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Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Surry, Unit 1

Analysis of Core Damage Frequency from
Internal Fires During Mid-Loop Operations

Main Report

Prepared by
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Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

Traditionally, probabilistic risk assessments (PRA) of severe accidents in nuclear power plants have considered initiating events potentially occurring only during full power operation. Some previous screening analysis that were performed for other modes of operation suggested that risks during those modes were small relative to full power operation. However, more recent studies and operational experience have implied that accidents during low power and shutdown could be significant contributors to risk.

During 1989, the Nuclear Regulatory Commission (NRC) initiated an extensive program to carefully examine the potential risks during low power and shutdown operations. The program includes two parallel projects being performed by Brookhaven National Laboratory (BNL) and Sandia National Laboratories (SNL). Two plants, Surry (pressurized water reactor) and Grand Gulf (boiling water reactor), were selected as the plants to be studied.

The objectives of the program were to assess the risks of severe accidents initiated during plant operational states other than full power operation and to compare the estimated core damage frequencies, important accident sequences and other qualitative and quantitative results with those accidents initiated during full power operation as assessed in NUREG-1150. The scope of the program includes that of a Level-3 PRA.

A phased approach was used in the Level-1 program. In Phase 1 which was completed in Fall 1991, a coarse screening analysis including internal fire and flood was performed for all plant operational states (POSS). The objective of the Phase 1 study was to identify potential vulnerable plant configurations, to characterize (on a high, medium, or low basis) the potential core damage accident scenarios, and to provide a foundation for a detailed Phase 2 analysis.

In Phase 2, mid-loop operation was selected as the plant configuration to be analyzed based on the results of the Phase 1 study. The objective of the Phase 2 study is to perform a detailed analysis of the potential accident scenarios that may occur during mid-loop operation, and compare the results with those of NUREG-1150. The scope of the Level-1 study includes plant damage state analysis and uncertainty analysis. Volume 1 summarizes the results of the study. Internal events analysis is documented in Volume 2. Internal fire and internal flood analyses are documented in Volumes 3 and 4. A separate study on seismic analysis, documented in Volume 5, was performed for the NRC by Future Resources Associated, Inc.. Volume 6 documents the accident progression, source terms, and consequence analysis.

In the Phase 2 study, system models applicable for shutdown conditions were developed and supporting thermal hydraulic analyses were performed to determine both the timing of the accidents and success criteria for systems. Initiating events that may occur during mid-loop operations were identified and accident sequence event trees were developed and quantified. In the preliminary quantification of the mid-loop accident sequences, it was found that the decay heat at which the accident initiating event occurs is an important parameter that determines both the success criteria for the mitigating functions and time available for operator actions. In order to better account for the decay heat, a "time window" approach was developed. In this approach, time windows after shutdown were defined based on the success criteria established for the various methods that can be used to mitigate the accident. Within each time window, the decay heat and accident sequence timing are more accurately defined and new event trees developed and quantified accordingly. Statistical analysis of the past outage data was performed to determine the time at which a mid-loop condition is reached, and the duration of the mid-loop operation. Past outage data were used to determine the probability that an accident initiating event occurs in each of the time windows. This probability is used in the quantification of the accident sequences.

The major objective of the Surry internal fire analysis was to provide an improved understanding of the risk arising from internal fire-related events. The mean core damage frequency of the Surry plant due to internal fire events during mid-loop operations is $2\text{E-}05$ per year, and the 5th and 95th percentiles are $1\text{E-}06$ and $8\text{E-}05$ per year, respectively. This can be compared with the mean core frequency of $1\text{E-}05$ per year estimated in the NUREG-1150 study for accidents initiated by fires during full power operations.

TABLE OF CONTENTS

Abstract	iii
Table of Contents	v
List of Figures	ix
List of Tables	x
Executive Summary	xiii
Foreword	xix
Acknowledgements	xxi
1. Introduction and Overview	1-1
1.1 Scope of the Study	1-1
1.2 Results of Previous Fire Risk Analyses for Surry	1-1
1.3 Methodology Overview	1-1
1.4 Assumptions and Simplifications	1-2
1.5 Internal PRA Results	1-2
1.6 Plant Visits and Interaction with Virginia Power	1-3
1.7 Organization of the Report	1-3
1.8 References	1-3
2. Methodology Overview	2-1
2.1 Fire Frequency Calculations	2-1
2.2 Scenario Development	2-1
2.3 Fire Growth Modeling	2-1
2.4 Fire Suppression and Damage Fraction Calculation	2-1
2.5 Fault Tree and Event Tree Modifications	2-2
2.6 Model Quantification	2-2
2.7 References	2-3
3. Important Fire Areas Analyzed	3-1
3.1 Unit 1 Emergency Switchgear Room (ESGR)	3-1
3.2 Cable Vault and Tunnel (CVT)	3-2
3.3 Containment (CT)	3-2
3.4 Normal Switchgear Room (NSGR) (Unit 1)	3-2
3.5 Fire Areas Not Analyzed	3-3
4. Fire Frequency Calculations	4-1
4.1 Methodology	4-1
4.2 Sandia Fire Data Base	4-1
4.3 Criteria for Inclusion/Exclusion of Events	4-1
4.4 Exposure Time at Power and Shutdown	4-2
4.5 Pertinent Events from Data Base	4-2
4.6 Bayesian Updating Scheme	4-2
4.7 Component Based Fire Frequency	4-3
4.8 Insights	4-4
4.9 References	4-5
5. Scenario Development	5-1

