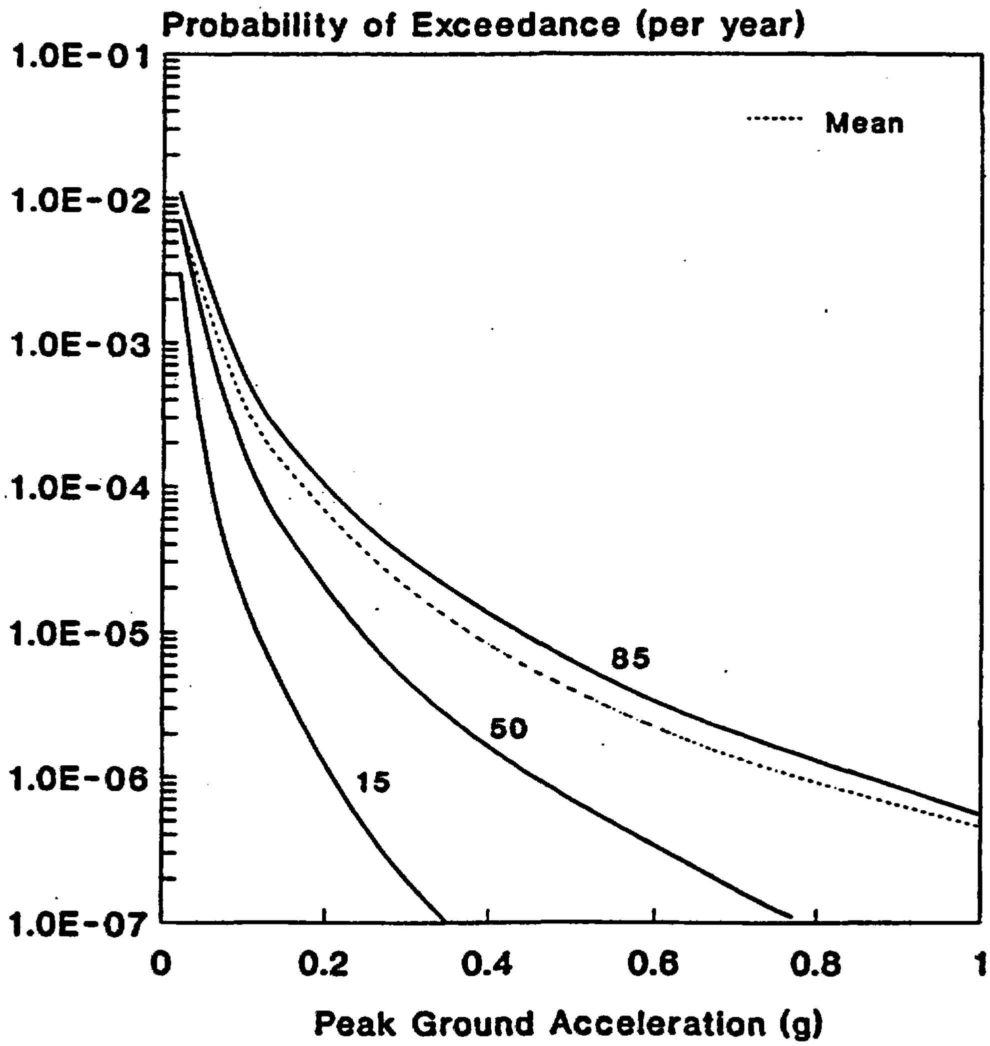

Figure 4.2. EPRI Hazard Curve: Mean, Median, 15th and 85th Percentile Curves.

Table 4.3

Core Damage Frequencies for Sensitivity Study 2-Reduced Probability of a Fire Given Tipping or Sliding Failure of an Energized Cabinet (Per Reactor Year)*

Root Cause	Sequence			Total
	T_1-3	T_1-5	T_1-9	
1	---	---	---	
2	---	---	---	
3	---	---	---	
4	---	---	---	
5	---	---	---	
6	---	---	---	
7	---	---	---	
8	---	---	---	
9	---	---	---	
10	---	---	---	
11	---	---	---	
12	2.8E-7	---	---	
13	---	---	---	
Totals	2.8E-7		---	2.8E-7

* All entries in this table are mean values.

4.3 Sensitivity Study 3--Decrease in Cable Damage From CO_2

In the base case analysis, any type of FPS actuation was assumed to damage cables with equal probability. Cable damage is assumed to occur due to inadequate seals for the cables and the possibility of erroneous signals being generated in cables exposed to an overdump of CO_2, water intrusion, or exposure to Halon. The probability of FPS damage to cables was treated as a sensitivity issue. In this sensitivity study, the mean probability of FPS damage to cables was lowered from 3.0E-3 to 6.0E-4.

For the plant under study, this reduced probability affects the cable vault/tunnel. The reason is that all of the other Fire Zones contain (primarily) active electromechanical equipment for which the probability of damage was kept as-is for the fire suppressant agent specific values developed as described in Chapter 3 of Reference 4.1. The cable vault/tunnel (Fire Zone 3) contains mostly cables with some motor control centers. Consequently, this sensitivity study was calculated assuming a probability of cable damage from FPS actuation of 6.0E-4 for Fire Zone 3, with all other zones remaining the same as in the base case.

The requantified incremental increases in core damage frequency are presented in Table 4.4.

4.4 Sensitivity Study 4--Decrease in Barrier Failure Probability

For the base case quantification, the probability of failure of the barriers between two Fire Zones was taken to be 0.1. The probability of barrier failure to steam for the turbine building/ESGR wall may be less than the generic barrier failure probability. Therefore, for this fourth sensitivity study, the barrier failure probability between zones was taken to be 0.01.

The requantified incremental increase in core damage frequency is presented in Table 4.5. Since Root Causes 4, 6, 8, 11, 12, and 13 do not depend on barrier failures, their values do not change in this case. For Root Cause 5, the value decreases an order of magnitude for the scenario involving the cable vault/tunnel.

4.5 Sensitivity Study 5--No Equipment Damage from Halon

For the base case analysis, Halon system actuation was assumed to have a conditional probability of 5.4E-3 of damaging nearby equipment. Nevertheless, the detailed LER review found no reports of any Halon release damaging safety-related equipment.

Consequently, for this sensitivity study, it is assumed that Halon system actuation cannot damage nearby plant equipment. All other numerical values were kept the same as in the base case. The accident sequence cut sets were requantified to determine a new value of the incremental increase in core damage frequency. Since the only Halon systems at the plant under study are in the two emergency switchgear rooms, only the cut sets involving these rooms changed in value.

The requantified contributions to the increase in core damage frequency are given in Table 4.6. The reason that the total core damage frequency reduction was 60 percent as compared with the base case analysis was that the emergency switchgear room is a dominant area contributor to core damage frequency. The cable vault/tunnel is not affected by

Table 4.4

Core Damage Frequencies for Sensitivity Study 3-Reduced Probability of Cable Damage from CO_2 (Per Reactor Year)*

Root Cause	Sequence 3	Total
1	---	
2	---	
3	---	
4	1.2E-6	
5	1.1E-6	
6	1.8E-6	
7	---	
8	2.5E-7	
9	---	
10	---	
11	3.0E-7	
12	---	
13	3.3E-7	
Totals	5.0E-6	5.0E-6

* All entries in this table are mean values.

changes in the Halon damagability estimate. The results also show that Sequence 3 is still the major contributing accident sequence for the root causes.

4.6 Sensitivity Study 6--Combination of Studies 1, 2, 3, 4 and 5

For this final sensitivity study, the changes mentioned in the five previous studies were incorporated simultaneously. Specifically, the EPRI seismic hazard curves were used in place of the LLNL curves to obtain the CDF contribution for each of the seismic root causes, the probability of a fire given tipping or sliding failure of an energized cabinet was taken to 0.1, the mean probability of CO_2 FPS damage in

Table 4.5

Core Damage Frequencies for Sensitivity Study 4-Reduced Probability of Barrier Failure (Per Reactor Year)*

Root Cause	Sequence 3	Total
1	---	
2	---	
3	---	
4	---	
5	1.1E-6	
6	---	
7	---	
8	---	
9	---	
10	---	
11	---	
12	---	
13	---	
Totals	1.1E-6	1.1E-6

* All entries in this table are mean values.

Fire Zone 1 was taken to be 6.0E-4, the probability of barrier failure was assumed to be 0.01, and it was assumed that Halon could not damage nearby equipment.

The accident sequence cut sets were then requantified with all other values being kept the samé as in the base case. Hence, this sensitivity study represents the most optimistic analysis--and the most optimistic results--in this report.

The resulting increments in core damage frequency are summarized in Table 4.7. General transient sequence 3 and Fire Zone 3 remain the major contributors to core damage frequency.

Table 4.6

Core Damage Frequencies for Sensitivity Study 5-No Equipment Damage From Halon (Per Reactor Year)*

Root Cause	Sequence 3	Total
1	---	
2	---	
3	---	
4	3.0E-7	
5	5.9E-8	
6	3.9E-7	
7	---	
8	---	
9	---	
10	---	
11	1.7E-7	
12	---	
13	3.0E-7	
Totals	1.2E-6	1.2E-6

* All entries in this table are mean values.

The total increment for Root Cause 4 decreases from 1.4E-6/ry in the base case to 6.0E-8/ry here. General transient sequence 3 remains as the dominant contributor.

For Root Cause 5, the total increment decreases from 1.1E-6/ry to 1.2E-8/ry. General transient sequence 3 remains as the dominant contributor.

For Root Cause 6, the total increment decreases from 2.1E-6/ry to 8.0E-8/ry. General transient sequence 3 remains as the dominant contributor.

Table 4.7

Core Damage Frequencies for Sensitivity Study 6 - Combination of Sensitivity Studies 1, 2, 3, 4 and 5 (Per Reactor Year)*

Root Cause	Sequence				Total
	3	T_1-3	T_1-5	T_1-9	
1	---	---	---	---	
2	---	---	---	---	
3	---	---	---	---	
4	6.0E-8	---	---	---	
5	1.2E-8	---	---	---	
6	8.0E-8	---	---	---	
7	---	---	---	---	
8	---	---	<1.0E-8	3.2E-8	
9	---	---	---	---	
10	---	---	---	---	
11	3.4E-8	---	---		
12	---	4.0E-8	---	---	
13	6.0E-8	---	---	---	
Totals	2.5E-7	4.0E-8	<1.0E-8	3.2E-8	3.2E-7

* All entries in this table are mean values.

For Root Cause 11, core damage frequency decreased from 4.2E-7/ry to 3.4E-8/ry with general transient sequence 3 still being the dominant contributor.

The total increment for the Root Cause 13 contribution to core damage frequency decreased from 5.7E-7/ry to 6.0E-8/ry. General transient sequence 3 is the dominant contributor.

The core damage frequency contribution from seismic Root Cause 8, which involves relay chatter in the Diesel Generator rooms, decreased from 2.6E-7/ry to 3.2E-8/ry. The reduction in core damage frequency of almost an order of magnitude is a result of utilizing the EPRI hazard curves to calculate the CDF.

For Root Cause 12, which is seismic/fire interaction in the cable vault/tunnel, the reduction in the probability of fire given tipping or sliding failure of an energized cabinet, combined with utilizing the EPRI hazard curves to calculate the CDF, reduced core damage frequency from 1.4E-6/ry to 4.0E-8/ry.

The data for this sensitivity study are shown in Table 4.7. The net result of this most optimistic analysis is to decrease the increments in total core damage frequency by more than an order of magnitude. However, Root Cause 6 remains the dominant root cause.

4.7 Summary

The requantified contributions to core damage frequency are summarized in Table 4.1. The results of these sensitivity studies show that the most dominant effect was elimination of the probability of Halon damage to nearby equipment. This reduced the core damage frequency by 60 percent. The second most dominant effect on reduction of CDF was utilization of the EPRI hazard curves.

The effect of decreasing the probability of a seismic/fire, reduced CO_2 damage to cable, and lowering of barrier failure probability led to only relatively minor reductions in total CDF. Additional data for the uncertain parameters varied in these studies will be required to understand the true incremental increase in core damage frequency due to FPS actuations.

4.8 References

4.1 J. A. Lambright, et al., Evaluation of Generic Issue 57: Effects of Fire Protection System Actuation on Safety-Related Equipment, Main Report, NUREG/CR-5580, SAND91-1507, Sandia National Laboratories, December 1992.

4.2 M. P. Bohn and J. A. Lambright, NUREG/CR-4550, SAND86-2084, Rev. 1/Vol.3, Part 4, Sandia National Laboratories, January, 1991.

4.3 R. L. Iman, et al., A User's Guide for the Top Event Matrix Analysis Code (TEMAC), NUREG/CR-4598, SAND86-0960, Sandia National Laboratories, August 1986.

4.4 R. L. Iman, et al., A Fortran 77 Program and User's Guide for the Generation of Latin Hypercube and Random Samples for Use with Computer Models, NUREG/CR-3624, SAND83-2365, Sandia National Laboratories, June 1984.

5.0 RISK ASSESSMENT

This chapter will provide the derivation of the offsite dose calculations for this analysis and present the risk calculations for each of the applicable root causes.

Appendix B presents the uncertainty calculations for risk as well as for each cut set for the seismic and non-seismic root causes.

5.1 Offsite Dose Calculations

To convert the calculated core damage frequencies to offsite dose, a simple containment failure event tree was used. Section 4.3 of Reference 5.1 outlines the basic methodology that can be applied to any PWR. This section details the specific application of this methodology to this plant.

A detailed cable tracing and equipment location mapping for all containment systems was performed. For a description of these containment systems refer to Chapter 2. This vital area analysis revealed that either the fire zones analyzed contained all containment systems or none at all. In addition, the seismically induced station blackout scenarios failed all AC electrical power, thus failing all containment systems due to failure of AC electric motor-driven spray pumps. Table 5.1 provides a listing of the containment failure branch for each fire zone.

It was found that for both the $\bar{Z}\bar{C}_2\bar{F}'$ and ZC_2 containment failure sequences the dominant release category was δV. This release category contributed 87 percent of the total to sequence ZC_2 and 65 percent to sequence $\bar{Z}\bar{C}_2\bar{F}'$.

Almost the entire contribution of the seismic and non-seismic root causes was mapped into containment failure sequence ZC_2. For the seismic root causes (base case) approximately 99 percent mapped into ZC_2 while the remainder mapped into $\bar{Z}\bar{C}_2\bar{F}'$. These percentages remained approximately constant no matter which sensitivity study was being performed.

Table 5.2 provides the results in terms of risk (person-REM) for the base case as well as the six sensitivity studies described in Chapter 4. The base case total is 6.8 person-REM. It was assumed for these calculations a remaining plant operational lifetime of 20 years.

The leading contributor to base case risk is Root Cause 12, followed by Root Causes 6 and 13. The Root Cause 12 contribution is 51% of the total.

As can be seen from the sensitivity study results, eliminating the probability of damage from Halon agent release had the greatest reduction on overall risk. This is because Fire Zone 3 (emergency switchgear room)

Table 5.1

Containment Failure Mode for Each Fire Zone or Fire Zone Combinations

Fire Zone	Containment Failure Mode
FZ-1	ZC_2
FZ-2	$\bar{Z}\ \bar{C}_2\ \bar{F}'$
FZ-3	ZC_2
FZ-4	$\bar{Z}\ \bar{C}_2\ \bar{F}'$
FZ-17	$\bar{Z}\ \bar{C}_2\ \bar{F}'$
FZ-6, FZ-8*	ZC_2

* Loss of offsite power and failure of both diesel generators.

contributes to core damage in each root cause except Root Cause 12. Also, Fire Zone 3 maps 100 percent into the dominant release sequence ZC_2.

It was also found that Sensitivity Studies 4 and 5 (reduced CO_2 damage and lowering barrier failure probability) led to relatively minor reductions in total person-REM release (10 percent and <1 percent, respectively). In the reduced CO_2 damage case, it only reduced the contribution from Fire Zone 1. Lowering the barrier failure probability by one order of magnitude effected only Root Cause 5.

Sensitivity Studies 1 and 2 (EPRI Hazard curve and decrease in probability of a seismic fire) also led to relatively minor reductions in risk. These two sensitivity studies only affected the seismic root causes which were not the dominant contributors to risk in the base case analysis.

The most optimistic analysis, combining all five sensitivity studies together, led to a 96 percent reduction in risk. The major contributor to this reduction was once again eliminating the probability of Halon damage in the emergency switchgear room.

Table 5.2

Summary of Base Case and Sensitivity Study Results in Terms of Risk (Person-REM)

Root Cause	Base Case	Study 1 EPRI Hazard Curves	Study 2 Decrease in Probability of a Seismic Fire	Study 3 No Halon Damage
1.	Not applicable for the plant under consideration.			
2.	Not applicable for the plant under consideration.			
3.	Not applicable for the plant under consideration.			
4.	5.8E-1	N/A*	N/A	1.2E-1
5.	1.1E-1	N/A	N/A	<0.1
6.	9.3E-1	N/A	N/A	1.4E-1
7.	Not applicable for the plant under consideration.			
8.	5.6E-1	<0.1	N/A	N/A
9.	Not applicable for the plant under consideration.			
10.	Not applicable for the plant under consideration.			
11.	3.8E-1	N/A	N/A	1.7E-1
12.	3.5	0.5	0.7	N/A
13.	6.7E-1	N/A	N/A	3.4E-1
Total	6.8	3.2	3.4	4.8

*N/A reflects no modification from the base case.
**All values listed in table are mean values.

Table 5.2 (Continued)

Summary of Base Case and Sensitivity Study Results
in Terms of Risk (Person-REM)

Root Cause	Base Case	Study 4 Reduced CO_2 Damage to Cable	Study 5 Barrier Failure-0.01	Study 6 All Combined
1.	Not applicable for the plant under consideration.			
2.	Not applicable for the plant under consideration.			
3.	Not applicable for the plant under consideration.			
4.	5.8E-1	4.9E-1	N/A	1.8E-2
5.	1.1E-1	1.1E-1	1.1E-1	<1.0E-2
6.	9.3E-1	8.0E-1	N/A	3.6E-2
7.	Not applicable for the plant under consideration.			
8.	5.6E-1	5.6E-1	N/A	<1.0E-2
9.	Not applicable for the plant under consideration.			
10.	Not applicable for the plant under consideration.			
11.	3.8E-1	2.5E-1	N/A	4.2E-2
12.	3.5	N/A*	N/A	1.0E-1
13.	6.7E-1	3.8E-1	N/A	4.8E-2
Total	6.8	6.1	6.8	2.4E-1

*N/A reflects no modification from the base case.
**All values listed in table are mean values.