Table of Contents (continued)

5.1 Assumptions and Simplifications	5-1
5.2 Initiators Considered	5-3
5.3 Important Equipment and Cable Locations	5-3
5.4 Types of Fire Damage to Components	5-3
5.5 Important Locations and Scenarios Within Fire Zones	5-4
5.5.1 ESGR	5-4
5.5.2 CVT	5-7
5.5.3 CT	5-7
5.5.4 NSGR	5-8
5.6 Scenario Quantification	5-8
5.7 References	5-8
6. Fire Growth Analysis	6-1
6.1 COMPBRN IIIe Capabilities and Limitations	6-1
6.2 Modeling of Fires in Important Fire Areas	6-2
6.2.1 ESGR	6-2
6.2.2 CVT	6-3
6.3 Fire Analysis	6-3
6.3.1 Oil Fire	6-3
6.3.2 Cable Fires	6-4
6.3.3 Cabinet Fire	6-5
6.3.4 Trash Fire	6-5
6.4 Sensitivity Study	6-5
6.4.1 Pool Fire Size	6-5
6.4.2 Effect of Wall on Plume Entrainment	6-6
6.4.3 Forced Ventilation	6-6
6.4.4 Forced Ventilation and Doorway Opening	6-6
6.5 References	6-7
7. Fire Suppression Modeling	7-1
7.1 Transition Diagram of Fire Detection and Suppression	7-1
7.2 Calculation of Parameters for f_{ns}	7-2
7.3 References	7-2
8. Damage Fraction Calculations	8-1
8.1 ESGR	8-1
8.2 CVT	8-1
8.3 CT	8-1
8.4 Results	8-2
9. Control Room Fire Risk Analysis	9-1
9.1 Fire Scenario Identification	9-2
9.1.1 Shutdown Accident Mitigation Equipment and Control Locations	9-3
9.1.2 Significant Scenario Identification	9-4
9.2 Fire Scenario Quantification	9-9
9.2.1 Control Room Walkdown	9-10

Table of Contents (continued)

9.2.2 Industrial Fire Events Specialization	9-11
9.2.3 Control Room Fire Frequency Assessment	9-13
9.2.4 Control Room Fire Frequency Apportionment	9-14
9.2.5 Scenario Frequency Quantification	9-14
9.3 References	9-17
10. Modification of the Internal PRA Model	10-1
10.1 References	10-1
11. Quantification	11-1
11.1 Summary of Procedure	11-1
11.2 Quantification of HEP for High-Level Human Action Events	11-1
11.2.1 High Level HEP Quantification	11-1
11.2.2 Recovery Actions	11-1
11.3 Successful System Correction	11-1
11.4 Uncertainty Analysis	11-2
11.5 References	11-3
12. Results	12-1
12.1 Point Estimate Results	12-1
12.2 Uncertainty Results	12-2
12.3 Conclusions	12-3
13. Plant Damage State Analysis	13-1
13.1 Definition of Plant Damage State Indicators	13-1
13.2 PDS Analysis, Rules	13-1
13.3 PDS Uncertainty Analysis	13-1
APPENDIX A-List of Plants and Pertinent Times	
APPENDIX B-Pertinent Events from the Fire Data Base	
B1 Generic Events	
B2 Surry Events	
APPENDIX C-Derivation of Phi, The Trash Combustible Fraction	
APPENDIX D-Cable Tray Trace Information	
APPENDIX E-Derivation of the Hot Short Spurious Operation	
Probability	
APPENDIX F-Fire Suppression Model	
APPENDIX G-High Level Human Errors Tables	
APPENDIX I-Event Trees Used in Fire Analysis	
APPENDIX H-Not Used	
APPENDIX J-Fault Trees Modified for Fire Events	
APPENDIX K-Input for Scenario Initiating Event Uncertainty Analysis.	
K1 Algebraic Expressions for Fire Scenario Initiating Events	
K2 Uncertainty Data For Variables in Appendix K.1	
K3 Description of Variables	
APPENDIX L-Fire Scenario Initiating Event Histograms	
APPENDIX M-Sequence Quantification	

Table of Contents (continued)

APPENDIX N-Basic Event Reports

N.1 Basic Event Uncertainty Report

N.2 Basic Event Descriptions

APPENDIX O-The Most Important Cutsets for the Total Core Damage Frequency Due to Fire at Midloop