5.2 References

5.1 J. A. Lambright, et al., Evaluation of Generic Issue 57: Effects of Fire Protection System Actuation on Safety-Related Equipment, Main Report, NUREG/CR-5580, SAND91-1507, Sandia National Laboratories, December 1992.

APPENDIX A

Uncertainty Analysis
Core Damage Frequency

Definition of Terms

QR	-failure probability to cross connect unit #2 HPI
PDAMH	-probability of equipment damage due to Halon
L-RAH	-frequency of random failures of Halon system
L-OPH	-frequency of operator error failures of Halon system
PDAMC	-probability of cable damage due to CO_2
L-PB	-frequency of pipe breaks
L-RAC	-frequency of hardware failures of CO_2 system
L-UNC	-frequency of unknown failures of CO_2 system
L-UNH	-frequency of unknown failures of Halon system
FA4	-area ratio for fire, emergency switchgear room
FSI	-severity ratio for large fire
L-SGR	-frequency of fire, emergency switchgear room
L-OPC	-frequency of operator error failures of CO_2 system
FA3	-area ratio for fire, cable vault/tunnel
QITG	-probability of failure to manually suppress fire, cable vault/tunnel
L-CSR	-frequency of fire, cable vault/tunnel
QB-AUTO	-probability of automatic suppression, cable vault/tunnel
PBAR	-probability of barrier failure
PACT	-probability of manual actuation of FPS
L-TB	-frequency of fire, turbine building
FA2	-area ratio for fire, turbine building
L-AUX	-frequency of fire, auxiliary building
FA1	-area ratio for fire, auxiliary building
A	-Root Cause 8, diesel generator rooms

Definition of Terms (Concluded)

B -Root Cause 8, cable vault/tunnel

C -Root Cause 8, emergency switchgear room

D -Root Cause 12, cable vault/tunnel

PNRDG -probability of non-recovery of the diesel generators within 7 hours after seismic event

PNRHPI -probability of non-recovery of the High Pressure Injection system

Top Event Matrix Analysis Code

The following printouts represent the output of the Top Event Matrix Analysis Code (TEMAC) used to quantify the uncertainty analyses for Core Damage Frequency and for Risk. TEMAC accomplishes this quantification using parameter value samples generated by the Latin Hypercube Sampling code (LHS). LHS is a constrained Monte Carlo technique which forces all parts of a distribution to be sampled. For the composite, and for each Root Cause, the following information is provided:

- Top event frequency distribution.
- Risk increases and reductions by base events sorted by risk reduction.
- Risk reduction by base event.
- Risk increase by base event.
- Cutset frequencies.
- Cutsets contributing to the Root Cause.

Definitions of key terms in the TEMAC printouts are:

• Risk reduction - For each basic event, the probability of occurrence of that event is set to zero and the reduction in core damage frequency or risk is calculated.

• Risk increase - For each basic event, the probability of occurrence of that event is set to 1.0 and the increase in core damage frequency or risk is calculated.

• Uncertainty importance - For each basic event, its distribution is eliminated from the overall uncertainty calculation by setting the event to its mean value. The percent decrease in the logarithm of the overall uncertainty is then calculated.

Composite Run for all Root Causes

COMPOSITE RUN FOR ALL ROOT CAUSES -- JULY 1991 RERUN

TOP EVENT COMPOSITE CONTAINS 24 EVENTS IN 14 CUT SETS

THE FREQUENCY OF TOP EVENT COMPOSITE IS 7.30E-06

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT COMPOSITE

```
N                100
MEAN        7.32E-06
STD DEV     9.17E-06
LOWER 5%    5.86E-07
LOWER 25%   1.84E-06
MEDIAN      4.15E-06
UPPER 25%   9.51E-06
UPPER 5%    2.60E-05
```

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE, ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

   RISK REDUCTION = PD x EV(J)
   = TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

   RISK INCREASE = PD - RISK REDUCTION
   = PD x (1 - EV(J))
   = TEF(EVALUATED WITH EV(J) = 1) - TEF

COMPOSITE RUN FOR ALL ROOT CAUSES -- JULY 1991 RERUN

RISK REDUCTIONS RISK INCREASES BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
QR	16	4.40E-02	(9.0)	4.11E-06	(1.0)	8.93E-05	(14.0)
PDAMH	5	5.40E-03	(10.0)	3.21E-06	(2.0)	5.92E-04	(5.0)
D	1	8.23E-06	(21.0)	2.14E-06	(3.5)	2.60E-01	(4.0)
PNRHP1	1	2.60E-01	(7.0)	2.14E-06	(3.5)	8.09E-08	(17.0)
L-RAH	1	5.30E-03	(11.0)	1.26E-06	(5.0)	2.36E-04	(10.0)
PNRDQ	3	6.00E-01	(4.0)	1.05E-06	(6.0)	7.01E-07	(18.0)
A	1	1.66E-06	(22.0)	9.96E-07	(7.0)	6.00E-01	(2.0)
PDAMC	5	3.00E-03	(13.5)	8.95E-07	(8.0)	2.97E-04	(6.0)
L-OPH	1	3.50E-03	(12.0)	8.32E-07	(9.0)	2.37E-04	(9.0)
L-PB	2	3.00E-03	(13.5)	7.52E-07	(10.0)	2.50E-04	(7.0)
L-RAC	1	2.30E-03	(17.0)	3.04E-07	(11.0)	1.32E-04	(13.0)
L-UNC	1	1.80E-03	(18.0)	2.38E-07	(12.0)	1.32E-04	(12.0)
L-UNH	1	8.80E-04	(20.0)	2.09E-07	(13.0)	2.37E-04	(8.0)
L-SGR	1	2.97E-03	(15.0)	2.01E-07	(15.0)	6.75E-05	(15.0)
FS1	1	3.00E-01	(6.0)	2.01E-07	(15.0)	4.69E-07	(19.0)
FA4	1	9.50E-01	(1.5)	2.01E-07	(15.0)	1.06E-08	(23.0)
L-OPC	1	1.40E-03	(19.0)	1.86E-07	(17.0)	1.32E-04	(11.0)
L-CSR	1	2.68E-03	(16.0)	1.29E-07	(19.5)	4.80E-05	(16.0)
Q1T6	1	8.00E-01	(3.0)	1.29E-07	(19.5)	3.23E-08	(22.0)
QB-AUTO	1	9.50E-01	(1.5)	1.29E-07	(19.5)	6.79E-09	(24.0)
FA3	1	4.00E-01	(5.0)	1.29E-07	(19.5)	1.40E-07	(21.0)
PBAR	1	1.00E-01	(8.0)	3.90E-08	(22.0)	3.56E-07	(20.0)
C	1	5.76E-08	(23.0)	3.46E-08	(23.0)	6.00E-01	(2.0)
B	1	3.42E-08	(24.0)	2.05E-08	(24.0)	6.00E-01	(2.0)

COMPOSITE RUN FOR ALL ROOT CAUSES -- JULY 1991 RERUN

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
QR	10	4.40E-02	(9.0)	4.11E-06	(1.0)	3.68E-07	2.20E-05
PDAWH	5	5.40E-03	(10.0)	3.21E-06	(2.0)	1.86E-07	1.91E-05
D	1	8.23E-06	(21.0)	2.14E-06	(3.5)	1.99E-09	8.44E-06
PNRHP1	1	2.60E-01	(7.0)	2.14E-06	(3.5)	1.99E-09	8.44E-06
L-RAH	1	5.30E-03	(11.0)	1.26E-06	(5.0)	4.09E-08	8.01E-06
PNRDG	3	6.00E-01	(4.0)	1.05E-06	(6.0)	5.51E-10	1.00E-06
A	1	1.00E-06	(22.0)	9.96E-07	(7.0)	2.24E-10	9.80E-07
PDAMC	5	3.00E-03	(13.5)	8.95E-07	(8.0)	3.57E-08	4.38E-06
L-DPH	1	3.50E-03	(12.0)	8.32E-07	(9.0)	2.28E-08	5.20E-06
L-PB	2	3.00E-03	(13.5)	7.52E-07	(10.0)	3.02E-08	4.73E-06
L-RAC	1	2.30E-03	(17.0)	3.04E-07	(11.0)	5.90E-09	1.79E-06
L-UNC	1	1.80E-03	(18.0)	2.38E-07	(12.0)	5.28E-09	1.13E-06
L-UNH	1	8.80E-04	(20.0)	2.09E-07	(13.0)	3.99E-09	1.65E-06
L-SGR	1	2.97E-03	(15.0)	2.01E-07	(15.0)	6.93E-09	1.13E-06
FS1	1	3.00E-01	(6.0)	2.01E-07	(15.0)	6.93E-09	1.13E-06
FA4	1	9.50E-01	(1.5)	2.01E-07	(15.0)	6.93E-09	1.13E-06
L-DPC	1	1.40E-03	(19.0)	1.85E-07	(17.0)	5.35E-09	1.14E-06
L-CSR	1	2.68E-03	(16.0)	1.29E-07	(19.5)	4.42E-09	6.31E-07
Q1T6	1	8.00E-01	(3.0)	1.29E-07	(19.5)	4.42E-09	6.31E-07
QB-AUTO	1	9.50E-01	(1.5)	1.29E-07	(19.5)	4.42E-09	6.31E-07
FA3	1	4.80E-01	(5.0)	1.29E-07	(19.5)	4.42E-09	6.31E-07
PBAR	1	1.00E-01	(8.0)	3.96E-08	(22.0)	6.07E-10	2.18E-07
C	1	5.70E-08	(23.0)	3.40E-08	(23.0)	2.06E-11	5.80E-08
B	1	3.42E-08	(24.0)	2.05E-08	(24.0)	5.10E-12	2.60E-08

COMPOSITE RUN FOR ALL ROOT CAUSES -- JULY 1991 RERUN

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
B	1	3.42E-08	(24.0)	6.00E-01	(2.0)	1.37E-01	9.61E-01
C	1	5.76E-08	(23.0)	6.00E-01	(2.0)	1.37E-01	9.61E-01
A	1	1.66E-06	(22.0)	6.00E-01	(2.0)	1.37E-01	9.61E-01
D	1	8.23E-06	(21.0)	2.60E-01	(4.0)	1.93E-01	3.98E-01
PDAWH	5	5.40E-03	(10.0)	5.92E-04	(5.0)	7.22E-05	2.06E-03
PDAWC	5	3.00E-03	(13.5)	2.97E-04	(6.0)	4.19E-05	9.95E-04
L-PB	2	3.00E-03	(13.5)	2.50E-04	(7.0)	1.77E-05	1.59E-03
L-UNH	1	8.80E-04	(20.0)	2.37E-04	(8.0)	1.58E-05	1.57E-03
L-OPH	1	3.50E-03	(12.0)	2.37E-04	(9.0)	1.58E-05	1.57E-03
L-RAH	1	5.30E-03	(11.0)	2.36E-04	(10.0)	1.58E-05	1.57E-03
L-OPC	1	1.40E-03	(19.0)	1.32E-04	(11.0)	6.23E-06	5.36E-04
L-UNC	1	1.80E-03	(18.0)	1.32E-04	(12.0)	6.23E-06	5.35E-04
L-RAC	1	2.30E-03	(17.0)	1.32E-04	(13.0)	6.23E-06	5.35E-04
QR	10	4.40E-02	(9.0)	8.93E-05	(14.0)	1.00E-05	3.66E-04
L-SGR	1	2.97E-03	(15.0)	6.75E-05	(15.0)	4.11E-06	3.63E-04
L-CSR	1	2.60E-03	(16.0)	4.80E-05	(16.0)	2.18E-06	2.20E-04
PNRHP1	1	2.60E-01	(7.0)	6.09E-06	(17.0)	5.58E-09	1.76E-05
PNRDG	3	6.00E-01	(4.0)	7.01E-07	(18.0)	2.88E-10	1.49E-06
FS1	1	3.00E-01	(6.0)	4.69E-07	(19.0)	1.80E-08	3.14E-06
PBAR	1	1.00E-01	(8.0)	3.56E-07	(20.0)	9.13E-09	1.90E-06
FA3	1	4.80E-01	(5.0)	1.40E-07	(21.0)	4.20E-09	7.33E-07
Q1T6	1	8.00E-01	(3.0)	3.28E-08	(22.0)	4.56E-10	1.71E-07
FA4	1	9.50E-01	(1.5)	1.00E-08	(23.0)	2.82E-10	6.08E-08
QB-AUTO	1	9.50E-01	(1.5)	6.79E-09	(24.0)	1.02E-10	2.39E-08

CO[illegible] ; FOR ALL ROOT CAUSES -- JULY 1991 RERUN

UNCE[illegible]Y IMPORTANCE BY BASE EVENT

BASE EVENT	OCCUR	PROB	(RANK)	% REDUCTION IN THE UNCERTAINTY OF LOG RISK	(RANK)	Y.05/TE.05*	Y.95/TE.95*
QR	10	4.40E-02	(9.0)	40.1	(1.0)	1.93	0.82
PDAMH	5	5.40E-03	(10.0)	27.7	(2.0)	1.50	0.71
D	1	8.23E-06	(21.0)	15.2	(3.0)	4.09	0.93
QB-AUTO	1	9.50E-01	(1.5)	10.7	(4.0)	1.00	1.00
PNRDG	3	6.00E-01	(4.0)	9.2	(5.0)	1.00	1.00
PNRHP1	1	2.00E-01	(7.0)	8.5	(6.0)	1.00	0.95
FS1	1	3.00E-01	(6.0)	7.5	(7.0)	1.01	1.00
L-UNH	1	8.00E-04	(20.0)	6.4	(8.0)	0.95	0.99
FA3	1	4.00E-01	(5.0)	5.1	(9.0)	1.00	1.00
L-RAH	1	5.30E-03	(11.0)	4.9	(10.0)	1.01	0.99
L-OPC	1	1.40E-03	(19.0)	4.8	(11.0)	0.99	0.98
L-SGR	1	2.97E-03	(15.0)	4.4	(12.0)	1.01	1.04
PDAMC	5	3.00E-03	(13.5)	3.9	(13.0)	1.00	0.95
PBAR	1	1.00E-01	(8.0)	2.6	(14.0)	1.00	1.00
L-OPH	1	3.50E-03	(12.0)	2.2	(15.0)	1.04	1.00
L-UNC	1	1.80E-03	(18.0)	0.0	(20.0)		
L-RAC	1	2.30E-03	(17.0)	0.0	(20.0)		
FA4	1	9.50E-01	(1.5)	0.0	(20.0)		
C	1	5.70E-08	(23.0)	0.0	(20.0)		
Q1T6	1	8.00E-01	(3.0)	0.0	(20.0)		
L-PB	2	3.00E-03	(13.5)	0.0	(20.0)		
L-CSR	1	2.60E-03	(16.0)	0.0	(20.0)		
B	1	3.42E-08	(24.0)	0.0	(20.0)		
A	1	1.00E-06	(22.0)	0.0	(20.0)		

COMPOSITE RUN FOR ALL ROOT CAUSES -- JULY 1991 RERUN

BASE EVENTS RANKED BY VARIOUS METHODS (RANK 1 = MOST IMPORTANT) AND SORTED BY RISK REDUCTION

BASE EVENT	RISK REDUCTION	RISK INCREASE	UNCERTAINTY IMPORTANCE
QR	1.0	14.0	1.0
PDAMH	2.0	5.0	2.0
D	3.5	4.0	3.0
PNRHP1	3.5	17.0	6.0
L-RAH	5.0	10.0	10.0
PNRDQ	6.0	18.0	5.0
A	7.0	2.0	20.0
PDAMC	8.0	6.0	13.0
L-OPH	9.0	9.0	15.0
L-PB	10.0	7.0	20.0
L-RAC	11.0	13.0	20.0
L-UNC	12.0	12.0	20.0
L-UNH	13.0	8.0	8.0
L-SGR	15.0	15.0	12.0
FS1	15.0	19.0	7.0
FA4	15.0	23.0	20.0
L-OPC	17.0	11.0	11.0
L-CSR	19.5	16.0	20.0
Q1T6	19.5	22.0	20.0
QB-AUTO	19.5	24.0	4.0
FA3	19.5	21.0	9.0
PBAR	22.0	20.0	14.0
C	23.0	2.0	20.0
B	24.0	2.0	20.0

COMPOSITE RUN FOR ALL ROOT CAUSES -- JULY 1991 RERUN

MATRIX OF TOP-DOWN CORRELATION COEFFICIENTS

RISK INCR	0.0703	
UNC IMP	0.7790**	-0.1441
	RISK RED	RISK INCR

** SIGNIFICANT AT APPROXIMATELY THE .01 LEVEL

THE TOP-DOWN CORRELATION COEFFICIENTS ARE USED TO DETERMINE THE LEVEL OF AGREEMENT AMONG ALL PAIRS OF RANKINGS IN THE PREVIOUS TABLE. THE TOP-DOWN CORRELATION COEFFICIENT GIVES MORE WEIGHT TO THE SMALLEST RANKS. NOTE THAT THE SMALLEST RANKS ARE ASSIGNED TO THE MOST IMPORTANT BASE EVENTS. MORE DETAIL ON THIS STATISTIC CAN BE FOUND IN THE IMAN AND CONOVER (1985) REFERENCE IN THE USER'S GUIDE THAT ACCOMPANIES THIS CODE.

COMPOSITE RUN FOR ALL ROOT CAUSES -- JULY 1991 RERUN

CUT SET FREQUENCIES AND NORMALIZED CUT SET FREQUENCIES (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%	NORMALIZED FREQUENCY	CUMULATIVE NORMALIZED FREQUENCY	LOWER 5%	UPPER 5%
3	2	2.14E-06	(1.0)	1.99E-09	8.44E-06	0.2931	0.2931	0.0004	0.7731
11	3	1.26E-06	(2.0)	4.09E-08	8.01E-06	0.1726	0.4657	0.0176	0.5696
12	2	9.96E-07	(3.0)	2.24E-10	9.80E-07	0.1364	0.6021	0.0000	0.2604
7	3	8.32E-07	(4.0)	2.20E-08	5.29E-06	0.1139	0.7160	0.0168	0.3907
9	3	7.13E-07	(5.0)	2.25E-08	4.68E-06	0.0977	0.8137	0.0120	0.3982
10	3	3.04E-07	(6.0)	5.96E-09	1.79E-06	0.0416	0.8553	0.0023	0.2601
4	3	2.38E-07	(7.0)	5.20E-09	1.13E-06	0.0326	0.8878	0.0019	0.1841
5	3	2.09E-07	(8.0)	3.99E-09	1.05E-06	0.0286	0.9165	0.0017	0.1380
2	5	2.01E-07	(9.0)	6.93E-09	1.13E-06	0.0276	0.9440	0.0032	0.0970
6	3	1.85E-07	(10.0)	5.35E-09	1.14E-06	0.0253	0.9693	0.0014	0.1472
1	6	1.29E-07	(11.0)	4.42E-09	6.31E-07	0.0177	0.9870	0.0013	0.1283
8	4	3.96E-08	(12.0)	6.07E-10	2.18E-07	0.0054	0.9925	0.0002	0.0262
14	2	3.46E-08	(13.0)	2.66E-11	5.80E-08	0.0047	0.9972	0.0000	0.0158
13	2	2.05E-08	(14.0)	5.10E-12	2.60E-08	0.0028	1.0000	0.0000	0.0040

COMPOSITE RUN FOR ALL ROOT CAUSES -- JULY 1991 RERUN

CUT SET NUMBERS, CUT SET ORDERS, CUT SET FREQUENCIES,
CUMULATIVE NORMALIZED CUT SET FREQUENCIES AND CUT SETS
FOR TOP EVENT COMPOSITE WITH TOP EVENT FREQUENCY 7.30E-06

(THE FIRST COLUMN OF NUMBERS IS THE LINE NUMBERS FOR THE FILE TEMACSETS.DNF)

2	3	2	2.14E-06	0.29315	D	* PNRHP1	+		
3	11	3	1.26E-06	0.46566	L-RAH	* PDAMH	* QR	+	
4	12	2	9.96E-07	0.60211	A	* PNRDG	+		
5	7	3	8.32E-07	0.71604	L-OPH	* PDAMH	* QR	+	
6	9	3	7.13E-07	0.81369	L-PB	* PDAMH	* QR	+	
7	10	3	3.04E-07	0.85528	L-RAC	* PDAMC	* QR	+	
8	4	3	2.38E-07	0.88784	L-UNC	* PDAMC	* QR	+	
9	5	3	2.09E-07	0.91648	L-UNH	* PDAMH	* QR	+	
10	2	5	2.01E-07	0.94403	FA4	* FS1	* L-SGR	* PDAMH	*
11					QR	+			
12	6	3	1.85E-07	0.96935	L-OPC	* PDAMC	* QR	+	
13	1	6	1.29E-07	0.98703	FA3	* L-CSR	* PDAMC	* Q1T6	*
14					QB-AUTO	* QR	+		
15	8	4	3.96E-08	0.99245	L-PB	* PBAR	* PDAMC	* QR	+
16	14	2	3.46E-08	0.99719	C	* PNRDG	+		
17	13	2	2.05E-08	1.00000	B	* PNRDG	.		

Root Cause 4 Run

ROOT CAUSE 4 RUN -- JULY 1991 RERUN

TOP EVENT ROOT-CAUSE-4 CONTAINS 5 EVENTS IN 2 CUT SETS

THE FREQUENCY OF TOP EVENT ROOT-CAUSE-4 IS 1.02E-06

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT ROOT-CAUSE-4

N	100
MEAN	1.38E-06
STD DEV	2.23E-06
LOWER 5%	5.34E-08
LOWER 25%	2.04E-07
MEDIAN	6.29E-07
UPPER 25%	1.39E-06
UPPER 5%	6.23E-06

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE, ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

RISK REDUCTION = PD x EV(J)
= TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

RISK INCREASE = PD - RISK REDUCTION
= PD x (1 - EV(J))
= TEF(EVALUATED WITH EV(J) = 1) - TEF

ROOT CAUSE 4 RUN -- JULY 1991 RERUN

RISK REDUCTIONS   RISK INCREASES   BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
QR	2	4.40E-02	(1.0)	1.02E-06	(1.0)	2.21E-05	(5.0)
L-OPH	1	3.50E-03	(3.0)	8.32E-07	(2.5)	2.37E-04	(1.0)
PDAMH	1	5.40E-03	(2.0)	8.32E-07	(2.5)	1.53E-04	(2.0)
L-OPC	1	1.40E-03	(5.0)	1.85E-07	(4.5)	1.32E-04	(3.0)
PDAMC	1	3.00E-03	(4.0)	1.85E-07	(4.5)	6.14E-05	(4.0)

ROOT CAUSE 4 RUN -- JULY 1991 RERUN

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
QR	2	4.40E-02	(1.0)	1.02E-06	(1.0)	5.34E-08	6.23E-06
L-OPH	1	3.50E-03	(3.0)	8.32E-07	(2.5)	1.66E-08	5.07E-06
PDAMH	1	5.40E-03	(2.0)	8.32E-07	(2.5)	1.66E-08	5.07E-06
L-OPC	1	1.40E-03	(5.0)	1.85E-07	(4.5)	4.83E-09	8.58E-07
PDAMC	1	3.00E-03	(4.0)	1.85E-07	(4.5)	4.83E-09	8.58E-07

ROOT CA... 4 RUN -- JULY 1991 RERUN

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
L-OPH	1	3.50E-03	(3.0)	2.37E-04	(1.0)	1.30E-05	1.44E-03
PDAMH	1	5.40E-03	(2.0)	1.53E-04	(2.0)	6.47E-06	5.81E-04
L-OPC	1	1.40E-03	(5.0)	1.32E-04	(3.0)	7.26E-06	6.70E-04
PDAMC	1	3.00E-03	(4.0)	6.14E-05	(4.0)	4.23E-06	2.72E-04
QR	2	4.40E-02	(1.0)	2.21E-05	(5.0)	2.19E-06	9.10E-05

ROOT CAUSE 4 RUN -- JULY 1991 RERUN

UNCERTAINTY IMPORTANCE BY BASE EVENT

BASE EVENT	OCCUR	PROB	(RANK)	% REDUCTION IN THE UNCERTAINTY OF LOG RISK	(RANK)	Y.05/TE.05*	Y.95/TE.95*
QR	2	4.40E-02	(1.0)	41.2	(1.0)	1.04	0.65
PDAMH	1	5.40E-03	(2.0)	29.2	(2.0)	1.29	0.61
L-DPH	1	3.50E-03	(3.0)	21.8	(3.0)	1.05	0.93
L-DPC	1	1.40E-03	(5.0)	10.9	(4.0)	1.24	0.86
PDAMC	1	3.00E-03	(4.0)	4.2	(5.0)	1.15	0.91

ROOT CAUSE 4 RUN -- JULY 1991 RERUN

BASE EVENTS RANKED BY VARIOUS METHODS (RANK 1 = MOST IMPORTANT) AND SORTED BY RISK REDUCTION

BASE EVENT	RISK REDUCTION	RISK INCREASE	UNCERTAINTY IMPORTANCE
QR	1.0	5.0	1.0
L-OPH	2.5	1.0	3.0
PDAMH	2.5	2.0	2.0
L-OPC	4.5	3.0	4.0
PDAMC	4.5	4.0	5.0

ROOT CAUSE 4 RUN -- JULY 1991 RERUN

MATRIX OF TOP-DOWN CORRELATION COEFFICIENTS

RISK INCR	-0.1733	
UNC IMP	0.9708*	-0.2449
	RISK RED	RISK INCR

* SIGNIFICANT AT APPROXIMATELY THE .05 LEVEL

THE TOP-DOWN CORRELATION COEFFICIENTS ARE USED TO DETERMINE THE LEVEL OF AGREEMENT AMONG ALL PAIRS OF RANKINGS IN THE PREVIOUS TABLE. THE TOP-DOWN CORRELATION COEFFICIENT GIVES MORE WEIGHT TO THE SMALLEST RANKS. NOTE THAT THE SMALLEST RANKS ARE ASSIGNED TO THE MOST IMPORTANT BASE EVENTS. MORE DETAIL ON THIS STATISTIC CAN BE FOUND IN THE IMAN AND CONOVER (1985) REFERENCE IN THE USER'S GUIDE THAT ACCOMPANIES THIS CODE.

RUD. CAUSE 4 RUN -- JULY 1991 RERUN

CUT SET FREQUENCIES AND NORMALIZED CUT SET FREQUENCIES (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%	NORMALIZED FREQUENCY	CUMULATIVE NORMALIZED FREQUENCY	LOWER 5%	UPPER 5%
2	3	8.32E-07 (	1.0)	1.66E-08	5.07E-06	0.8182	0.8182	0.1137	0.9909
1	3	1.85E-07 (	2.0)	4.83E-09	8.58E-07	0.1818	1.0000	0.0091	0.8863

ROOT CAUSE 4 RUN -- JULY 1991 RERUN

CUT SET NUMBERS, CUT SET ORDERS, CUT SET FREQUENCIES,
CUMULATIVE NORMALIZED CUT SET FREQUENCIES AND CUT SETS
FOR TOP EVENT ROOT-CAUSE-4   WITH TOP EVENT FREQUENCY   1.02E-06

(THE FIRST COLUMN OF NUMBERS IS THE LINE NUMBERS FOR THE FILE TEMACSETS.DNF)

2	2	3	8.32E-07	0.81818	L-OPH	*	PDAMH	*	QR	*
3	1	3	1.85E-07	1.00000	L-OPC	*	PDAMC	*	QR	.

Root Cause 5 Run

ROOT CAUSE 5 RUN -- JULY 1991 RERUN

TOP EVENT ROOT-CAUSE-5 CONTAINS 5 EVENTS IN 2 CUT SETS

THE FREQUENCY OF TOP EVENT ROOT-CAUSE-5 IS 7.52E-07

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT ROOT-CAUSE-5

N	100
MEAN	1.12E-06
STD DEV	2.29E-06
LOWER 5%	2.75E-08
LOWER 25%	1.33E-07
MEDIAN	3.30E-07
UPPER 25%	9.79E-07
UPPER 5%	4.14E-06

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE, ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

RISK REDUCTION = PD x EV(J)
= TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

RISK INCREASE = PD - RISK REDUCTION
= PD x (1 - EV(J))
= TEF(EVALUATED WITH EV(J) = 1) - TEF

ROOT CAUSE 5 RUN -- JULY 1991 RERUN

RISK REDUCTIONS RISK INCREASES BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
L-PB	2	3.00E-03	(4.5)	7.52E-07	(1.5)	2.50E-04	(1.0)
QR	2	4.40E-02	(2.0)	7.52E-07	(1.5)	1.63E-05	(3.0)
PDAMH	1	5.40E-03	(3.0)	7.13E-07	(3.0)	1.31E-04	(2.0)
PDAMC	1	3.00E-03	(4.5)	3.96E-08	(4.5)	1.32E-05	(4.0)
PBAR	1	1.00E-01	(1.0)	3.96E-08	(4.5)	3.56E-07	(5.0)

ROOT CAUSE 5 RUN -- JULY 1991 RERUN

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
L-PB	2	3.00E-03	(4.5)	7.52E-07	(1.5)	2.75E-08	4.14E-06
QR	2	4.40E-02	(2.0)	7.52E-07	(1.5)	2.75E-08	4.14E-06
PDAWH	1	5.40E-03	(3.0)	7.13E-07	(3.0)	2.15E-08	4.10E-06
PDAWC	1	3.00E-03	(4.5)	3.96E-08	(4.5)	4.72E-10	2.35E-07
PBAR	1	1.00E-01	(1.0)	3.96E-08	(4.5)	4.72E-10	2.35E-07

ROOT CAUSE 5 RUN -- JULY 1991 RERUN

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
L-PB	2	3.00E-03	(4.5)	2.50E-04	(1.0)	1.92E-05	1.40E-03
PDAMH	1	5.40E-03	(3.0)	1.31E-04	(2.0)	7.10E-06	5.23E-04
QR	2	4.40E-02	(2.0)	1.63E-05	(3.0)	1.28E-06	7.81E-05
PDAMC	1	3.00E-03	(4.5)	1.32E-05	(4.0)	2.28E-07	5.08E-05
PBAR	1	1.00E-01	(1.0)	3.50E-07	(5.0)	1.12E-08	2.00E-06

ROOT CAUSE 5 RUN -- JULY 1991 RERUN

UNCERTAINTY IMPORTANCE BY BASE EVENT

BASE EVENT	OCCUR	PROB	(RANK)	% REDUCTION IN THE UNCERTAINTY OF LOG RISK	(RANK)	Y.05/TE.05*	Y.95/TE.95*
QR	2	4.40E-02	(2.0)	36.4	(1.0)	2.22	0.85
L-PB	2	3.00E-03	(4.5)	35.9	(2.0)	2.10	1.06
PDAMH	1	5.40E-03	(3.0)	31.7	(3.0)	1.45	0.76
PBAR	1	1.00E-01	(1.0)	9.8	(4.0)	1.08	1.00
PDAMC	1	3.00E-03	(4.5)	0.0	(5.0)		

ROOT CAUSE 5 RUN -- JULY 1991 RERUN

BASE EVENTS RANKED BY VARIOUS METHODS (RANK 1 = MOST IMPORTANT) AND SORTED BY RISK REDUCTION

BASE EVENT	RISK REDUCTION	RISK INCREASE	UNCERTAINTY IMPORTANCE
L-PB	1.5	1.0	2.0
QR	1.5	3.0	1.0
PDAMH	3.0	2.0	3.0
PDAMC	4.5	4.0	5.0
PBAR	4.5	5.0	4.0

ROOT CAUSE 5 RUN -- JULY 1991 RERUN

MATRIX OF TOP-DOWN CORRELATION COEFFICIENTS

RISK INCR	0.6917	
UNC IMP	0.8969*	0.3328
	RISK RED	RISK INCR

* SIGNIFICANT AT APPROXIMATELY THE .05 LEVEL

THE TOP-DOWN CORRELATION COEFFICIENTS ARE USED TO DETERMINE THE LEVEL OF AGREEMENT AMONG ALL PAIRS OF RANKINGS IN THE PREVIOUS TABLE. THE TOP-DOWN CORRELATION COEFFICIENT GIVES MORE WEIGHT TO THE SMALLEST RANKS. NOTE THAT THE SMALLEST RANKS ARE ASSIGNED TO THE MOST IMPORTANT BASE EVENTS. MORE DETAIL ON THIS STATISTIC CAN BE FOUND IN THE IMAN AND CONOVER (1985) REFERENCE IN THE USER'S GUIDE THAT ACCOMPANIES THIS CODE.

ROOT CAUSE 5 RUN -- JULY 1991 RERUN

CUT SET FREQUENCIES AND NORMALIZED CUT SET FREQUENCIES (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%	NORMALIZED FREQUENCY	CUMULATIVE NORMALIZED FREQUENCY	LOWER 5%	UPPER 5%
2	3	7.13E-07	(1.0)	2.15E-08	4.10E-06	0.9474	0.9474	0.6620	0.9969
1	4	3.96E-08	(2.0)	4.72E-10	2.35E-07	0.0526	1.0000	0.0031	0.3380

ROOT CAUSE 5 RUN -- JULY 1991 RERUN

CUT SET NUMBERS, CUT SET ORDERS, CUT SET FREQUENCIES,
CUMULATIVE NORMALIZED CUT SET FREQUENCIES AND CUT SETS
FOR TOP EVENT ROOT-CAUSE-5 WITH TOP EVENT FREQUENCY 7.52E-07

(THE FIRST COLUMN OF NUMBERS IS THE LINE NUMBERS FOR THE FILE TEMACSETS.DNF)

2	2	3	7.13E-07	0.94737	L-PB	* PDAMH	* QR	*
3	1	4	3.96E-08	1.00000	L-PB	* PBAR	* PDAMC	* QR

Root Cause 6 Run

ROOT CAUSE 6 RUN -- JULY 1991 RERUN

TOP EVENT ROOT-CAUSE-6 CONTAINS 5 EVENTS IN 2 CUT SETS

THE FREQUENCY OF TOP EVENT ROOT-CAUSE-6 IS 1.56E-06

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT ROOT-CAUSE-6

N	100
MEAN	2.12E-06
STD DEV	3.52E-06
LOWER 5%	7.25E-08
LOWER 25%	3.09E-07
MEDIAN	8.45E-07
UPPER 25%	2.35E-06
UPPER 5%	8.96E-06

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE, ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

RISK REDUCTION = PD x EV(J)
= TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

RISK INCREASE = PD - RISK REDUCTION
= PD x (1 - EV(J))
= TEF(EVALUATED WITH EV(J) = 1) - TEF

ROOT CAUSE 6 RUN -- JULY 1991 RERUN

RISK REDUCTIONS   RISK INCREASES   BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
QR	2	4.40E-02	(1.0)	1.50E-06	(1.0)	3.40E-05	(5.0)
L-RAH	1	5.30E-03	(3.0)	1.20E-06	(2.5)	2.30E-04	(1.0)
PDAMH	1	5.40E-03	(2.0)	1.20E-06	(2.5)	2.32E-04	(2.0)
L-RAC	1	2.30E-03	(5.0)	3.04E-07	(4.5)	1.32E-04	(3.0)
PDAMC	1	3.00E-03	(4.0)	3.04E-07	(4.5)	1.01E-04	(4.0)

ROOT CAUSE 6 RUN -- JULY 1991 RERUN

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
QR	2	4.40E-02	(1.0)	1.50E-06	(1.0)	7.25E-08	8.90E-06
L-RAH	1	5.30E-03	(3.0)	1.20E-06	(2.5)	3.12E-08	8.70E-06
PDAMH	1	5.40E-03	(2.0)	1.20E-06	(2.5)	3.12E-08	8.70E-06
L-RAC	1	2.30E-03	(5.0)	3.04E-07	(4.5)	8.04E-09	1.18E-06
PDAMC	1	3.00E-03	(4.0)	3.04E-07	(4.5)	8.04E-09	1.18E-06

ROOT CAUSE 6 RUN -- JULY 1991 RERUN

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
L-RAH	1	5.30E-03	(3.0)	2.30E-04	(1.0)	1.30E-05	1.43E-03
PDAWH	1	5.40E-03	(2.0)	2.32E-04	(2.0)	1.27E-05	9.52E-04
L-RAC	1	2.30E-03	(5.0)	1.32E-04	(3.0)	7.25E-06	6.70E-04
PDAWC	1	3.00E-03	(4.0)	1.01E-04	(4.0)	4.33E-06	2.93E-04
QR	2	4.40E-02	(1.0)	3.40E-05	(5.0)	3.56E-06	1.35E-04

ROOT CAUSE 6 RUN -- JULY 1991 RERUN

UNCERTAINTY IMPORTANCE BY BASE EVENT

BASE EVENT	OCCUR	PROB	(RANK)	% REDUCTION IN THE UNCERTAINTY OF LOG RISK	(RANK)	Y.05/TE.05*	Y.95/TE.95*
QR	2	4.40E-02	(1.0)	40.3	(1.0)	2.21	0.70
L-RAH	1	5.30E-03	(3.0)	29.9	(2.0)	2.23	0.92
PDAMH	1	5.40E-03	(2.0)	24.4	(3.0)	1.40	0.67
L-RAC	1	2.30E-03	(5.0)	11.6	(4.0)	1.66	1.02
PDAMC	1	3.60E-03	(4.0)	7.2	(5.0)	1.38	1.01

ROOT CAUSE 6 RUN -- JULY 1991 RERUN

BASE EVENTS RANKED BY VARIOUS METHODS (RANK 1 = MOST IMPORTANT) AND SORTED BY RISK REDUCTION

BASE EVENT	RISK REDUCTION	RISK INCREASE	UNCERTAINTY IMPORTANCE
QR	1.0	5.0	1.0
L-RAH	2.5	1.0	2.0
PDAMH	2.5	2.0	3.0
L-RAC	4.5	3.0	4.0
PDAMC	4.5	4.0	5.0

ROOT CAUSE 6 RUN -- JULY 1991 RERUN

MATRIX OF TOP-DOWN CORRELATION COEFFICIENTS

	RISK RED	RISK INCR
RISK INCR	-0.1733	
UNC IMP	0.9708*	-0.6608

* SIGNIFICANT AT APPROXIMATELY THE .05 LEVEL

THE TOP-DOWN CORRELATION COEFFICIENTS ARE USED TO DETERMINE THE LEVEL OF AGREEMENT AMONG ALL PAIRS OF RANKINGS IN THE PREVIOUS TABLE. THE TOP-DOWN CORRELATION COEFFICIENT GIVES MORE WEIGHT TO THE SMALLEST RANKS. NOTE THAT THE SMALLEST RANKS ARE ASSIGNED TO THE MOST IMPORTANT BASE EVENTS. MORE DETAIL ON THIS STATISTIC CAN BE FOUND IN THE IMAN AND CONOVER (1985) REFERENCE IN THE USER'S GUIDE THAT ACCOMPANIES THIS CODE.