APPENDIX P-Basic Event Importance Reports

P.1 Basic Event Importance Sorted by Fussell-Vesely Importance

P.2 Basic Event Importance Sorted Alphabetically

APPENDIX Q-Rules for Recovery Actions and Successful System Correction

LIST OF FIGURES

S.1	Fire Area Contribution to CDF	xv
3.1	Unit 1 Emergency Switchgear Room Fire Doors	3-4
3.2	Unit 1 Cable Vault and Tunnel Fire Doors	3-5
3.3	Emergency Switchgear Room Equipment Layout and Cable Tray Locations	3-6
3.4	Plan View of the Cable Vault and Tunnel with the Cross Section of the Tunnel, Showing Approximate Cable Tray Locations and the MCCs	3-7
3.5	Containment Layout at 18'4" Showing Critical Tray Locations	3-8
3.5a	Containment Layout at RHR Flats Showing Critical Tray Locations	3-9
3.6	Unit 1 and Unit 2 Normal Switchgear Rooms	3-10
3.7	Surry Station 4 kV Electrical Distribution System	3-11
5.1	Emergency Switchgear Room Equipment Layout and Cable Tray Locations	5-9
5.2	Plan View of the Cable Vault and Tunnel with the Cross Section of the Tunnel, Showing Approximate Cable Tray Locations and the MCCs	5-10
5.3	Containment Layout at 18'4" Showing Critical Tray Locations	5-11
5.3a	Containment Layout at RHR Flats Showing Critical Tray Locations	5-12
7.1	Fire Suppression Model	7-4
9.1	Surry Unit 1 Main Control Room Equipment Arrangement	9-19
9.2	$F_p(r)$ for Control Room Fires	9-20
9.3	Illustration of Five Severity Factor Calculations for Scenario BB-1-1	9-21
12.1	Fire Area Contribution to CDF	12-4
12.2	Contribution of Windows to Fire CDF	12-5
12.3	POS Contribution to Fire CDF	12-6
12.4	Significant Scenario, POS, Window Combinations Contributors to Fire CDF	12-7
12.5	Scenario Contribution to CDF	12-8

LIST OF TABLES

S.1	Summary of Point Estimate CDFs for Fire Events	xvii
S.2	Results of the Fire Uncertainty Analysis	xviii
1.1	Shutdown Fire Frequencies [6]	1-4
1.2	Results of Coarse Screening Fire Analysis for POS 6	1-5
1.3	Surry Fire Initiating Event Frequencies for Full Power Operation (/yr)	1-6
1.4	Surry Fire Area Full Power Core Damage Frequency	1-7
1.5	Summary of Results-Core Damage Frequency by Initiating Event and Plant Operational States	1-8
3.1	Surry Power Station - Units 1 and 2 Identification of Fire Areas	3-12
3.2	Combustible Loading Summary+	3-13
3.3A	Surry Power Station - Unit 1 Existing Fire Protection Features by Important Fire Area	3-14
3.3B	Miscellaneous Passive Fire Protection Items - Appendix R	3-15
3.4	Room Volume and Ventilation Rate for Select Rooms at Surry Summary of HVAC Information	3-16
3.5	Important Loads 4160 VAC Emergency Bus 1H, 11 Cabinets	3-17
3.6	Important Loads 480 VAC Emergency Bus 1H, 10 Cabinets	3-18
3.7	Important Loads 480 VAC Emergency Bus 1H1, 7 Cabinets	3-19
3.8	Important Loads 4160 VAC Emergency Bus 1J, 11 Cabinets	3-20
3.9	Important Loads 480 VAC Emergency Bus 1J, 10 Cabinets	3-21
3.10	Important Loads 480 VAC Emergency Bus 1J1, 7 Cabinets	3-22
3.11	Important Loads MCC 1H1-1, 40 Cabinets	3-23
3.12	Important Loads MCC 1J1-1, 42 Cabinets	3-24
3.13	Important Loads MCC 1H1-2	3-25
3.14	Important Loads MCC 1J1-2	3-26
4.1	Exposure Time, All U.S. Plants to 12/89	4-6
4.2	Exposure Time, Surry Units	4-7
4.3	Important Fire Events Initiated in Pertinent Equipment from Sandia Fire Data Base Type of Equipment MCC	4-8

List of Tables (continued)