ROOT CAUSE 6 RUN -- JULY 1991 RERUN

CUT SET FREQUENCIES AND NORMALIZED CUT SET FREQUENCIES (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%	NORMALIZED FREQUENCY	CUMULATIVE NORMALIZED FREQUENCY	LOWER 5%	UPPER 5%
2	3	1.26E-06	(1.0)	3.12E-08	8.78E-06	0.8057	0.8057	0.1298	0.9919
1	3	3.04E-07	(2.0)	8.04E-09	1.18E-06	0.1943	1.0000	0.0081	0.8702

ROOT CAUSE 6 RUN -- JULY 1991 RERUN

CUT SET NUMBERS, CUT SET ORDERS, CUT SET FREQUENCIES,
CUMULATIVE NORMALIZED CUT SET FREQUENCIES AND CUT SETS
FOR TOP EVENT ROOT-CAUSE-6 WITH TOP EVENT FREQUENCY 1.56E-06

(THE FIRST COLUMN OF NUMBERS IS THE LINE NUMBERS FOR THE FILE TEMACSETS.DNF)

2	2	3	1.26E-06	0.80574	L-RAH	*	PDAMH	*	QR	+
3	1	3	3.04E-07	1.00000	L-RAC	*	PDAMC	*	QR	.

Root Cause 8 Run

ROOT CAUSE 8 RUN -- JULY 1991 RERUN

TOP EVENT ROOT-CAUSE-8 CONTAINS 4 EVENTS IN 3 CUT SETS

THE FREQUENCY OF TOP EVENT ROOT-CAUSE-8 IS 1.05E-06

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT ROOT-CAUSE-8

N	100
MEAN	2.64E-07
STD DEV	8.49E-07
LOWER 5%	5.14E-10
LOWER 25%	1.67E-09
MEDIAN	9.67E-09
UPPER 25%	7.40E-08
UPPER 5%	1.54E-06

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE,
ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

RISK REDUCTION = PD x EV(J)
= TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

RISK INCREASE = PD - RISK REDUCTION
= PD x (1 - EV(J))
= TEF(EVALUATED WITH EV(J) = 1) - TEF

ROOT CAUSE 8 RUN -- JULY 1991 RERUN

RISK REDUCTIONS RISK INCREASES BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
PNRDG	3	6.00E-01	(1.0)	1.05E-06	(1.0)	7.01E-07	(4.0)
A	1	1.00E-06	(2.0)	9.98E-07	(2.0)	6.00E-01	(2.0)
C	1	5.76E-08	(3.0)	3.46E-08	(3.0)	6.00E-01	(2.0)
B	1	3.42E-08	(4.0)	2.05E-08	(4.0)	6.00E-01	(2.0)

ROOT CAUSE 8 RUN -- JULY 1991 RERUN

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
PNRDG	3	6.00E-01	(1.0)	1.05E-06	(1.0)	5.14E-10	1.54E-06
A	1	1.00E-06	(2.0)	9.96E-07	(2.0)	2.53E-10	1.51E-06
C	1	5.76E-08	(3.0)	3.46E-08	(3.0)	2.26E-11	6.02E-08
B	1	3.42E-08	(4.0)	2.05E-08	(4.0)	3.47E-12	2.14E-08

ROOT CAUSE 8 RUN -- JULY 1991 RERUN

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
B	1	3.42E-08	(4.0)	6.00E-01	(2.0)	1.37E-01	9.61E-01
C	1	5.76E-08	(3.0)	6.00E-01	(2.0)	1.37E-01	9.61E-01
A	1	1.66E-06	(2.0)	6.00E-01	(2.0)	1.37E-01	9.61E-01
PNRDG	3	6.00E-01	(1.0)	7.01E-07	(4.0)	1.58E-10	1.11E-06

ROOT CAUSE 8 RUN -- JULY 1991 RERUN

CUT SET FREQUENCIES (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%
1	2	9.96E-07	(1.0)	2.53E-10	1.51E-06
3	2	3.46E-08	(2.0)	2.26E-11	6.62E-08
2	2	2.05E-08	(3.0)	3.47E-12	2.14E-08

ROOT CAUSE 8 RUN -- JULY 1991 RERUN

CUT SET NUMBERS, CUT SET ORDERS, CUT SET FREQUENCIES,
CUMULATIVE NORMALIZED CUT SET FREQUENCIES AND CUT SETS
FOR TOP EVENT ROOT-CAUSE-8   WITH TOP EVENT FREQUENCY   1.05E-06

(THE FIRST COLUMN OF NUMBERS IS THE LINE NUMBERS FOR THE FILE TEMACSETS.DNF)

2	1	2	9.96E-07	0.00000	A	*	PNRDG	+
3	3	2	3.46E-08	0.00000	C	*	PNRDG	+
4	2	2	2.05E-08	0.00000	B	*	PNRDG	.

Root Cause 11 Run

ROOT CAUSE 11 RUN -- JULY 1991 RERUN

TOP EVENT ROOT-CAUSE-11   CONTAINS   10 EVENTS IN   2 CUT SETS

THE FREQUENCY OF TOP EVENT ROOT-CAUSE-11   IS   3.30E-07

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT ROOT-CAUSE-11

N	100
MEAN	4.24E-07
STD DEV	5.70E-07
LOWER 5%	3.25E-08
LOWER 25%	8.20E-08
MEDIAN	1.90E-07
UPPER 25%	4.70E-07
UPPER 5%	1.38E-06

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE, ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

RISK REDUCTION = PD x EV(J)
= TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

RISK INCREASE = PD - RISK REDUCTION
= PD x (1 - EV(J))
= TEF(EVALUATED WITH EV(J) = 1) - TEF

ROOT CAUSE 11 RUN -- JULY 1991 RERUN

RISK REDUCTIONS   RISK INCREASES   BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
QR	2	4.40E-02	(6.0)	3.30E-07	(1.0)	7.17E-06	(5.0)
L-SQR	1	2.97E-03	(9.0)	2.01E-07	(3.5)	6.76E-05	(1.0)
PDAMH	1	5.40E-03	(7.0)	2.01E-07	(3.5)	3.76E-05	(4.0)
FS1	1	3.00E-01	(5.0)	2.01E-07	(3.5)	4.69E-07	(6.0)
FA4	1	9.56E-01	(1.5)	2.01E-07	(3.5)	1.06E-08	(9.0)
L-CSR	1	2.68E-03	(10.0)	1.29E-07	(8.0)	4.80E-05	(2.0)
QB-AUTO	1	9.56E-01	(1.5)	1.29E-07	(8.0)	6.79E-09	(10.0)
Q1T6	1	8.00E-01	(3.0)	1.29E-07	(8.0)	3.23E-08	(8.0)
PDAMC	1	3.00E-03	(8.0)	1.29E-07	(8.0)	4.29E-05	(3.0)
FA3	1	4.80E-01	(4.0)	1.29E-07	(8.0)	1.46E-07	(7.0)

ROOT CAUSE 11 RUN -- JULY 1991 RERUN

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
QR	2	4.40E-02	(6.0)	3.30E-07	(1.0)	3.25E-08	1.38E-06
L-SGR	1	2.97E-03	(9.0)	2.01E-07	(3.5)	6.84E-09	1.14E-06
PDAMH	1	5.40E-03	(7.0)	2.01E-07	(3.5)	6.84E-09	1.14E-06
FS1	1	3.00E-01	(5.0)	2.01E-07	(3.5)	6.84E-09	1.14E-06
FA4	1	9.50E-01	(1.5)	2.01E-07	(3.5)	6.84E-09	1.14E-06
L-CSR	1	2.08E-03	(10.0)	1.29E-07	(8.0)	2.60E-09	5.24E-07
QB-AUTO	1	9.50E-01	(1.5)	1.29E-07	(8.0)	2.60E-09	5.24E-07
Q1T6	1	8.00E-01	(3.0)	1.29E-07	(8.0)	2.60E-09	5.24E-07
PDAMC	1	3.00E-03	(8.0)	1.29E-07	(8.0)	2.60E-09	5.24E-07
FA3	1	4.00E-01	(4.0)	1.29E-07	(8.0)	2.60E-09	5.24E-07

ROOT CAUSE 11 RUN -- JULY 1991 RERUN

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
L-SCR	1	2.97E-03	(9.0)	6.75E-05	(1.0)	3.26E-06	3.96E-04
L-CSR	1	2.68E-03	(10.0)	4.80E-05	(2.0)	2.06E-06	2.32E-04
PDAMC	1	3.00E-03	(8.0)	4.29E-05	(3.0)	2.91E-06	1.22E-04
PDAMH	1	5.40E-03	(7.0)	3.70E-05	(4.0)	2.49E-06	1.38E-04
QR	2	4.40E-02	(6.0)	7.17E-06	(5.0)	1.35E-06	2.79E-05
FS1	1	3.00E-01	(5.0)	4.69E-07	(6.0)	1.76E-08	2.36E-06
FA3	1	4.80E-01	(4.0)	1.40E-07	(7.0)	3.48E-09	6.02E-07
Q1T6	1	8.00E-01	(3.0)	3.23E-08	(8.0)	3.89E-10	1.76E-07
FA4	1	9.50E-01	(1.5)	1.06E-08	(9.0)	3.51E-10	5.02E-08
QB-AUTO	1	9.50E-01	(1.5)	6.79E-09	(10.0)	9.01E-11	3.24E-08

ROOT CAUSE 11 RUN -- JULY 1991 RERUN

UNCERTAINTY IMPORTANCE BY BASE EVENT

BASE EVENT	OCCUR	PROB	(RANK)	% REDUCTION IN THE UNCERTAINTY OF LOG RISK	(RANK)	Y.05/TE.05*	Y.95/TE.95*
QR	2	4.40E-02	(6.0)	51.0	(1.0)	1.87	0.93
PDAMH	1	5.40E-03	(7.0)	20.9	(2.0)	0.89	0.82
L-SGR	1	2.97E-03	(9.0)	14.6	(3.0)	0.94	1.15
L-CSR	1	2.60E-03	(10.0)	11.3	(4.0)	1.18	1.11
FS1	1	3.00E-01	(5.0)	10.8	(5.0)	1.05	1.05
PDAMC	1	3.00E-03	(8.0)	6.5	(6.0)	0.84	1.06
Q1T6	1	8.00E-01	(3.0)	4.2	(7.0)	1.02	1.03
QB-AUTO	1	9.50E-01	(1.5)	0.0	(9.0)		
FA4	1	9.50E-01	(1.5)	0.0	(9.0)		
FA3	1	4.80E-01	(4.0)	0.0	(9.0)		

ROOT CAUSE 11 RUN -- JULY 1991 RERUN

BASE EVENTS RANKED BY VARIOUS METHODS (RANK 1 = MOST IMPORTANT) AND SORTED BY RISK REDUCTION

BASE EVENT	RISK REDUCTION	RISK INCREASE	UNCERTAINTY IMPORTANCE
QR	1.0	5.0	1.0
L-SGR	3.5	1.0	3.0
PDAMH	3.5	4.0	2.0
FS1	3.5	6.0	5.0
FA4	3.5	9.0	9.0
L-CSR	8.0	2.0	4.0
QB-AUTO	8.0	10.0	9.0
Q1T6	8.0	8.0	7.0
PDAMC	8.0	3.0	6.0
FA3	8.0	7.0	9.0

ROOT CAUSE 11 RUN -- JULY 1991 RERUN

MATRIX OF TOP-DOWN CORRELATION COEFFICIENTS

```
RISK INCR   0.0690

UNC IMP     0.8114**    0.3811

            RISK RED    RISK INCR
** SIGNIFICANT AT APPROXIMATELY THE .01 LEVEL
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THE TOP-DOWN CORRELATION COEFFICIENTS ARE USED TO DETERMINE THE LEVEL OF AGREEMENT AMONG ALL PAIRS OF RANKINGS IN THE PREVIOUS TABLE. THE TOP-DOWN CORRELATION COEFFICIENT GIVES MORE WEIGHT TO THE SMALLEST RANKS. NOTE THAT THE SMALLEST RANKS ARE ASSIGNED TO THE MOST IMPORTANT BASE EVENTS. MORE DETAIL ON THIS STATISTIC CAN BE FOUND IN THE IMAN AND CONOVER (1986) REFERENCE IN THE USER'S GUIDE THAT ACCOMPANIES THIS CODE.

ROOT CAUSE 11 RUN -- JULY 1991 RERUN

CUT SET FREQUENCIES AND NORMALIZED CUT SET FREQUENCIES (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%	NORMALIZED FREQUENCY	CUMULATIVE NORMALIZED FREQUENCY	LOWER 5%	UPPER 5%
2	5	2.01E-07 (	1.0)	6.04E-09	1.14E-06	0.6091	0.6091	0.1345	0.9782
1	6	1.29E-07 (	2.0)	2.66E-09	5.24E-07	0.3909	1.0000	0.0218	0.8055

ROOT CAUSE 11 RUN -- JULY 1991 RERUN

CUT SET NUMBERS, CUT SET ORDERS, CUT SET FREQUENCIES,
CUMULATIVE NORMALIZED CUT SET FREQUENCIES AND CUT SETS
FOR TOP EVENT ROOT-CAUSE-11 WITH TOP EVENT FREQUENCY 3.30E-07

(THE FIRST COLUMN OF NUMBERS IS THE LINE NUMBERS FOR THE FILE TEMACSETS.DNF)

2	2	5	2.01E-07	0.60913	FA4	*	FS1	*	L-SGR	*	PDAMH	*
3					QR	*						
4	1	6	1.29E-07	1.00000	FA3	*	L-CSR	*	PDAMC	*	Q1T6	*
5					QB-AUTO	*	QR	.				

Root Cause 12 Run

ROOT CAUSE 12 RUN -- JULY 1991 RERUN

TOP EVENT ROOT-CAUSE-12 CONTAINS 2 EVENTS IN 1 CUT SETS

THE FREQUENCY OF TOP EVENT ROOT-CAUSE-12 IS 2.14E-06

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT ROOT-CAUSE-12

N	100
MEAN	1.46E-06
STD DEV	3.95E-06
LOWER 5%	1.99E-09
LOWER 25%	2.89E-08
MEDIAN	1.43E-07
UPPER 25%	6.76E-07
UPPER 5%	6.44E-06

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE, ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

RISK REDUCTION = PD x EV(J)
= TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

RISK INCREASE = PD - RISK REDUCTION
= PD x (1 - EV(J))
= TEF(EVALUATED WITH EV(J) = 1) - TEF

ROOT CAUSE 12 RUN -- JULY 1991 RERUN

RISK REDUCTIONS RISK INCREASES BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
PNRHP1	1	2.60E-01	(1.0)	2.14E-08	(1.5)	6.09E-08	(2.0)
D	1	8.23E-08	(2.0)	2.14E-08	(1.5)	2.60E-01	(1.0)

ROOT CAUSE 12 RUN -- JULY 1991 RERUN

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
PNRHP1	1	2.60E-01	(1.0)	2.14E-06	(1.5)	1.99E-09	8.44E-06
D	1	8.23E-06	(2.0)	2.14E-06	(1.5)	1.99E-09	8.44E-06

ROOT CAUSE 12 RUN -- JULY 1991 RERUN

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
D	1	8.23E-06	(2.0)	2.60E-01	(1.0)	1.93E-01	3.98E-01
PNRHP1	1	2.60E-01	(1.0)	6.09E-06	(2.0)	5.58E-09	1.70E-05

ROOT CAUSE 12 RUN -- JULY 1991 RERUN

CUT SET FREQUENCIES (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%
1	2	2.14E-06	(1.0)	1.99E-09	8.44E-06

ROOT CAUSE 12 RUN -- JULY 1991 RERUN

CUT SET NUMBERS, CUT SET ORDERS, CUT SET FREQUENCIES,
CUMULATIVE NORMALIZED CUT SET FREQUENCIES AND CUT SETS
FOR TOP EVENT ROOT-CAUSE-12   WITH TOP EVENT FREQUENCY   2.14E-06

(THE FIRST COLUMN OF NUMBERS IS THE LINE NUMBERS FOR THE FILE TEMACSETS.DNF)

2	1	2	2.14E-06	0.00000	D	*	PNRHP1

Root Cause 13 Run

ROOT CAUSE 13 RUN -- JULY 1991 RERUN

TOP EVENT ROOT-CAUSE-13 CONTAINS 5 EVENTS IN 2 CUT SETS

THE FREQUENCY OF TOP EVENT ROOT-CAUSE-13 IS 4.47E-07

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT ROOT-CAUSE-13

N	100
MEAN	5.75E-07
STD DEV	8.07E-07
LOWER 5%	2.34E-08
LOWER 25%	1.07E-07
MEDIAN	2.38E-07
UPPER 25%	6.50E-07
UPPER 5%	2.42E-06

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE, ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

RISK REDUCTION = PD x EV(J)
= TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

RISK INCREASE = PD - RISK REDUCTION
= PD x (1 - EV(J))
= TEF(EVALUATED WITH EV(J) = 1) - TEF

ROOT CAUSE 13 RUN -- JULY 1991 RERUN

RISK REDUCTIONS   RISK INCREASES   BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
QR	2	4.40E-02	(1.0)	4.47E-07	(1.0)	9.71E-06	(5.0)
PDAMC	1	3.00E-03	(3.0)	2.38E-07	(2.5)	7.90E-05	(3.0)
L-UNC	1	1.80E-03	(4.0)	2.38E-07	(2.5)	1.32E-04	(2.0)
PDAMH	1	5.40E-03	(2.0)	2.09E-07	(4.5)	3.85E-05	(4.0)
L-UNH	1	8.80E-04	(5.0)	2.09E-07	(4.5)	2.37E-04	(1.0)

ROOT CAUSE 13 RUN -- JULY 1991 RERUN

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
QR	2	4.46E-02	(1.0)	4.47E-07	(1.0)	2.34E-08	2.42E-06
PDAMC	1	3.66E-03	(3.0)	2.38E-07	(2.5)	6.71E-09	1.27E-06
L-UNC	1	1.86E-03	(4.0)	2.38E-07	(2.5)	6.71E-09	1.27E-06
PDAMH	1	5.46E-03	(2.0)	2.09E-07	(4.5)	5.52E-09	1.26E-06
L-UNH	1	8.86E-04	(5.0)	2.09E-07	(4.5)	5.52E-09	1.26E-06

ROOT CAUSE 13 RUN -- JULY 1991 RERUN

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
L-UNH	1	8.00E-04	(5.0)	2.37E-04	(1.0)	1.31E-05	1.44E-03
L-UNC	1	1.00E-03	(4.0)	1.32E-04	(2.0)	7.25E-06	6.69E-04
PDAWC	1	3.00E-03	(3.0)	7.90E-05	(3.0)	5.28E-06	3.59E-04
PDAWH	1	5.40E-03	(2.0)	3.85E-05	(4.0)	2.20E-06	1.81E-04
QR	2	4.40E-02	(1.0)	9.71E-06	(5.0)	1.32E-06	3.80E-05

ROOT CAUSE 13 RUN -- JULY 1991 RERUN

UNCERTAINTY IMPORTANCE BY BASE EVENT

BASE EVENT	OCCUR	PROB	(RANK)	% REDUCTION IN THE UNCERTAINTY OF LOG RISK	(RANK)	Y.05/TE.05*	Y.95/TE.95*
QR	2	4.40E-02	(1.0)	45.4	(1.0)	2.60	0.72
L-UNH	1	8.80E-04	(5.0)	19.0	(2.0)	1.77	0.87
L-UNC	1	1.80E-03	(4.0)	17.5	(3.0)	1.48	0.90
PDAMH	1	5.40E-03	(2.0)	13.0	(4.0)	1.63	0.79
PDAMC	1	3.00E-03	(3.0)	11.5	(5.0)	1.70	1.00

ROOT CAUSE 13 RUN -- JULY 1991 RERUN

BASE EVENTS RANKED BY VARIOUS METHODS (RANK 1 = MOST IMPORTANT) AND SORTED BY RISK REDUCTION

BASE EVENT	RISK REDUCTION	RISK INCREASE	UNCERTAINTY IMPORTANCE
QR	1.0	5.0	1.0
PDAMC	2.5	3.0	5.0
L-UNC	2.5	2.0	3.0
PDAMH	4.5	4.0	4.0
L-UNH	4.5	1.0	2.0

ROOT CAUSE 13 RUN -- JULY 1991 RERUN

MATRIX OF TOP-DOWN CORRELATION COEFFICIENTS

RISK INCR	-0.5761	
UNC IMP	0.0799	-0.0915
	RISK RED	RISK INCR

THERE ARE NO TOP-DOWN CORRELATIONS THAT ARE SIGNIFICANT AT THE .05 LEVEL OR LESS

THE TOP-DOWN CORRELATION COEFFICIENTS ARE USED TO DETERMINE THE LEVEL OF AGREEMENT AMONG ALL PAIRS OF RANKINGS IN THE PREVIOUS TABLE. THE TOP-DOWN CORRELATION COEFFICIENT GIVES MORE WEIGHT TO THE SMALLEST RANKS. NOTE THAT THE SMALLEST RANKS ARE ASSIGNED TO THE MOST IMPORTANT BASE EVENTS. MORE DETAIL ON THIS STATISTIC CAN BE FOUND IN THE IMAN AND CONOVER (1985) REFERENCE IN THE USER'S GUIDE THAT ACCOMPANIES THIS CODE.

ROOT CAUSE 13 RUN -- JULY 1991 RERUN

CUT SET FREQUENCIES AND NORMALIZED CUT SET FREQUENCIES (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%	NORMALIZED FREQUENCY	CUMULATIVE NORMALIZED FREQUENCY	LOWER 5%	UPPER 5%
1	3	2.38E-07 (	1.0)	6.71E-09	1.27E-06	0.5319	0.5319	0.0307	0.9772
2	3	2.09E-07 (	2.0)	5.52E-09	1.26E-06	0.4681	1.0000	0.0228	0.9693

ROOT CAUSE 13 RUN -- JULY 1991 RERUN

CUT SET NUMBERS, CUT SET ORDERS, CUT SET FREQUENCIES,
CUMULATIVE NORMALIZED CUT SET FREQUENCIES AND CUT SETS
FOR TOP EVENT ROOT-CAUSE-13 WITH TOP EVENT FREQUENCY 4.47E-07

(THE FIRST COLUMN OF NUMBERS IS THE LINE NUMBERS FOR THE FILE TEMACSETS.DNF)

2	1	3	2.38E-07	0.53191	L-UNC	* PDAMC	* QR	+
3	2	3	2.09E-07	1.00000	L-UNH	* PDAMH	* QR	.

APPENDIX B

Uncertainty Analysis
(Risk)

Composite Uncertainty Analysis

SURRY RISK UNCERTAINTY COMPOSITE RUN 6-22-92

TOP EVENT ALL-RSK-UNC CONTAINS 22 EVENTS IN 40 CUT SETS

THE FREQUENCY OF TOP EVENT ALL-RSK-UNC IS 7.08E+00

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT ALL-RSK-UNC

N	100
MEAN	6.79E+00
STD DEV	6.44E+00
LOWER 5%	1.00E+00
LOWER 25%	2.41E+00
MEDIAN	4.37E+00
UPPER 25%	8.62E+00
UPPER 5%	2.17E+01

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE, ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

RISK REDUCTION = PD x EV(J)
= TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

RISK INCREASE = PD - RISK REDUCTION
= PD x (1 - EV(J))
= TEF(EVALUATED WITH EV(J) = 1) - TEF

SURRY RISK UNCERTAINTY COMPOSITE RUN 8-22-92

RISK REDUCTIONS RISK INCREASES BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
S4	8	1.80E-01	(3.0)	6.16E+00	(1.0)	2.81E+01	(10.0)
CDF12	5	1.46E-06	(8.0)	3.74E+00	(2.0)	2.56E+06	(3.5)
CDF6	5	3.42E-07	(9.0)	8.77E-01	(3.0)	2.56E+06	(3.5)
CDF8	10	2.64E-07	(10.0)	6.61E-01	(4.0)	2.50E+06	(7.0)
CON-97	5	9.70E-01	(1.0)	6.57E-01	(5.0)	2.03E-02	(14.0)
CDF4	5	2.53E-07	(11.0)	6.49E-01	(6.0)	2.56E+06	(3.5)
CDF13	5	2.38E-07	(12.0)	6.10E-01	(7.0)	2.56E+06	(3.5)
S3	8	1.40E-02	(5.0)	5.81E-01	(8.0)	4.09E+01	(8.0)
CDF11	5	1.66E-07	(13.0)	4.26E-01	(9.0)	2.56E+06	(3.5)
S5	8	2.50E-01	(2.0)	3.04E-01	(10.0)	9.11E-01	(12.0)
CDF5	5	4.43E-08	(14.0)	1.14E-01	(11.0)	2.56E+06	(3.5)
S2	8	2.00E-03	(6.0)	2.98E-02	(12.0)	1.49E+01	(11.0)
CON-03	5	3.00E-02	(4.0)	4.34E-03	(13.0)	1.40E-01	(13.0)
S1	8	1.00E-04	(7.0)	3.65E-03	(14.0)	3.65E+01	(9.0)

RISK REDUCTIONS BY INITIATING EVENT AND SORTED BY RISK REDUCTION

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)
IE-20	40	2.00E+01	(8.0)	7.08E+00	(1.0)
IE-RC3	8	6.20E+05	(3.0)	6.16E+00	(2.0)
IE-RC2	7	7.50E+05	(1.0)	5.79E-01	(3.0)
IE-RC6	7	2.20E+04	(6.0)	3.04E-01	(4.0)
IE-RC4	7	2.70E+05	(4.0)	2.98E-02	(5.0)
IE-RC1	8	6.60E+05	(2.0)	3.65E-03	(6.0)
IE-RC5	2	1.00E+05	(5.0)	2.88E-03	(7.0)
IE-RC7	1	1.70E+03	(7.0)	6.73E-05	(8.0)

SURRY RISK UNCERTAINTY COMPOSITE RUN 6-22-92

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
S4	8	1.80E-01	(3.0)	6.16E+00	(1.0)		
CDF12	5	1.46E-06	(8.0)	3.74E+00	(2.0)	2.08E-02	1.93E+01
CDF6	5	3.42E-07	(9.0)	8.77E-01	(3.0)	3.42E-02	4.09E+00
CDF8	10	2.64E-07	(10.0)	6.61E-01	(4.0)	1.90E-03	3.03E+00
CON-97	5	9.70E-01	(1.0)	6.57E-01	(5.0)		
CDF4	5	2.53E-07	(11.0)	6.49E-01	(6.0)	2.56E-02	2.67E+00
CDF13	5	2.38E-07	(12.0)	6.10E-01	(7.0)	2.90E-02	2.65E+00
S3	8	1.40E-02	(5.0)	5.81E-01	(8.0)		
CDF11	5	1.66E-07	(13.0)	4.26E-01	(9.0)	1.60E-02	1.42E+00
S5	8	2.50E-01	(2.0)	3.04E-01	(10.0)		
CDF5	5	4.43E-08	(14.0)	1.14E-01	(11.0)	3.31E-03	4.73E-01
S2	8	2.00E-03	(6.0)	2.98E-02	(12.0)		
CON-03	5	3.00E-02	(4.0)	4.34E-03	(13.0)		
S1	8	1.00E-04	(7.0)	3.65E-03	(14.0)		

RISK REDUCTION BY INITIATING EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
IE-20	40	2.00E+01	(8.0)	7.08E+00	(1.0)		
IE-RC3	8	6.20E+05	(3.0)	6.16E+00	(2.0)	8.79E-01	1.94E+01
IE-RC2	7	7.50E+05	(1.0)	5.79E-01	(3.0)	9.16E-02	1.55E+00
IE-RC6	7	2.20E+04	(6.0)	3.04E-01	(4.0)	4.88E-02	1.29E+00
IE-RC4	7	2.70E+05	(4.0)	2.98E-02	(5.0)	4.68E-03	9.52E-02
IE-RC1	8	6.60E+05	(2.0)	3.65E-03	(6.0)	5.20E-04	9.52E-03
IE-RC5	2	1.00E+05	(5.0)	2.88E-03	(7.0)	9.45E-06	1.71E-02
IE-RC7	1	1.70E+03	(7.0)	6.73E-05	(8.0)	2.13E-07	3.78E-04

SURRY RISK UNCERTAINTY COMPOSITE RUN 6-22-92

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
CDF5	5	4.43E-08	(14.0)	2.56E+06	(3.5)	1.98E+06	3.42E+06
CDF11	5	1.66E-07	(13.0)	2.56E+06	(3.5)	1.98E+06	3.42E+06
CDF13	5	2.38E-07	(12.0)	2.56E+06	(3.5)	1.98E+06	3.42E+06
CDF4	5	2.53E-07	(11.0)	2.56E+06	(3.5)	1.98E+06	3.42E+06
CDF6	5	3.42E-07	(9.0)	2.56E+06	(3.5)	1.98E+06	3.42E+06
CDF12	5	1.46E-06	(8.0)	2.56E+06	(3.5)	1.98E+06	3.42E+06
CDF8	10	2.64E-07	(10.0)	2.50E+06	(7.0)	1.93E+06	3.34E+06
S3	8	1.40E-02	(5.0)	4.09E+01	(8.0)		
S1	8	1.00E-04	(7.0)	3.65E+01	(9.0)		
S4	8	1.80E-01	(3.0)	2.81E+01	(10.0)		
S2	8	2.00E-03	(6.0)	1.49E+01	(11.0)		
S5	8	2.50E-01	(2.0)	9.11E-01	(12.0)		
CON-03	5	3.00E-02	(4.0)	1.40E-01	(13.0)		
CON-97	5	9.70E-01	(1.0)	2.03E-02	(14.0)		

SURRY RISK UNCERTAINTY COMPOSITE RUN 6-22-92

BASE EVENTS RANKED BY VARIOUS METHODS (RANK 1 = MOST IMPORTANT) AND SORTED BY RISK REDUCTION

BASE EVENT	RISK REDUCTION	RISK INCREASE
S4	1.0	10.0
CDF12	2.0	3.5
CDF6	3.0	3.5
CDF8	4.0	7.0
CON-97	5.0	14.0
CDF4	6.0	3.5
CDF13	7.0	3.5
S3	8.0	8.0
CDF11	9.0	3.5
S5	10.0	12.0
CDF5	11.0	3.5
S2	12.0	11.0
CON-03	13.0	13.0
S1	14.0	9.0