4.3A	Important Cable and Transient Fire Events, Sandia Fire Data Base	
	Cable Fires	4-10
4.4	Pertinent Surry Fire Events	4-11
4.5	Parameters of Generic Fire Frequency Distribution (/yr) and Its Lognormal Fit from the Bayesian Updating and for Various Fire Categories and Evidence for Surry Events in that Category ..	4-12
4.5A	Parameters of Generic Fire Frequency Distribution (/yr) and its Lognormal Fit from the Bayesian Updating and for Transients in Various Fire Areas+ and Evidence for Surry Events in that Category	4-13
4.6	Parameters of Surry-Specific Fire Frequency Distribution (/yr) from Bayesian Updating for Various Categories+	4-14
4.7	Point Values for Plant-Wide Fire Frequency (/sdy)	4-15
4.8	Component Based Frequency Derivation	
	Point Estimates, Fire Frequency (/sdy)	4-16
4.9	Cable Fire Frequency Derivation per Tray-Foot	
	Frequency (/sdy/ft)	4-17
4.10	Transient Fire Frequency Derivation per Square Foot	4-18
4.11	Cable Tray Length in Fire Areas Unit 1	4-19
4.11A	Cable Tray Length in Fire Areas Unit 2	4-20
4.12	Class B Fire Frequency	4-21
5.1	Room (Floor Elevation)	5-13
5.2	Cable Insulation Types Used at Surry Unit 1 for Select Systems	
	Cable Types+	5-18
5.3	Fire Scenario Quantification	5-19
5.4	Initiating Event Frequencies (/yr.) for the Scenarios vs.Pos-Windows Combinations	5-20
6.1	Physical Property Parameters	6-8
6.2	Model Parameters	6-9
6.3	Cable Damage Time for Oil Fires in ESGR Room J	6-10
6.4	Probabilistic Distributions Assumed for Uncertainty Analysis	6-11
6.5	Results of Uncertainty Analysis	6-12
6.6	Cable Damage and Ignition Time for Oil Fire in Cable Vault Tunnel (Time in Minutes)	6-13
6.7	Cable Damage and Ignition Time for Cable Fires in the Vault/Tunnel Region (Time in Minutes)	6-15
6.8	Effect of Oil Pool Size on Combustion Characteristics	6-16
6.9	Effect of Oil Pool Size on Cable Damage Time	6-23
7.1	Classification of Fire Areas into Suppression Categories of Table 1.8, Appendix F	7-4
7.2	Parameters and for Fire Areas	7-4
8.1	Nonsuppression Fraction, f_{ns} , vs. Time in ESGR	8-3
8.2	Nonsuppression Fraction, f_{ns} , vs. Time in CVT	8-3
8.3	Nonsuppression Fraction, f_{ns} , vs. Time in CT	8-3
8.4	Damage Fractions for Fire Scenarios	8-3

List of Tables (continued)

9.1	List of Surry Unit 1 Shutdown PRA Basic Events for Equipment with Controls in Main Control Room	9-22
9.2	Control Locations for Surry Unit 1 Shutdown Accident Mitigation Equipment	9-25
9.3	Scenario Description and Preliminary Screening Results	9-28
9.4	Summary of Control Room Walkdown Observations and Frequency Apportionment for Benchboards 1-1 and 1-2, and Vertical Boards -1 and 1-2	9-31
9.5	Empirical Database Specialization	9-32
9.6	Summary of Control Room Age Assessment	9-36
9.7	Main Characteristics of the Noninformative Prior	9-41
9.8	Main Characteristics of the Posterior	9-42
9.9	Control Room Cabinet Fire Frequency Apportionment	9-43
9.10	Fire Frequency Apportionment of Panel Subsections in Benchboard Boards 1-1 and 1-2	9-44
9.11	Fire Frequency Apportionment of Panel Subsections in Vertical Boards 1-1 and 1-2	9-45
9.12	Summary of Scenario Quantification	9-46
12.1	Quantification of Sequences Greater than 10^{-7} /yr	12-9
12.2	Total Core Damage Frequency (/yr)	12-11
12.3	Total CDF for Each POS and Scenario	12-13
12.4	CDF for Window 1	12-17
12.5	Conditional Core Damage Probability vs. Scenario	12-19
12.6	Conditional Core Damage Probability vs. Scenario and POS	12-21
12.7	Conditional Core Damage Probability for Window 1	12-25
12.8	Results of Uncertainty Analysis for Total Core Damage Frequency (1/yr.)	12-27
12.9	Quantiles of Uncertainty Distribution for Total Core Damage Frequency (/yr)	12-28
13.1	Plant Damage State Definitions	13-2
13.2	Plant Damage State Point Estimates and Uncertainty Parameters	13-3

EXECUTIVE SUMMARY

S.1 Background and Objectives

This document presents the results of a Level 1 fire risk assessment of the Surry Power Station Unit 1 for accidents initiated during mid-loop operations. It is a part of the program to assess the risk of a Pressurized Water Reactor (PWR) during low power and shutdown operations. This program was initiated in support of the Nuclear Regulatory Commission (NRC) response to the Chernobyl accident, and was later modified by the staff's follow-up actions to the March 20, 1990 Vogtle incident. The work was performed by Brookhaven National Laboratory (BNL) for the U.S. NRC Office of Nuclear Regulatory Research (RES).

A phased approach was taken in this program. In Phase 1, a broadly scoped screening analysis, which included internal fires and flooding, was completed in November, 1991. This screening analysis produced a preliminary Level 1 Probabilistic Risk Assessment (PRA) for accidents initiated during low power and shutdown. It also provided insights on potential accident scenarios and potentially vulnerable configurations during low power and shutdown conditions. Phase 2 of the study focused on a detailed analysis of mid-loop operation. Mid-loop operation was selected because many incidents have occurred during mid-loop operations throughout the world, and recent studies, including Phase 1 of this program, found that the core damage frequency during mid-loop operation is comparable to that of power operation. This report documents the results and findings of the Phase 2 fire risk assessment. The work on internal events, internal flooding, seismic analysis, and Level 2/3 analysis are reported in separate volumes.