SURRY RISK UNCERTAINTY COMPOSITE RUN 6-22-92

MATRIX OF TOP-DOWN CORRELATION COEFFICIENTS

RISK INCR   Ø.1369

RISK RED
THERE ARE NO TOP-DOWN CORRELATIONS THAT ARE SIGNIFICANT AT THE .Ø5 LEVEL OR LESS

THE TOP-DOWN CORRELATION COEFFICIENTS ARE USED TO DETERMINE THE LEVEL OF AGREEMENT AMONG ALL PAIRS OF RANKINGS IN THE PREVIOUS TABLE. THE TOP-DOWN CORRELATION COEFFICIENT GIVES MORE WEIGHT TO THE SMALLEST RANKS. NOTE THAT THE SMALLEST RANKS ARE ASSIGNED TO THE MOST IMPORTANT BASE EVENTS. MORE DETAIL ON THIS STATISTIC CAN BE FOUND IN THE IMAN AND CONOVER (1985) REFERENCE IN THE USER'S GUIDE THAT ACCOMPANIES THIS CODE.

SURRY RISK UNCERTAINTY COMPOSITE RUN 6-22-92

CUT SET FREQUENCIES AND NORMALIZED CUT SET FREQUENCIES (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%	NORMALIZED FREQUENCY	CUMULATIVE NORMALIZED FREQUENCY	LOWER 5%	UPPER 5%
34	4	3.26E+00	(1.0)	1.77E-02	1.70E+01	0.4603	0.4603	0.0060	0.7981
14	4	7.63E-01	(2.0)	3.01E-02	3.53E+00	0.1078	0.5681	0.0036	0.5956
19	5	5.72E-01	(3.0)	1.66E-03	2.57E+00	0.0807	0.6488	0.0002	0.4937
4	4	5.65E-01	(4.0)	2.23E-02	2.32E+00	0.0798	0.7286	0.0047	0.4174
39	4	5.31E-01	(5.0)	2.54E-02	2.27E+00	0.0750	0.8036	0.0042	0.4882
29	4	3.71E-01	(6.0)	1.39E-02	1.24E+00	0.0523	0.8560	0.0027	0.3163
33	4	3.07E-01	(7.0)	1.39E-03	1.29E+00	0.0433	0.8993	0.0005	0.0669
35	4	1.61E-01	(8.0)	8.90E-04	1.02E+00	0.0227	0.9220	0.0004	0.0607
9	4	9.89E-02	(9.0)	2.89E-03	4.11E-01	0.0140	0.9359	0.0004	0.1298
13	4	7.18E-02	(10.0)	2.34E-03	2.91E-01	0.0101	0.9461	0.0003	0.0495
18	5	5.38E-02	(11.0)	1.39E-04	2.39E-01	0.0076	0.9537	0.0000	0.0386
3	4	5.31E-02	(12.0)	1.78E-03	1.91E-01	0.0075	0.9612	0.0004	0.0352
38	4	5.00E-02	(13.0)	2.20E-03	1.79E-01	0.0071	0.9682	0.0003	0.0397
15	4	3.76E-02	(14.0)	1.57E-03	2.16E-01	0.0053	0.9736	0.0002	0.0403
28	4	3.49E-02	(15.0)	1.46E-03	1.08E-01	0.0049	0.9785	0.0002	0.0306
20	5	2.82E-02	(16.0)	8.28E-05	1.80E-01	0.0040	0.9825	0.0000	0.0237
5	4	2.78E-02	(17.0)	1.17E-03	1.44E-01	0.0039	0.9864	0.0002	0.0269
40	4	2.62E-02	(18.0)	1.45E-03	1.29E-01	0.0037	0.9901	0.0002	0.0276
30	4	1.83E-02	(19.0)	8.23E-04	7.94E-02	0.0026	0.9927	0.0002	0.0225
32	4	1.58E-02	(20.0)	9.94E-05	7.77E-02	0.0022	0.9949	0.0000	0.0043
8	4	9.30E-03	(21.0)	2.25E-04	3.55E-02	0.0013	0.9962	0.0000	0.0114
10	4	4.87E-03	(22.0)	1.44E-04	2.77E-02	0.0007	0.9969	0.0000	0.0085
12	4	3.69E-03	(23.0)	1.51E-04	1.96E-02	0.0005	0.9974	0.0000	0.0031
24	5	2.85E-03	(24.0)	9.35E-06	1.69E-02	0.0004	0.9978	0.0000	0.0026
17	5	2.77E-03	(25.0)	8.48E-06	1.76E-02	0.0004	0.9982	0.0000	0.0030
2	4	2.73E-03	(26.0)	1.08E-04	1.14E-02	0.0004	0.9986	0.0000	0.0022
37	4	2.57E-03	(27.0)	1.18E-04	1.26E-02	0.0004	0.9990	0.0000	0.0026
31	4	1.93E-03	(28.0)	1.01E-05	8.29E-03	0.0003	0.9992	0.0000	0.0004
27	4	1.79E-03	(29.0)	7.56E-05	7.05E-03	0.0003	0.9995	0.0000	0.0019
23	5	1.37E-03	(30.0)	4.00E-06	6.18E-03	0.0002	0.9997	0.0000	0.0012
7	4	4.78E-04	(31.0)	1.49E-05	2.92E-03	0.0001	0.9997	0.0000	0.0008
11	4	4.51E-04	(32.0)	1.35E-05	1.93E-03	0.0001	0.9998	0.0000	0.0003
16	5	3.38E-04	(33.0)	8.81E-07	1.52E-03	0.0000	0.9999	0.0000	0.0002
1	4	3.34E-04	(34.0)	1.02E-05	1.28E-03	0.0000	0.9999	0.0000	0.0002
36	4	3.14E-04	(35.0)	1.34E-05	1.27E-03	0.0000	0.9999	0.0000	0.0002
26	4	2.19E-04	(36.0)	9.20E-06	6.47E-04	0.0000	1.0000	0.0000	0.0002
25	5	6.73E-05	(37.0)	2.13E-07	3.78E-04	0.0000	1.0000	0.0000	0.0001
6	4	5.85E-05	(38.0)	1.57E-06	2.28E-04	0.0000	1.0000	0.0000	0.0001
22	5	3.17E-05	(39.0)	1.04E-07	1.87E-04	0.0000	1.0000	0.0000	0.0000
21	5	1.05E-05	(40.0)	2.72E-08	4.71E-05	0.0000	1.0000	0.0000	0.0000

SURRY RISK UNCERTAINTY COMPOSITE RUN 6-22-92

CUT SET NUMBERS, CUT SET ORDERS, CUT SET FREQUENCIES,
CUMULATIVE NORMALIZED CUT SET FREQUENCIES AND CUT SETS
FOR TOP EVENT ALL-RSK-UNC WITH TOP EVENT FREQUENCY 7.08E+00

(THE FIRST COLUMN OF NUMBERS IS THE LINE NUMBERS FOR THE FILE TEMACSETS.DNF)

2	34	4	3.26E+00	0.46029	CDF12	*	IE-20	*	IE-RC3	*	S4	+
3	14	4	7.63E-01	0.56811	CDF6	*	IE-20	*	IE-RC3	*	S4	+
4	19	5	5.72E-01	0.64884	CDF8	*	CON-97	*	IE-20	*	IE-RC3	*
5					S4	+						
6	4	4	5.65E-01	0.72861	CDF4	*	IE-20	*	IE-RC3	*	S4	+
7	39	4	5.31E-01	0.80364	CDF13	*	IE-20	*	IE-RC3	*	S4	+
8	29	4	3.71E-01	0.85597	CDF11	*	IE-20	*	IE-RC3	*	S4	+
9	33	4	3.07E-01	0.89928	CDF12	*	IE-20	*	IE-RC2	*	S3	+
10	35	4	1.61E-01	0.92197	CDF12	*	IE-20	*	IE-RC6	*	S5	+
11	9	4	9.89E-02	0.93593	CDF5	*	IE-20	*	IE-RC3	*	S4	+
12	13	4	7.18E-02	0.94608	CDF6	*	IE-20	*	IE-RC2	*	S3	+
13	18	5	5.38E-02	0.95367	CDF8	*	CON-97	*	IE-20	*	IE-RC2	*
14					S3	+						
15	3	4	5.31E-02	0.96118	CDF4	*	IE-20	*	IE-RC2	*	S3	+
16	38	4	5.00E-02	0.96824	CDF13	*	IE-20	*	IE-RC2	*	S3	+
17	15	4	3.76E-02	0.97355	CDF6	*	IE-20	*	IE-RC6	*	S5	+
18	28	4	3.49E-02	0.97847	CDF11	*	IE-20	*	IE-RC2	*	S3	+
19	20	5	2.82E-02	0.98245	CDF8	*	CON-97	*	IE-20	*	IE-RC6	*
20					S5	+						
21	5	4	2.78E-02	0.98638	CDF4	*	IE-20	*	IE-RC6	*	S5	+
22	40	4	2.62E-02	0.99008	CDF13	*	IE-20	*	IE-RC6	*	S5	+
23	30	4	1.83E-02	0.99266	CDF11	*	IE-20	*	IE-RC6	*	S5	+
24	32	4	1.58E-02	0.99489	CDF12	*	IE-20	*	IE-RC4	*	S2	+
25	8	4	9.30E-03	0.99620	CDF5	*	IE-20	*	IE-RC2	*	S3	+
26	10	4	4.87E-03	0.99689	CDF5	*	IE-20	*	IE-RC6	*	S5	+
27	12	4	3.69E-03	0.99741	CDF6	*	IE-20	*	IE-RC4	*	S2	+
28	24	5	2.85E-03	0.99782	CDF8	*	CON-03	*	IE-20	*	IE-RC5	*
29					S4	+						
30	17	5	2.77E-03	0.99821	CDF8	*	CON-97	*	IE-20	*	IE-RC4	*
31					S2	+						
32	2	4	2.73E-03	0.99859	CDF4	*	IE-20	*	IE-RC4	*	S2	+
33	37	4	2.57E-03	0.99895	CDF13	*	IE-20	*	IE-RC4	*	S2	+
34	31	4	1.93E-03	0.99923	CDF12	*	IE-20	*	IE-RC1	*	S1	+
35	27	4	1.79E-03	0.99948	CDF11	*	IE-20	*	IE-RC4	*	S2	+
36	23	5	1.37E-03	0.99967	CDF8	*	CON-03	*	IE-20	*	IE-RC3	*
37					S3	+						
38	7	4	4.78E-04	0.99974	CDF5	*	IE-20	*	IE-RC4	*	S2	+
39	11	4	4.51E-04	0.99981	CDF6	*	IE-20	*	IE-RC1	*	S1	+
40	16	5	3.38E-04	0.99985	CDF8	*	CON-97	*	IE-20	*	IE-RC1	*
41					S1	+						
42	1	4	3.34E-04	0.99990	CDF4	*	IE-20	*	IE-RC1	*	S1	+
43	36	4	3.14E-04	0.99995	CDF13	*	IE-20	*	IE-RC1	*	S1	+
44	26	4	2.19E-04	0.99998	CDF11	*	IE-20	*	IE-RC1	*	S1	+
45	25	5	6.73E-05	0.99999	CDF8	*	CON-03	*	IE-20	*	IE-RC7	*
46					S5	+						
47	6	4	5.85E-05	0.99999	CDF5	*	IE-20	*	IE-RC1	*	S1	+
48	22	5	3.17E-05	1.00000	CDF8	*	CON-03	*	IE-20	*	IE-RC5	*
49					S2	+						
50	21	5	1.05E-05	1.00000	CDF8	*	CON-03	*	IE-20	*	IE-RC1	*

Root Cause 4

SURRY RISK UNCERTAINTY ROOT CAUSE 4 RUN 6-22-92

TOP EVENT RC4-RSK-UNC CONTAINS 12 EVENTS IN 5 CUT SETS

THE FREQUENCY OF TOP EVENT RC4-RSK-UNC IS 6.49E-01

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT RC4-RSK-UNC

N	100
MEAN	5.82E-01
STD DEV	8.17E-01
LOWER 5%	2.56E-02
LOWER 25%	6.26E-02
MEDIAN	1.89E-01
UPPER 25%	6.08E-01
UPPER 5%	2.67E+00

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE, ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

RISK REDUCTION = PD x EV(J)
= TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

RISK INCREASE = PD - RISK REDUCTION
= PD x (1 - EV(J))
= TEF(EVALUATED WITH EV(J) = 1) - TEF

SURRY RISK UNCERTAINTY ROOT CAUSE 4 RUN 6-22-92

RISK REDUCTIONS RISK INCREASES BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
CDF4	5	2.53E-07	(6.0)	6.49E-01	(1.0)	2.56E+06	(1.0)
S4	1	1.80E-01	(2.0)	5.65E-01	(2.0)	2.57E+00	(4.0)
S3	1	1.40E-02	(3.0)	5.31E-02	(3.0)	3.74E+00	(2.0)
S5	1	2.50E-01	(1.0)	2.78E-02	(4.0)	8.35E-02	(6.0)
S2	1	2.00E-03	(4.0)	2.73E-03	(5.0)	1.36E+00	(5.0)
S1	1	1.00E-04	(5.0)	3.34E-04	(6.0)	3.34E+00	(3.0)

RISK REDUCTIONS BY INITIATING EVENT AND SORTED BY RISK REDUCTION

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)
IE-26	5	2.00E+01	(6.0)	6.49E-01	(1.0)
IE-RC3	1	6.20E+05	(3.0)	5.65E-01	(2.0)
IE-RC2	1	7.50E+05	(1.0)	5.31E-02	(3.0)
IE-RC6	1	2.20E+04	(5.0)	2.78E-02	(4.0)
IE-RC4	1	2.70E+05	(4.0)	2.73E-03	(5.0)
IE-RC1	1	6.60E+05	(2.0)	3.34E-04	(6.0)

SURRY RISK UNCERTAINTY ROOT CAUSE 4 RUN 6-22-92

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
CDF4	5	2.53E-07	(6.0)	6.49E-01	(1.0)	2.56E-02	2.67E+00
S4	1	1.80E-01	(2.0)	5.65E-01	(2.0)		
S3	1	1.40E-02	(3.0)	5.31E-02	(3.0)		
S5	1	2.50E-01	(1.0)	2.78E-02	(4.0)		
S2	1	2.00E-03	(4.0)	2.73E-03	(5.0)		
S1	1	1.00E-04	(5.0)	3.34E-04	(6.0)		

RISK REDUCTION BY INITIATING EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
IE-20	5	2.00E+01	(6.0)	6.49E-01	(1.0)		
IE-RC3	1	6.20E+05	(3.0)	5.65E-01	(2.0)	2.23E-02	2.32E+00
IE-RC2	1	7.50E+05	(1.0)	5.31E-02	(3.0)	1.78E-03	1.91E-01
IE-RC6	1	2.20E+04	(5.0)	2.78E-02	(4.0)	1.17E-03	1.44E-01
IE-RC4	1	2.70E+05	(4.0)	2.73E-03	(5.0)	1.08E-04	1.14E-02
IE-RC1	1	6.60E+05	(2.0)	3.34E-04	(6.0)	1.02E-05	1.28E-03

SURRY RISK UNCERTAINTY ROOT CAUSE 4 RUN 6-22-92

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
CDF4	5	2.53E-07	(6.0)	2.56E+06	(1.0)	1.98E+06	3.42E+06
S3	1	1.40E-02	(3.0)	3.74E+00	(2.0)		
S1	1	1.00E-04	(5.0)	3.34E+00	(3.0)		
S4	1	1.80E-01	(2.0)	2.57E+00	(4.0)		
S2	1	2.00E-03	(4.0)	1.36E+00	(5.0)		
S5	1	2.50E-01	(1.0)	8.35E-02	(6.0)		

SURRY RISK UNCERTAINTY ROOT CAUSE 4 RUN 6-22-92

CUT SET FREQUENCIES AND NORMALIZED CUT SET FREQUENCIES (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%	NORMALIZED FREQUENCY	CUMULATIVE NORMALIZED FREQUENCY	LOWER 5%	UPPER 5%
4	4	5.65E-01	(1.0)	2.23E-02	2.32E+00	0.8705	0.8705	0.8200	0.9029
3	4	5.31E-02	(2.0)	1.78E-03	1.91E-01	0.0819	0.9524	0.0546	0.1028
5	4	2.78E-02	(3.0)	1.17E-03	1.44E-01	0.0429	0.9953	0.0288	0.0914
2	4	2.73E-03	(4.0)	1.08E-04	1.14E-02	0.0042	0.9995	0.0025	0.0073
1	4	3.34E-04	(5.0)	1.02E-05	1.28E-03	0.0005	1.0000	0.0003	0.0007

SURRY RISK UNCERTAINTY ROOT CAUSE 4 RUN 6-22-92

CUT SET NUMBERS, CUT SET ORDERS, CUT SET FREQUENCIES,
CUMULATIVE NORMALIZED CUT SET FREQUENCIES AND CUT SETS
FOR TOP EVENT RC4-RSK-UNC WITH TOP EVENT FREQUENCY 6.49E-01

(THE FIRST COLUMN OF NUMBERS IS THE LINE NUMBERS FOR THE FILE TEMACSETS.DNF)

2	4	4	5.65E-01	0.87047	CDF4	*	IE-20	*	IE-RC3	*	S4	+
3	3	4	5.31E-02	0.95237	CDF4	*	IE-20	*	IE-RC2	*	S3	+
4	5	4	2.78E-02	0.99527	CDF4	*	IE-20	*	IE-RC6	*	S5	+
5	2	4	2.73E-03	0.99949	CDF4	*	IE-20	*	IE-RC4	*	S2	+
6	1	4	3.34E-04	1.00000	CDF4	*	IE-20	*	IE-RC1	*	S1	.

Root Cause 5

SURRY RISK UNCERTAINTY ROOT CAUSE 5 RUN 6-22-92

TOP EVENT RC5-RSK-UNC CONTAINS 12 EVENTS IN 5 CUT SETS

THE FREQUENCY OF TOP EVENT RC5-RSK-UNC IS 1.14E-01

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT RC5-RSK-UNC

N	100
MEAN	1.14E-01
STD DEV	1.62E-01
LOWER 5%	3.31E-03
LOWER 25%	1.14E-02
MEDIAN	3.36E-02
UPPER 25%	1.32E-01
UPPER 5%	4.73E-01

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE, ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

RISK REDUCTION = PD x EV(J)
= TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

RISK INCREASE = PD - RISK REDUCTION
= PD x (1 - EV(J))
= TEF(EVALUATED WITH EV(J) = 1) - TEF

SURRY RISK UNCERTAINTY ROOT CAUSE 5 RUN 6-22-92

RISK REDUCTIONS   RISK INCREASES   BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
CDF5	5	4.43E-08	(6.0)	1.14E-01	(1.0)	2.58E+08	(1.0)
S4	1	1.80E-01	(2.0)	9.89E-02	(2.0)	4.50E-01	(4.0)
S3	1	1.40E-02	(3.0)	9.30E-03	(3.0)	6.55E-01	(2.0)
S5	1	2.50E-01	(1.0)	4.87E-03	(4.0)	1.46E-02	(6.0)
S2	1	2.00E-03	(4.0)	4.78E-04	(5.0)	2.39E-01	(5.0)
S1	1	1.00E-04	(5.0)	5.85E-05	(6.0)	5.85E-01	(3.0)

RISK REDUCTIONS   BY INITIATING EVENT AND SORTED BY RISK REDUCTION

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)
IE-20	5	2.00E+01	(6.0)	1.14E-01	(1.0)
IE-RC3	1	6.20E+05	(3.0)	9.89E-02	(2.0)
IE-RC2	1	7.50E+05	(1.0)	9.30E-03	(3.0)
IE-RC6	1	2.20E+04	(5.0)	4.87E-03	(4.0)
IE-RC4	1	2.70E+05	(4.0)	4.78E-04	(5.0)
IE-RC1	1	6.60E+05	(2.0)	5.85E-05	(6.0)

SURRY RISK UNCERTAINTY ROOT CAUSE 5 RUN 6-22-92

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
CDF5	5	4.43E-08	(6.0)	1.14E-01	(1.0)	3.31E-03	4.73E-01
S4	1	1.80E-01	(2.0)	9.89E-02	(2.0)		
S3	1	1.40E-02	(3.0)	9.30E-03	(3.0)		
S5	1	2.50E-01	(1.0)	4.87E-03	(4.0)		
S2	1	2.00E-03	(4.0)	4.78E-04	(5.0)		
S1	1	1.00E-04	(5.0)	5.85E-05	(6.0)		

RISK REDUCTION BY INITIATING EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
IE-20	5	2.00E+01	(6.0)	1.14E-01	(1.0)		
IE-RC3	1	6.20E+05	(3.0)	9.89E-02	(2.0)	2.89E-03	4.11E-01
IE-RC2	1	7.50E+05	(1.0)	9.30E-03	(3.0)	2.25E-04	3.55E-02
IE-RC6	1	2.20E+04	(5.0)	4.87E-03	(4.0)	1.44E-04	2.77E-02
IE-RC4	1	2.70E+05	(4.0)	4.78E-04	(5.0)	1.49E-05	2.92E-03
IE-RC1	1	6.60E+05	(2.0)	5.85E-05	(6.0)	1.57E-06	2.28E-04

SURRY RISK UNCERTAINTY ROOT CAUSE 5 RUN 6-22-92

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
CDF5	5	4.43E-08	(6.0)	2.56E+06	(1.0)	1.98E+06	3.42E+06
S3	1	1.40E-02	(3.0)	6.55E-01	(2.0)		
S1	1	1.00E-04	(5.0)	5.85E-01	(3.0)		
S4	1	1.80E-01	(2.0)	4.50E-01	(4.0)		
S2	1	2.00E-03	(4.0)	2.39E-01	(5.0)		
S5	1	2.50E-01	(1.0)	1.46E-02	(6.0)		

SURRY RISK UNCERTAINTY ROOT CAUSE 5 RUN 6-22-92

CUT SET FREQUENCIES AND NORMALIZED CUT SET FREQUENCIES (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%	NORMALIZED FREQUENCY	CUMULATIVE NORMALIZED FREQUENCY	LOWER 5%	UPPER 5%
4	4	9.89E-02	(1.0)	2.89E-03	4.11E-01	0.8705	0.8705	0.8200	0.9029
3	4	9.30E-03	(2.0)	2.25E-04	3.55E-02	0.0819	0.9524	0.0546	0.1028
5	4	4.87E-03	(3.0)	1.44E-04	2.77E-02	0.0429	0.9953	0.0288	0.0914
2	4	4.78E-04	(4.0)	1.49E-05	2.92E-03	0.0042	0.9995	0.0025	0.0073
1	4	5.85E-05	(5.0)	1.57E-06	2.28E-04	0.0005	1.0000	0.0003	0.0007

SURRY RISK UNCERTAINTY ROOT CAUSE 5 RUN 6-22-92

CUT SET NUMBERS, CUT SET ORDERS, CUT SET FREQUENCIES,
CUMULATIVE NORMALIZED CUT SET FREQUENCIES AND CUT SETS
FOR TOP EVENT RC5-RSK-UNC WITH TOP EVENT FREQUENCY 1.14E-01

(THE FIRST COLUMN OF NUMBERS IS THE LINE NUMBERS FOR THE FILE TEMACSETS.DNF)

2	4	4	9.89E-02	0.87047	CDF5	*	IE-20	*	IE-RC3	*	S4	+
3	3	4	9.30E-03	0.95237	CDF5	*	IE-20	*	IE-RC2	*	S3	+
4	5	4	4.87E-03	0.99527	CDF5	*	IE-20	*	IE-RC6	*	S5	+
5	2	4	4.78E-04	0.99949	CDF5	*	IE-20	*	IE-RC4	*	S2	+
6	1	4	5.85E-05	1.00000	CDF5	*	IE-20	*	IE-RC1	*	S1	.

Root Cause 6

SURRY RISK UNCERTAINTY ROOT CAUSE 6 RUN 6-22-92

TOP EVENT RC6-RSK-UNC CONTAINS 12 EVENTS IN 5 CUT SETS

THE FREQUENCY OF TOP EVENT RC6-RSK-UNC IS 8.77E-01

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT RC6-RSK-UNC

N	100
MEAN	9.30E-01
STD DEV	1.28E+00
LOWER 5%	3.42E-02
LOWER 25%	1.09E-01
MEDIAN	3.41E-01
UPPER 25%	8.92E-01
UPPER 5%	4.09E+00

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE, ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

RISK REDUCTION = PD x EV(J)
= TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

RISK INCREASE = PD - RISK REDUCTION
= PD x (1 - EV(J))
= TEF(EVALUATED WITH EV(J) = 1) - TEF

SURRY RISK UNCERTAINTY ROOT CAUSE 6 RUN 6-22-92

RISK REDUCTIONS RISK INCREASES BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
CDF6	5	3.42E-07	(6.0)	8.77E-01	(1.0)	2.56E+06	(1.0)
S4	1	1.80E-01	(2.0)	7.63E-01	(2.0)	3.48E+00	(4.0)
S3	1	1.40E-02	(3.0)	7.18E-02	(3.0)	5.06E+00	(2.0)
S5	1	2.50E-01	(1.0)	3.76E-02	(4.0)	1.13E-01	(6.0)
S2	1	2.00E-03	(4.0)	3.69E-03	(5.0)	1.84E+00	(5.0)
S1	1	1.00E-04	(5.0)	4.51E-04	(6.0)	4.51E+00	(3.0)

RISK REDUCTIONS BY INITIATING EVENT AND SORTED BY RISK REDUCTION

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)
IE-20	5	2.00E+01	(6.0)	8.77E-01	(1.0)
IE-RC3	1	6.20E+05	(3.0)	7.63E-01	(2.0)
IE-RC2	1	7.50E+05	(1.0)	7.18E-02	(3.0)
IE-RC6	1	2.20E+04	(5.0)	3.76E-02	(4.0)
IE-RC4	1	2.70E+05	(4.0)	3.69E-03	(5.0)
IE-RC1	1	6.60E+05	(2.0)	4.51E-04	(6.0)

SURRY RISK UNCERTAINTY ROOT CAUSE 6 RUN 6-22-92

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
CDF6	5	3.42E-07	(6.0)	8.77E-01	(1.0)	3.42E-02	4.09E+00
S4	1	1.80E-01	(2.0)	7.63E-01	(2.0)		
S3	1	1.40E-02	(3.0)	7.18E-02	(3.0)		
S5	1	2.50E-01	(1.0)	3.76E-02	(4.0)		
S2	1	2.00E-03	(4.0)	3.69E-03	(5.0)		
S1	1	1.00E-04	(5.0)	4.51E-04	(6.0)		

RISK REDUCTION BY INITIATING EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
IE-20	5	2.00E+01	(6.0)	8.77E-01	(1.0)		
IE-RC3	1	6.20E+05	(3.0)	7.63E-01	(2.0)	3.01E-02	3.53E+00
IE-RC2	1	7.50E+05	(1.0)	7.18E-02	(3.0)	2.34E-03	2.91E-01
IE-RC6	1	2.20E+04	(5.0)	3.76E-02	(4.0)	1.57E-03	2.16E-01
IE-RC4	1	2.70E+05	(4.0)	3.69E-03	(5.0)	1.51E-04	1.98E-02
IE-RC1	1	6.60E+05	(2.0)	4.51E-04	(6.0)	1.35E-05	1.93E-03

SURRY RISK UNCERTAINTY ROOT CAUSE 6 RUN 6-22-92

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
CDF6	5	3.42E-07	(6.0)	2.56E+06	(1.0)	1.98E+06	3.42E+06
S3	1	1.40E-02	(3.0)	5.06E+00	(2.0)		
S1	1	1.00E-04	(5.0)	4.51E+00	(3.0)		
S4	1	1.80E-01	(2.0)	3.48E+00	(4.0)		
S2	1	2.00E-03	(4.0)	1.84E+00	(5.0)		
S5	1	2.50E-01	(1.0)	1.13E-01	(6.0)		

SURRY RISK UNCERTAINTY ROOT CAUSE 6 RUN 6-22-92

CUT SET FREQUENCIES AND NORMALIZED CUT SET FREQUENCIES (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%	NORMALIZED FREQUENCY	CUMULATIVE NORMALIZED FREQUENCY	LOWER 5%	UPPER 5%
4	4	7.63E-01	(1.0)	3.01E-02	3.53E+00	0.8705	0.8705	0.8200	0.9029
3	4	7.18E-02	(2.0)	2.34E-03	2.91E-01	0.0819	0.9524	0.0546	0.1028
5	4	3.76E-02	(3.0)	1.57E-03	2.16E-01	0.0429	0.9953	0.0288	0.0914
2	4	3.69E-03	(4.0)	1.51E-04	1.96E-02	0.0042	0.9995	0.0025	0.0073
1	4	4.51E-04	(5.0)	1.35E-05	1.93E-03	0.0005	1.0000	0.0003	0.0007

SURRY RISK UNCERTAINTY ROOT CAUSE 6 RUN 6-22-92

CUT SET NUMBERS, CUT SET ORDERS, CUT SET FREQUENCIES,
CUMULATIVE NORMALIZED CUT SET FREQUENCIES AND CUT SETS
FOR TOP EVENT RC6-RSK-UNC WITH TOP EVENT FREQUENCY 8.77E-01

(THE FIRST COLUMN OF NUMBERS IS THE LINE NUMBERS FOR THE FILE TEMACSETS.DNF)

2	4	4	7.63E-01	0.87047	CDF6	*	IE-20	*	IE-RC3	*	S4	+
3	3	4	7.18E-02	0.95237	CDF6	*	IE-20	*	IE-RC2	*	S3	+
4	5	4	3.76E-02	0.99527	CDF6	*	IE-20	*	IE-RC6	*	S5	+
5	2	4	3.69E-03	0.99949	CDF6	*	IE-20	*	IE-RC4	*	S2	+
6	1	4	4.51E-04	1.00000	CDF6	*	IE-20	*	IE-RC1	*	S1	.

Root Cause 8

SURRY RISK UNCERTAINTY ROOT CAUSE 8 RUN 6-22-92

TOP EVENT RC8-RSK-UNC CONTAINS 16 EVENTS IN 10 CUT SETS

THE FREQUENCY OF TOP EVENT RC8-RSK-UNC IS 6.61E-01

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT RC8-RSK-UNC

N	100
MEAN	5.61E-01
STD DEV	1.07E+00
LOWER 5%	1.90E-03
LOWER 25%	4.79E-03
MEDIAN	3.01E-02
UPPER 25%	2.59E-01
UPPER 5%	3.03E+00

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE, ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

RISK REDUCTION = PD x EV(J)
= TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

RISK INCREASE = PD - RISK REDUCTION
= PD x (1 - EV(J))
= TEF(EVALUATED WITH EV(J) = 1) - TEF

SURRY RISK UNCERTAINTY ROOT CAUSE 8 RUN 6-22-92

RISK REDUCTIONS   RISK INCREASES   BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
CDF8	10	2.64E-07	(8.0)	6.61E-01	(1.0)	2.50E+06	(1.0)
CON-97	5	9.70E-01	(1.0)	6.57E-01	(2.0)	2.03E-02	(8.0)
S4	2	1.80E-01	(3.0)	5.74E-01	(3.0)	2.62E+00	(4.0)
S3	2	1.40E-02	(5.0)	5.52E-02	(4.0)	3.88E+00	(2.0)
S5	2	2.50E-01	(2.0)	2.82E-02	(5.0)	8.47E-02	(7.0)
CON-03	5	3.00E-02	(4.0)	4.34E-03	(6.0)	1.40E-01	(6.0)
S2	2	2.00E-03	(6.0)	2.80E-03	(7.0)	1.40E+00	(5.0)
S1	2	1.00E-04	(7.0)	3.48E-04	(8.0)	3.48E+00	(3.0)

RISK REDUCTIONS   BY INITIATING EVENT AND SORTED BY RISK REDUCTION

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)
IE-20	10	2.00E+01	(8.0)	6.61E-01	(1.0)
IE-RC3	2	6.20E+05	(3.0)	5.73E-01	(2.0)
IE-RC2	1	7.50E+05	(1.0)	5.38E-02	(3.0)
IE-RC6	1	2.20E+04	(6.0)	2.82E-02	(4.0)
IE-RC5	2	1.00E+05	(5.0)	2.88E-03	(5.0)
IE-RC4	1	2.70E+05	(4.0)	2.77E-03	(6.0)
IE-RC1	2	6.60E+05	(2.0)	3.48E-04	(7.0)
IE-RC7	1	1.70E+03	(7.0)	6.73E-05	(8.0)

SURRY RISK UNCERTAINTY ROOT CAUSE 8 RUN 6-22-92

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
CDF8	10	2.64E-07	(8.0)	6.61E-01	(1.0)	1.90E-03	3.03E+00
CON-97	5	9.70E-01	(1.0)	6.57E-01	(2.0)		
S4	2	1.80E-01	(3.0)	5.74E-01	(3.0)		
S3	2	1.40E-02	(5.0)	5.52E-02	(4.0)		
S5	2	2.50E-01	(2.0)	2.82E-02	(5.0)		
CON-03	5	3.00E-02	(4.0)	4.34E-03	(6.0)		
S2	2	2.00E-03	(6.0)	2.80E-03	(7.0)		
S1	2	1.00E-04	(7.0)	3.48E-04	(8.0)		

RISK REDUCTION BY INITIATING EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
IE-20	10	2.00E+01	(8.0)	6.61E-01	(1.0)		
IE-RC3	2	6.20E+05	(3.0)	5.73E-01	(2.0)	1.67E-03	2.58E+00
IE-RC2	1	7.50E+05	(1.0)	5.38E-02	(3.0)	1.39E-04	2.39E-01
IE-RC6	1	2.20E+04	(6.0)	2.82E-02	(4.0)	8.28E-05	1.80E-01
IE-RC5	2	1.00E+05	(5.0)	2.88E-03	(5.0)	9.45E-06	1.71E-02
IE-RC4	1	2.70E+05	(4.0)	2.77E-03	(6.0)	8.48E-06	1.76E-02
IE-RC1	2	6.60E+05	(2.0)	3.48E-04	(7.0)	9.08E-07	1.57E-03
IE-RC7	1	1.70E+03	(7.0)	6.73E-05	(8.0)	2.13E-07	3.78E-04

SURRY RISK UNCERTAINTY ROOT CAUSE 8 RUN 6-22-92

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
CDF8	10	2.64E-07	(8.0)	2.50E+06	(1.0)	1.93E+06	3.34E+06
S3	2	1.40E-02	(5.0)	3.88E+00	(2.0)		
S1	2	1.00E-04	(7.0)	3.48E+00	(3.0)		
S4	2	1.80E-01	(3.0)	2.62E+00	(4.0)		
S2	2	2.00E-03	(6.0)	1.40E+00	(5.0)		
CON-03	5	3.00E-02	(4.0)	1.40E-01	(6.0)		
S5	2	2.50E-01	(2.0)	8.47E-02	(7.0)		
CON-97	5	9.70E-01	(1.0)	2.03E-02	(8.0)		

SURRY RISK UNCERTAINTY ROOT CAUSE 8 RUN 6-22-92

CUT SET FREQUENCIES AND NORMALIZED CUT SET FREQUENCIES (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%	NORMALIZED FREQUENCY	CUMULATIVE NORMALIZED FREQUENCY	LOWER 5%	UPPER 5%
4	5	5.72E-01	(1.0)	1.66E-03	2.57E+00	0.8648	0.8648	0.8127	0.8975
3	5	5.38E-02	(2.0)	1.39E-04	2.39E-01	0.0814	0.9461	0.0542	0.1020
5	5	2.82E-02	(3.0)	8.28E-05	1.80E-01	0.0426	0.9887	0.0286	0.0909
9	5	2.85E-03	(4.0)	9.35E-06	1.69E-02	0.0043	0.9931	0.0027	0.0089
2	5	2.77E-03	(5.0)	8.48E-06	1.76E-02	0.0042	0.9972	0.0025	0.0072
8	5	1.37E-03	(6.0)	4.00E-06	6.18E-03	0.0021	0.9993	0.0020	0.0022
1	5	3.38E-04	(7.0)	8.81E-07	1.52E-03	0.0005	0.9998	0.0003	0.0007
10	5	6.73E-05	(8.0)	2.13E-07	3.78E-04	0.0001	0.9999	0.0001	0.0002
7	5	3.17E-05	(9.0)	1.04E-07	1.87E-04	0.0000	1.0000	0.0000	0.0001
6	5	1.05E-05	(10.0)	2.72E-08	4.71E-05	0.0000	1.0000	0.0000	0.0000

SURRY RISK UNCERTAINTY ROOT CAUSE 8 RUN 6-22-92

CUT SET NUMBERS, CUT SET ORDERS, CUT SET FREQUENCIES,
CUMULATIVE NORMALIZED CUT SET FREQUENCIES AND CUT SETS
FOR TOP EVENT RC8-RSK-UNC WITH TOP EVENT FREQUENCY 6.61E-01

(THE FIRST COLUMN OF NUMBERS IS THE LINE NUMBERS FOR THE FILE TEMACSETS.DNF)

2	4	5	5.72E-01	0.86476	CDF8	*	CON-97	*	IE-20	*	IE-RC3	*
3					S4	+						
4	3	5	5.38E-02	0.94613	CDF8	*	CON-97	*	IE-20	*	IE-RC2	*
5					S3	+						
6	5	5	2.82E-02	0.98874	CDF8	*	CON-97	*	IE-20	*	IE-RC6	*
7					S5	+						
8	9	5	2.85E-03	0.99306	CDF8	*	CON-03	*	IE-20	*	IE-RC5	*
9					S4	+						
10	2	5	2.77E-03	0.99724	CDF8	*	CON-97	*	IE-20	*	IE-RC4	*
11					S2	+						
12	8	5	1.37E-03	0.99932	CDF8	*	CON-03	*	IE-20	*	IE-RC3	*
13					S3	+						
14	1	5	3.38E-04	0.99983	CDF8	*	CON-97	*	IE-20	*	IE-RC1	*
15					S1	+						
16	10	5	6.73E-05	0.99994	CDF8	*	CON-03	*	IE-20	*	IE-RC7	*
17					S5	+						
18	7	5	3.17E-05	0.99998	CDF8	*	CON-03	*	IE-20	*	IE-RC5	*
19					S2	+						
20	6	5	1.05E-05	1.00000	CDF8	*	CON-03	*	IE-20	*	IE-RC1	*
21					S1	.						

B-38

Root Cause 11

SURRY RISK UNCERTAINTY ROOT CAUSE 11 RUN 6-22-92

TOP EVENT RC11-RSK-UNC CONTAINS 12 EVENTS IN 5 CUT SETS

THE FREQUENCY OF TOP EVENT RC11-RSK-UNC IS 4.26E-01

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT RC11-RSK-UNC

N	100
MEAN	3.81E-01
STD DEV	4.45E-01
LOWER 5%	1.60E-02
LOWER 25%	5.23E-02
MEDIAN	1.60E-01
UPPER 25%	5.35E-01
UPPER 5%	1.42E+00

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE, ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

RISK REDUCTION = PD x EV(J)
= TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

RISK INCREASE = PD - RISK REDUCTION
= PD x (1 - EV(J))
= TEF(EVALUATED WITH EV(J) = 1) - TEF

SURRY RISK UNCERTAINTY ROOT CAUSE 11 RUN 6-22-92

RISK REDUCTIONS RISK INCREASES BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
CDF11	5	1.66E-07	(6.0)	4.26E-01	(1.0)	2.56E+06	(1.0)
S4	1	1.80E-01	(2.0)	3.71E-01	(2.0)	1.69E+00	(4.0)
S3	1	1.40E-02	(3.0)	3.49E-02	(3.0)	2.46E+00	(2.0)
S5	1	2.50E-01	(1.0)	1.83E-02	(4.0)	5.48E-02	(6.0)