Surry Unit 1 was chosen for this study in part because the Surry plant was previously analyzed in the Reactor Safety Study and NUREG-1150 and in part because Virginia Power offered their cooperation. The core damage frequency during low power and shutdown calculated in this study is compared with the core damage frequency calculated in NUREG-1150 for accidents during full power. The Surry plant contains two Pressurized Water Reactors (PWRs), each rated at 788 megawatts (electrical) capacity, and is located near Surry in Virginia. Grand Gulf, a boiling water reactor, was selected as the plant to be analyzed in a parallel study that was performed by Sandia National Laboratories (SNL).

S.2 Methodology

In order to take into consideration different shutdown configurations, the same outage types, plant operational states, and time windows as those used in internal event analysis were used in the fire risk assessment. Outages were grouped into four different types: refueling, drained maintenance, non-drained maintenance with use of the residual heat removal (RHR) system, and non-drained maintenance without the use of the RHR system. Due to the continuously changing plant configuration in any outage, plant operational states (POSSs) were defined and characterized within each outage type. Each POSS represents a unique set of operating conditions (e.g., temperature, pressure, and configuration). For example, in a refueling outage, up to 15 POSSs were used. They represent the evolution of the plant throughout a refueling from low power down to cold shutdown and refueling, and back up to low power. An extensive effort was made to collect Surry-specific data needed to characterize each POSS. This included review of operating and abnormal procedures for shutdown operations, review of shift supervisor's log books, review of monthly operating reports, and performance of supporting thermal hydraulic calculations.

In Phase 1 of the fire risk assessment project, a scoping study was performed on mid-loop operations and refueling operations. Critical rooms were identified and modeled by assuming that a fire in such rooms destroys all the equipment contained in the room (including any cables passing through). The scenarios were then used to modify the plant PRA model, and were subsequently quantified. The most important scenarios were: a fire in the emergency switchgear room (ESGR) which causes a station blackout and disables the steam generator (SG) feed and bleed,

charging pumps and gravity feed; a fire in the control room which causes a station blackout and disables gravity feed, Low Head Injection (LHI) MOVs and SG PORVs; a fire in the auxiliary building which causes a long-term loss of RHR and disables charging pumps; and a fire in the safeguards area which causes a long-term loss of RHR, SG feed and bleed, and gravity feed.

In Phase 2, a detailed fire risk assessment was performed for mid-loop POSs. Three mid-loop POSs, in which the reactor coolant system (RCS) level is lowered to the mid-plane of the hot leg, were selected for detailed analysis. Two of them occur in a refueling outage, POSs R6 and R10, and one in a drained maintenance outage, POS D6. They are characterized by different decay heat levels and different plant configurations, such as the number of RCS loops that are isolated, and whether or not the RCS has a large vent. R6 represents a mid-loop operation that takes place early in a refueling outage. This mid-loop operation allows fast draining of the RCS loops to permit eddy current testing of the steam generator tubes. R10 takes place after refueling operation is completed to allow additional maintenance of equipment in the RCS loops. D6 represents mid-loop operation in which maintenance activities require the plant to go to mid-loop, and is characterized by the highest decay heat level among the three mid-loop POSs.

In order to more accurately define the decay heat level when an accident is initiated, a time window approach was developed. A total of four time windows after shutdown were defined, each with its unique set of success criteria reflecting the decay heat level. For POSs R6 and D6, all four windows were needed. For POS R10, only time windows 3 and 4 are applicable. A statistical analysis on the time to mid-loop and the duration of mid-loop was performed to determine the probability that a given accident occurs in a particular time window, conditional on the accident occurring. In this approach, an event tree was developed for each accident initiating event, POS, and time window.

Surry-specific fire frequencies for important plant areas and various types of fire: cable fires, transient fires, and equipment fires (e.g., switchgear panels, pumps, etc.) were assessed using the latest available information. The fire is considered in this study as a localized phenomenon (as it usually is in nuclear power plants). Hence, the analysis pinpoints the precise location of possible sources of fire and vulnerable equipment and/or electrical cables within a plant fire area. For that reason, the cables of the most important systems (for this study) have been traced with a high degree of confidence. Fire growth calculations (with COMPBRN-IIIe) have been performed for the most vulnerable locations uncovered in our analysis. A sophisticated, transition-diagram type of suppression model has been used, which, in conjunction with the fire growth model, gives the damage fraction (i.e., the probability of damage given a fire in that location). The damage fraction was used in the event tree and fault tree models to arrive at the core damage frequency (CDF) from a given fire scenario. The scenario-dependent human error probabilities (HEPs) have been estimated using the same human reliability analysis (HRA) method used in the internal event analysis. A cutset by cutset analysis of possible operator recovery actions was also performed. Uncertainty analysis of the core damage frequency was also performed by propagating the uncertainties associated with the parameters used in the model.

S.3 Results and Insights

Table S.1 summarizes the point estimate results of the quantification. Table S.2 summarizes the results of the uncertainty analysis on the total core damage frequency due to fires. No uncertainty analysis was done for individual sequences. Note that the CDF is the frequency at which core damage occurs when the plant is at mid-loop. It accounts for the fact that the plant is at mid-loop only a small fraction of the time. The quantification indicates that certain scenarios in the H and J compartments of the emergency switchgear room, one scenario in the cable vault and tunnel, and one containment scenario dominate the CDF. The most dominant scenarios occur in the cable vault and tunnel (due to proximity of many emergency cables from both divisions in a closed, constrained space) and in the J room of the ESGR, where many emergency cables from both the H and the J divisions come together in close proximity (before entering the control room). In the containment, the relatively high CDF is due to a relatively high

scenario frequency combined with non-separation of RHR trains over significant distances. Other scenarios are also important, due to a moderate damage from the fire combined with a relatively high scenario frequency.

Figure S.1 shows the contribution of various fire areas to the core damage frequency.

POSS D6 and R6 are much more important than R10 (as R10 occurs in later time windows). D6 is more important than R6 due to constraints imposed by a drained maintenance outage and its tendency to occur in earlier time windows.

The earlier time windows are more important than the later ones, with window 4 being relatively unimportant. Windows 1 and 2 are of the highest importance, with window 2 being significantly more important than window 1. While the decay heat is higher and the success criteria are more stringent in window 1, this window doesn't last as long and the outages tend to occur in the later time windows. The most risk significant fire initiator occurs in the cable vault tunnel area, in window 2 and POS D6, followed by a few scenarios in the J room of the ESGR, in the same window and POS.

Before the recovery actions were applied, the core damage frequency due to fire events at mid-loop was $2.7E-05/\text{yr}$. After application of recovery actions, the core damage frequency is $1.7E-05/\text{yr}$. Note that this point estimate differs from the total core damage frequency of Table S.1, i.e., $1.8E-05/\text{yr}$. This is because the total core damage frequency of Table S.1 was calculated simply as the sum of the frequencies of the sequences, while the point estimate of $1.7E-05/\text{yr}$ was calculated using the minimum-cutset-upper-bound method implemented in the IRRAS computer code. The recovery actions do not reduce the core damage frequency by much, because they will only be effective in windows 3 and 4 (in order to satisfy the 24 hour success criterion), whereas windows 1 and 2 are more dominant.

Table S.2 summarizes the result of the uncertainty analysis for core damage accidents initiated by fires. The results were obtained by performing uncertainty analysis using 500 Latin Hypercube Sampling (LHS) samples. Also shown in the table is the uncertainty analysis results of the internal event analysis as well as the mean value of the internal fire analysis of NUREG-1150.

Figure S.1 Fire Area Contribution to CDF

Table S.1 Summary of Point Estimate CDFs for Fire Events (/yr)

Fire Area	R6	D6	R10	Total
Emergency Switchgear Room	4.1E-06	8.2E-06	2.1E-07	1.3E-05
Containment	7.0E-08	5.5E-07	5.0E-09	6.3E-07
Cable Vault and Tunnel	1.3E-06	2.7E-06	7.4E-08	4.0E-06
Normal Switchgear Room	1.5E-08	3.5E-08	1.4E-09	5.1E-08
Main Control Room	7.0E-08	5.3E-07	4.4E-09	6.0E-07
Total	5.5E-06	1.2E-05	2.9E-07	1.8E-05

Table S.2 Results of the Fire Uncertainty Analysis

	Fire Analysis- Mid-Loop Operation (CDF/yr. while at mid-loop)	Internal Events Analysis- Mid-Loop Operation (CDF/yr. while at mid-loop)
Mean*	2.2E-05	4.9E-06
5th Percentile	1.4E-06	4.8E-07
50th Percentile	9.1E-06	2.1E-06
95th Percentile	7.6E-05	1.5E-05
Error Factor	7.2	5.7
Point Estimate	1.8E-05	5.1E-06

* NUREG-1150 estimated a mean CDF of 1.1E-05 per year for power operation.

FOREWORD

(NUREG/CR-6143 and 6144) Low Power and Shutdown Probabilistic Risk Assessment Program

Traditionally, probabilistic risk assessments (PRA) of severe accidents in nuclear power plants have considered initiating events potentially occurring only during full power operation. Some previous screening analysis that were performed for other modes of operation suggested that risks during those modes were small relative to full power operation. However, more recent studies and operational experience have implied that accidents during low power and shutdown could be significant contributors to risk.

During 1989, the Nuclear Regulatory Commission (NRC) initiated an extensive program to carefully examine the potential risks during low power and shutdown operations. The program includes two parallel projects performed by Brookhaven National Laboratory (BNL) and Sandia National Laboratories (SNL), with the seismic analysis performed by Future Resources Associates. Two plants, Surry (pressurized water reactor) and Grand Gulf (boiling water reactor), were selected as the plants to be studied.

The objectives of the program are to assess the risks of severe accidents due to internal events, internal fires, internal floods, and seismic events initiated during plant operational states other than full power operation and to compare the estimated core damage frequencies, important accident sequences and other qualitative and quantitative results with those accidents initiated during full power operation as assessed in NUREG-1150. The scope of the program includes that of a level-3 PRA.