S2	1	2.00E-03	(4.0)	1.79E-03	(5.0)	8.95E-01	(5.0)
S1	1	1.00E-04	(5.0)	2.19E-04	(6.0)	2.19E+00	(3.0)

RISK REDUCTIONS BY INITIATING EVENT AND SORTED BY RISK REDUCTION

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)
IE-20	5	2.00E+01	(6.0)	4.26E-01	(1.0)
IE-RC3	1	6.20E+05	(3.0)	3.71E-01	(2.0)
IE-RC2	1	7.50E+05	(1.0)	3.49E-02	(3.0)
IE-RC6	1	2.20E+04	(5.0)	1.83E-02	(4.0)
IE-RC4	1	2.70E+05	(4.0)	1.79E-03	(5.0)
IE-RC1	1	6.60E+05	(2.0)	2.19E-04	(6.0)

SURRY RISK UNCERTAINTY ROOT CAUSE 11 RUN 6-22-92

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
CDF11	5	1.66E-07	(6.0)	4.26E-01	(1.0)	1.60E-02	1.42E+00
S4	1	1.80E-01	(2.0)	3.71E-01	(2.0)		
S3	1	1.40E-02	(3.0)	3.49E-02	(3.0)		
S5	1	2.50E-01	(1.0)	1.83E-02	(4.0)		
S2	1	2.00E-03	(4.0)	1.79E-03	(5.0)		
S1	1	1.00E-04	(5.0)	2.19E-04	(6.0)		

RISK REDUCTION BY INITIATING EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
IE-20	5	2.00E+01	(6.0)	4.26E-01	(1.0)		
IE-RC3	1	6.20E+05	(3.0)	3.71E-01	(2.0)	1.39E-02	1.24E+00
IE-RC2	1	7.50E+05	(1.0)	3.49E-02	(3.0)	1.46E-03	1.08E-01
IE-RC6	1	2.20E+04	(5.0)	1.83E-02	(4.0)	8.23E-04	7.94E-02
IE-RC4	1	2.70E+05	(4.0)	1.79E-03	(5.0)	7.56E-05	7.05E-03
IE-RC1	1	6.60E+05	(2.0)	2.19E-04	(6.0)	9.20E-06	6.47E-04

SURRY RISK UNCERTAINTY ROOT CAUSE 11 RUN 6-22-92

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
CDF11	5	1.66E-07	(6.0)	2.56E+06	(1.0)	1.98E+06	3.42E+06
S3	1	1.40E-02	(3.0)	2.46E+00	(2.0)		
S1	1	1.00E-04	(5.0)	2.19E+00	(3.0)		
S4	1	1.80E-01	(2.0)	1.69E+00	(4.0)		
S2	1	2.00E-03	(4.0)	8.95E-01	(5.0)		
S5	1	2.50E-01	(1.0)	5.48E-02	(6.0)		

SURRY RISK UNCERTAINTY ROOT CAUSE 11 RUN 6-22-92

CUT SET FREQUENCIES AND NORMALIZED CUT SET FREQUENCIES (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%	NORMALIZED FREQUENCY	CUMULATIVE NORMALIZED FREQUENCY	LOWER 5%	UPPER 5%
4	4	3.71E-01	(1.0)	1.39E-02	1.24E+00	0.8705	0.8705	0.8200	0.9029
3	4	3.49E-02	(2.0)	1.46E-03	1.08E-01	0.0819	0.9524	0.0546	0.1028
5	4	1.83E-02	(3.0)	6.23E-04	7.94E-02	0.0429	0.9953	0.0288	0.0914
2	4	1.79E-03	(4.0)	7.56E-05	7.05E-03	0.0042	0.9995	0.0025	0.0073
1	4	2.19E-04	(5.0)	9.20E-06	6.47E-04	0.0005	1.0000	0.0003	0.0007

SURRY RISK UNCERTAINTY ROOT CAUSE 11 RUN 6-22-92

CUT SET NUMBERS, CUT SET ORDERS, CUT SET FREQUENCIES,
CUMULATIVE NORMALIZED CUT SET FREQUENCIES AND CUT SETS
FOR TOP EVENT RC11-RSK-UNC WITH TOP EVENT FREQUENCY 4.26E-01

(THE FIRST COLUMN OF NUMBERS IS THE LINE NUMBERS FOR THE FILE TEMACSETS.DNF)

2	4	4	3.71E-01	0.87047	CDF11	*	IE-20	*	IE-RC3	*	S4	+
3	3	4	3.49E-02	0.95237	CDF11	*	IE-20	*	IE-RC2	*	S3	+
4	5	4	1.83E-02	0.99527	CDF11	*	IE-20	*	IE-RC6	*	S5	+
5	2	4	1.79E-03	0.99949	CDF11	*	IE-20	*	IE-RC4	*	S2	+
6	1	4	2.19E-04	1.00000	CDF11	*	IE-20	*	IE-RC1	*	S1	.

Root Cause 12

SURRY RISK UNCERTAINTY ROOT CAUSE 12 RUN 6-22-92

TOP EVENT RC12-RSK-UNC CONTAINS 12 EVENTS IN 5 CUT SETS

THE FREQUENCY OF TOP EVENT RC12-RSK-UNC IS 3.74E+00

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT RC12-RSK-UNC

N	100
MEAN	3.54E+00
STD DEV	6.10E+00
LOWER 5%	2.08E-02
LOWER 25%	8.43E-02
MEDIAN	4.35E-01
UPPER 25%	3.02E+00
UPPER 5%	1.93E+01

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE, ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

RISK REDUCTION = PD x EV(J)
= TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

RISK INCREASE = PD - RISK REDUCTION
= PD x (1 - EV(J))
= TEF(EVALUATED WITH EV(J) = 1) - TEF

SURRY RISK UNCERTAINTY ROOT CAUSE 12 RUN 6-22-92

RISK REDUCTIONS RISK INCREASES BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
CDF12	5	1.46E-06	(6.0)	3.74E+00	(1.0)	2.56E+06	(1.0)
S4	1	1.80E-01	(2.0)	3.26E+00	(2.0)	1.48E+01	(4.0)
S3	1	1.40E-02	(3.0)	3.07E-01	(3.0)	2.16E+01	(2.0)
S5	1	2.50E-01	(1.0)	1.61E-01	(4.0)	4.82E-01	(6.0)
S2	1	2.00E-03	(4.0)	1.58E-02	(5.0)	7.87E+00	(5.0)
S1	1	1.00E-04	(5.0)	1.93E-03	(6.0)	1.93E+01	(3.0)

RISK REDUCTIONS BY INITIATING EVENT AND SORTED BY RISK REDUCTION

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)
IE-20	5	2.00E+01	(6.0)	3.74E+00	(1.0)
IE-RC3	1	6.20E+05	(3.0)	3.26E+00	(2.0)
IE-RC2	1	7.50E+05	(1.0)	3.07E-01	(3.0)
IE-RC6	1	2.20E+04	(5.0)	1.61E-01	(4.0)
IE-RC4	1	2.70E+05	(4.0)	1.58E-02	(5.0)
IE-RC1	1	6.60E+05	(2.0)	1.93E-03	(6.0)

SURRY RISK UNCERTAINTY ROOT CAUSE 12 RUN 6-22-92

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
CDF12	5	1.46E-06	(6.0)	3.74E+00	(1.0)	2.08E-02	1.93E+01
S4	1	1.80E-01	(2.0)	3.26E+00	(2.0)		
S3	1	1.40E-02	(3.0)	3.07E-01	(3.0)		
S5	1	2.50E-01	(1.0)	1.61E-01	(4.0)		
S2	1	2.00E-03	(4.0)	1.58E-02	(5.0)		
S1	1	1.00E-04	(5.0)	1.93E-03	(6.0)		

RISK REDUCTION BY INITIATING EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
IE-20	5	2.00E+01	(6.0)	3.74E+00	(1.0)		
IE-RC3	1	6.20E+05	(3.0)	3.26E+00	(2.0)	1.77E-02	1.70E+01
IE-RC2	1	7.50E+05	(1.0)	3.07E-01	(3.0)	1.39E-03	1.29E+00
IE-RC6	1	2.20E+04	(5.0)	1.61E-01	(4.0)	8.90E-04	1.02E+00
IE-RC4	1	2.70E+05	(4.0)	1.58E-02	(5.0)	9.94E-05	7.77E-02
IE-RC1	1	6.60E+05	(2.0)	1.93E-03	(6.0)	1.01E-05	8.29E-03

SURRY RISK UNCERTAINTY ROOT CAUSE 12 RUN 6-22-92

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
CDF12	5	1.46E-06	(6.0)	2.56E+06	(1.0)	1.98E+06	3.42E+06
S3	1	1.40E-02	(3.0)	2.16E+01	(2.0)		
S1	1	1.00E-04	(5.0)	1.93E+01	(3.0)		
S4	1	1.80E-01	(2.0)	1.48E+01	(4.0)		
S2	1	2.00E-03	(4.0)	7.87E+00	(5.0)		
S5	1	2.50E-01	(1.0)	4.82E-01	(6.0)		

SURRY RISK UNCERTAINTY ROOT CAUSE 12 RUN 6-22-92

<u>CUT SET FREQUENCIES</u> AND <u>NORMALIZED CUT SET FREQUENCIES</u> (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%	NORMALIZED FREQUENCY	CUMULATIVE NORMALIZED FREQUENCY	LOWER 5%	UPPER 5%
4	4	3.26E+00	(1.0)	1.77E-02	1.70E+01	0.8705	0.8705	0.8200	0.9029
3	4	3.07E-01	(2.0)	1.39E-03	1.29E+00	0.0819	0.9524	0.0546	0.1028
5	4	1.61E-01	(3.0)	8.90E-04	1.02E+00	0.0429	0.9953	0.0288	0.0914
2	4	1.58E-02	(4.0)	9.94E-05	7.77E-02	0.0042	0.9995	0.0025	0.0073
1	4	1.93E-03	(5.0)	1.01E-05	8.29E-03	0.0005	1.0000	0.0003	0.0007

SURRY RISK UNCERTAINTY ROOT CAUSE 12 RUN 6-22-92

CUT SET NUMBERS, CUT SET ORDERS, CUT SET FREQUENCIES,
CUMULATIVE NORMALIZED CUT SET FREQUENCIES AND CUT SETS
FOR TOP EVENT RC12-RSK-UNC WITH TOP EVENT FREQUENCY 3.74E+00

(THE FIRST COLUMN OF NUMBERS IS THE LINE NUMBERS FOR THE FILE TEMACSETS.DNF)

2	4	4	3.26E+00	0.87047	CDF12	*	IE-20	*	IE-RC3	*	S4	+
3	3	4	3.07E-01	0.95237	CDF12	*	IE-20	*	IE-RC2	*	S3	+
4	5	4	1.61E-01	0.99527	CDF12	*	IE-20	*	IE-RC6	*	S5	+
5	2	4	1.58E-02	0.99949	CDF12	*	IE-20	*	IE-RC4	*	S2	+
6	1	4	1.93E-03	1.00000	CDF12	*	IE-20	*	IE-RC1	*	S1	.

Root Cause 13

SURRY RISK UNCERTAINTY ROOT CAUSE 13 RUN 6-22-92

TOP EVENT RC13-RSK-UNC CONTAINS 12 EVENTS IN 5 CUT SETS

THE FREQUENCY OF TOP EVENT RC13-RSK-UNC IS 6.10E-01

DESCRIPTIVE STATISTICS FOR THE FREQUENCY OF TOP EVENT RC13-RSK-UNC

N	100
MEAN	6.74E-01
STD DEV	8.27E-01
LOWER 5%	2.90E-02
LOWER 25%	9.25E-02
MEDIAN	2.98E-01
UPPER 25%	9.19E-01
UPPER 5%	2.65E+00

90% UNCERTAINTY INTERVAL FOR TOP EVENT FREQUENCY (INNERMOST BRACKETS DENOTE INTERQUARTILE RANGE, ASTERISK DENOTES MEDIAN, N DENOTES NOMINAL VALUE AND M DENOTES MEAN)

NOMENCLATURE:

PD = PARTIAL DERIVATIVE

TEF = FREQUENCY OF THE TOP EVENT

EV(J) = PROBABILITY OF EVENT J FOR BASE EVENTS
= FREQUENCY OF EVENT J FOR INITIATING EVENTS

MEASURES:

1. FOR BASE EVENTS AND INITIATING EVENTS:

RISK REDUCTION = PD x EV(J)
= TEF - TEF(EVALUATED WITH EV(J) = 0)

2. FOR BASE EVENTS ONLY:

RISK INCREASE = PD - RISK REDUCTION
= PD x (1 - EV(J))
= TEF(EVALUATED WITH EV(J) = 1) - TEF

SURRY RISK UNCERTAINTY ROOT CAUSE 13 RUN 6-22-92

RISK REDUCTIONS   RISK INCREASES   BY BASE EVENT AND SORTED BY RISK REDUCTION

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	RISK INCREASE	(RANK)
CDF13	5	2.38E-07	(6.0)	6.10E-01	(1.0)	2.56E+06	(1.0)
S4	1	1.80E-01	(2.0)	5.31E-01	(2.0)	2.42E+00	(4.0)
S3	1	1.40E-02	(3.0)	5.00E-02	(3.0)	3.52E+00	(2.0)
S5	1	2.50E-01	(1.0)	2.62E-02	(4.0)	7.85E-02	(6.0)
S2	1	2.00E-03	(4.0)	2.57E-03	(5.0)	1.28E+00	(5.0)
S1	1	1.00E-04	(5.0)	3.14E-04	(6.0)	3.14E+00	(3.0)

RISK REDUCTIONS   BY INITIATING EVENT AND SORTED BY RISK REDUCTION

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)
IE-20	5	2.00E+01	(6.0)	6.10E-01	(1.0)
IE-RC3	1	6.20E+05	(3.0)	5.31E-01	(2.0)
IE-RC2	1	7.50E+05	(1.0)	5.00E-02	(3.0)
IE-RC6	1	2.20E+04	(5.0)	2.62E-02	(4.0)
IE-RC4	1	2.70E+05	(4.0)	2.57E-03	(5.0)
IE-RC1	1	6.60E+05	(2.0)	3.14E-04	(6.0)

SURRY RISK UNCERTAINTY ROOT CAUSE 13 RUN 6-22-92

RISK REDUCTION BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
CDF13	5	2.38E-07	(6.0)	6.10E-01	(1.0)	2.90E-02	2.65E+00
S4	1	1.80E-01	(2.0)	5.31E-01	(2.0)		
S3	1	1.40E-02	(3.0)	5.00E-02	(3.0)		
S6	1	2.50E-01	(1.0)	2.62E-02	(4.0)		
S2	1	2.00E-03	(4.0)	2.57E-03	(5.0)		
S1	1	1.00E-04	(5.0)	3.14E-04	(6.0)		

RISK REDUCTION BY INITIATING EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

INIT EVENT	OCCUR	FREQ	(RANK)	RISK REDUCTION	(RANK)	LOWER 5%	UPPER 5%
IE-20	5	2.00E+01	(6.0)	6.10E-01	(1.0)		
IE-RC3	1	6.20E+05	(3.0)	5.31E-01	(2.0)	2.54E-02	2.27E+00
IE-RC2	1	7.50E+05	(1.0)	5.00E-02	(3.0)	2.20E-03	1.79E-01
IE-RC6	1	2.20E+04	(5.0)	2.62E-02	(4.0)	1.45E-03	1.29E-01
IE-RC4	1	2.70E+05	(4.0)	2.57E-03	(5.0)	1.18E-04	1.26E-02
IE-RC1	1	6.60E+05	(2.0)	3.14E-04	(6.0)	1.34E-05	1.27E-03

SURRY RISK UNCERTAINTY ROOT CAUSE 13 RUN 6-22-92

RISK INCREASE BY BASE EVENT (WITH ASSOCIATED UNCERTAINTY INTERVALS)

BASE EVENT	OCCUR	PROB	(RANK)	RISK INCREASE	(RANK)	LOWER 5%	UPPER 5%
CDF13	5	2.38E-07	(6.0)	2.56E+06	(1.0)	1.98E+06	3.42E+06
S3	1	1.40E-02	(3.0)	3.52E+00	(2.0)		
S1	1	1.00E-04	(5.0)	3.14E+00	(3.0)		
S4	1	1.80E-01	(2.0)	2.42E+00	(4.0)		
S2	1	2.00E-03	(4.0)	1.28E+00	(5.0)		
S5	1	2.50E-01	(1.0)	7.85E-02	(6.0)		

SURRY RISK UNCERTAINTY ROOT CAUSE 13 RUN 8-22-92

CUT SET FREQUENCIES AND NORMALIZED CUT SET FREQUENCIES (WITH ASSOCIATED UNCERTAINTY INTERVALS)

CUT SET	ORDER	CUT SET FREQUENCY	(RANK)	LOWER 5%	UPPER 5%	NORMALIZED FREQUENCY	CUMULATIVE NORMALIZED FREQUENCY	LOWER 5%	UPPER 5%
4	4	5.31E-01	(1.0)	2.54E-02	2.27E+00	0.8705	0.8705	0.8200	0.9029
3	4	5.00E-02	(2.0)	2.20E-03	1.79E-01	0.0819	0.9524	0.0546	0.1028
5	4	2.62E-02	(3.0)	1.45E-03	1.29E-01	0.0429	0.9953	0.0288	0.0914
2	4	2.57E-03	(4.0)	1.18E-04	1.26E-02	0.0042	0.9995	0.0025	0.0073
1	4	3.14E-04	(5.0)	1.34E-05	1.27E-03	0.0005	1.0000	0.0003	0.0007

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2	4	4	5.31E-01	0.87047	CDF13	*	IE-20	*	IE-RC3	*	S4	+
3	3	4	5.00E-02	0.95237	CDF13	*	IE-20	*	IE-RC2	*	S3	+
4	5	4	2.62E-02	0.99527	CDF13	*	IE-20	*	IE-RC5	*	S5	+
5	2	4	2.57E-03	0.99949	CDF13	*	IE-20	*	IE-RC4	*	S2	+
6	1	4	3.14E-04	1.00000	CDF13	*	IE-20	*	IE-RC1	*	S1	.

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11. ABSTRACT (200 words or less)

Nuclear power plants have experienced actuations of fire protection systems (FPS) under conditions for which these systems were not intended to actuate, and also have experienced advertent actuations with the presence of a fire. These actuations have often damaged nearby plant equipment. A review of past occurrences of both types of such events, a quantification of the risk of FPS actuation, a sensitivity study of the quantification of the risk of FPS actuation and risk calculations in terms of person-REM have been performed.

Thirteen different scenarios leading to actuation of fire protection systems due to a variety of causes were identified. A quantification of these thirteen scenarios, where applicable, was performed on a 3-loop Westinghouse Pressurized Water Reactor (PWR). This report estimates the contribution of FPS actuations to core damage frequency, proposes physical modifications to reduce the risk from the dominant contributors, and estimates the values and impacts of the proposed modifications.

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