The results of the program are documented in two reports, NUREG/CR-6143 and 6144. The reports are organized as follows:

For Grand Gulf:

NUREG/CR-6143 - Evaluation of Potential Severe Accidents during Low Power and Shutdown Operations at Grand Gulf, Unit 1

Volume 1: Summary of Results

Volume 2: Analysis of Core Damage Frequency from Internal Events for Operational State 5 During a Refueling Outage

Part 1: Main Report

Part 1A: Sections 1 - 9

Part 1B: Section 10

Part 1C: Sections 11 - 14

Part 2: Internal Events Appendices A to H

Part 3: Internal Events Appendices I and J

Part 4: Internal Events Appendices K to M

Volume 3: Analysis of Core Damage Frequency from Internal Fire Events for Plant Operational State 5 During a Refueling Outage

Volume 4: Analysis of Core Damage Frequency from Internal Flooding Events for Plant Operational State 5 During a Refueling Outage

Volume 5: Analysis of Core Damage Frequency from Seismic Events for Plant Operational State 5 During a Refueling Outage

Foreword (continued)

Volume 6: Evaluation of Severe Accident Risks for Plant Operational State 5 During a Refueling Outage

Part 1: Main Report

Part 2: Supporting MELCOR Calculations

For Surry:

NUREG/CR-6144- Evaluation of Potential Severe Accidents during Low Power and Shutdown Operations at Surry Unit-1

Volume 1: Summary of Results

Volume 2: Analysis of Core Damage Frequency from Internal Events during Mid-loop Operations

Part 1: Main Report

Part 1A: Chapters 1 - 6

Part 1B: Chapters 7 - 12

Part 2: Internal Events Appendices A to D

Part 3: Internal Events Appendix E

Part 3A: Sections E.1 - E.8

Part 3B: Sections E.9 - E.16

Part 4: Internal Events Appendices F to H

Part 5: Internal Events Appendix I

Volume 3: Analysis of Core Damage Frequency from Internal Fires during Mid-loop Operations

Part 1: Main Report

Part 2: Appendices

Volume 4: Analysis of Core Damage Frequency from Internal Floods during Mid-loop Operations

Volume 5: Analysis of Core Damage Frequency from Seismic Events during Mid-loop Operations

Volume 6: Evaluation of Severe Accident Risks during Mid-loop Operations

Part 1: Main Report

Part 2: Appendices

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1. INTRODUCTION AND OVERVIEW

1.1 Scope of the Study

Phase 2 is a continuation of Phase 1A work of Surry Low Power and Shutdown Study -- fire risk scoping analysis. The analysis presented here is a detailed look at fire risk, including location dependency, plant specific data, fire growth, and fire suppression modeling. This evaluation has been done for the mid-loop plant operational states, i.e., POSs 6 (refueling and drained maintenance outage) and 10 (refueling outage). These are the POSs identified in Phase 1 as having the highest risk potential.

In this report, both the point estimates and the uncertainty of Level 1 risk are presented.

Fires outside the plant are not considered (e.g., a fire in the transformer yard that causes a loss of offsite power).

1.2 Results of Previous Fire Risk Analyses for Surry

In Phase 1A of this study (which was a screening analysis), critical rooms were identified and modeled by assuming that a fire in such rooms destroys all the equipment within (including any cables passing through). The scenarios were then used to modify the plant Previous Risk Analyses (PRA) model, and were subsequently quantified. The most important scenarios were: fire in the emergency switchgear room (ESGR) causes station blackout and disables the steam generator (SG) feed and bleed, charging pumps and gravity feed; fire in the control room causes station blackout, disables gravity feed, Low Head Injection (LHI) MOVs and SG PORVs; fire in the auxiliary building causes long-term loss of residual heat removal (RHR) and disables charging pumps; and fire in the safeguards area causes long-term loss of RHR, SG feed and bleed, and gravity feed.

Generic room fire frequencies were used and Phase 1 (internal PRA screening analysis) event trees were modified to suit a particular room fire. A simplified suppression model was used. Tables 1.1 and 1.2 show the fire frequencies and the associated core damage frequencies for important scenarios in the Phase 1A work; Tables 1.3 and 1.4 show the same information from the 1150 work on fires at full power. Note that all the tables in the chapter show only the background material and results of earlier studies; no results of this study are presented herein.

1.3 Methodology Overview

In this work, we use Surry updated fire frequencies for important plant areas and various types of fire: cable fires, transient fires, and equipment fires (e.g., switchgear panels, pumps, etc.). The fire is considered in this study as a localized phenomenon (as it usually is in nuclear power plants). Hence, the analysis pinpoints the precise location of possible sources of fire and vulnerable equipment and/or electrical cables within a plant fire area. For that reason, the cables of most important systems (for this study) have been traced with a high degree of confidence. Fire growth calculations (with COMPBRN-IIIIE) have been performed for the most vulnerable locations uncovered in our analysis. A more sophisticated, transition-diagram type of suppression model has been used, which, in conjunction with the fire growth model, gives us the damage fraction (i.e., the probability of damage given a fire in that location). This is used in the fire analysis-modified plant model of Phase 2¹ (fault trees and event trees) to arrive at the core damage frequency from a given fire scenario. An analysis of operator recovery is also performed.

1.4 Assumptions and Simplifications

Some assumptions and simplifications were used in this study. As in the internal PRA, the 24-hour mission time was kept as the success criterion. Cutset probability cutoff was kept at 10^{-8} , and the fire scenario cutoff (meaning pre sequence quantification) was set at 10^{-7} .

Multiple initiators were not considered (e.g., loss of offsite power subsequent to a fire) for probabilistic reasons. For example, loss of offsite power probability in any 24 hour period is about $7.E-4$ for the Surry plant at mid-loop. Multiplying this by the mid-loop time fraction of 0.066 means that the scenario frequency would have to be a few times 10^{-3} in order for it to survive screening. No such scenarios were found.

Barrier failure was not considered as it was deemed probabilistically unimportant. For initiator-causing fires that occur near an important barrier (very few examples were found), the combination of fire frequency, probability of equipment failures causing an initiator, the mid-loop POS fraction, and barrier failure probability (on the order of 10^{-2} - 10^{-3})² was such that the fire scenario frequency was below the screening value. Also, comparing this probability to the conditional core damage probability for most scenarios (0.1) leads to screening of this consideration. It should be noted that in our visits to the plant (including during shutdown), it was observed that all normally closed fire doors were kept closed.

Certain cables were not traced due to lack of resources and/or because the scenarios would be probabilistically unimportant, or would not lead to an initiator, or would be irrelevant post-initiator for the particular initiators possible in the particular fire area (various compressed air systems, diesel generator cables, ventilation system cables, etc.). In some instances assumptions were made for the location of these and other cables (i.e. cables in conduits for which no precise tracing system is available at Surry).

It was assumed, for purposes of fire frequency calculations, that other plants are similar to Surry in terms of the number of pieces of equipment of a certain type in certain plant fire areas (e.g., number of switchgear cabinets in the emergency switchgear room).

Relay fires were screened probabilistically, because the combination of a relay fire frequency, mid-loop fraction, and the conditional probability of initiator occurrence was below the screening value.

The reader should refer to Sections 3.5, 4.3 and 5.1 for an in-depth discussion of assumptions and simplifications and justifications thereof.

It should be noted that both power and control cables were traced and the spurious operation following hot shorts was treated. Lack of electrical coordination between the 4160 V emergency buses and the 480 V load centers was also taken into account.

1.5 Internal PRA Results

The fire core damage PRA model relies heavily on the internal PRA model¹, as the latter is used (with modifications, to account for equipment taken out by the fire) in our calculations. Certain numerical results of the internal PRA model were used in screening out select fire scenarios. Table 1.5 presents a condensed summary of the internal PRA results.

1.6 Plant Visits and Interaction with Virginia Power

It should be noted that the plant was visited on several occasions for better understanding of the systems, layout, fire protection features and for cable tracing. One of these visits was during the refueling outage in early 1992 at Surry 1; access was obtained to various areas of the plant (including the containment and all the other areas considered in this study). In addition, there have been many occasions of written and telephone correspondence when a better understanding of a certain aspect was desired.

1.7 Organization of the Report

It should be noted that development of the main control room (MCR) fire scenarios and associated frequencies was treated as a separate task, which was carried out at a separate location. The product of this task was input into the plant model and quantified together with the other areas. However, it was necessary that the writeup on all aspects of scenario development and quantification for this area be put into a separate chapter (Chapter 9) and not included with the independent analysis of other areas (Chapters 3-8).

After a brief summary of methodology used, in Chapter 2, the important fire areas are identified in Chapter 3. Equipment within and fire protection features for each area are also shown in this chapter. Fire frequency calculation methodology and results are presented in Chapter 4. The scenario development is shown in Chapter 5 for each fire area of interest. Fire growth modeling and results are presented in Chapter 6. Fire suppression is discussed in Chapter 7 and the damage fraction calculations in Chapter 8. The modifications of the internal PRA model are described in Chapter 10 and the quantification aspects in Chapter 11. The results are presented in Chapter 12.

1.8 References

1. T-L. Chu, Z. Musicki, P. Kohut, et al., "Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Surry Unit-1: Analysis of Core Damage Frequencies from Internal Events During Mip-Loop Operations", NUREG/CR-6144, Volume 2, June 1994.
2. M.P. Bohn, et al., "Analysis of Core Damage Frequency: Surry Power Station, Unit 1 External Events," December 1990, NUREG/CR-4550, Vol. 3, Rev. 1, Part 3.

Table 1.1 Shutdown Fire Frequencies [6]
from a previous study
(not used in this study)

Frequency (per shutdown year)

Area Type	Mean	5th	50th	95th
Control Room	6.3×10^{-3}	2.1×10^{-4}	2.5×10^{-3}	2.4×10^{-2}
	($7.19 \times 10^{-7}/\text{hr}$)			
Cable Spreading Room	5.6×10^{-3}	1.7×10^{-4}	2.0×10^{-3}	1.4×10^{-2}
	($6.39 \times 10^{-7}/\text{hr}$)			
Auxiliary Building	7.2×10^{-2}	6.1×10^{-3}	5.0×10^{-2}	2.0×10^{-1}
	($8.22 \times 10^{-6}/\text{hr}$)			
Turbine Building	4.5×10^{-2}	9.9×10^{-4}	1.9×10^{-2}	1.5×10^{-1}
	($5.14 \times 10^{-6}/\text{hr}$)			
Containment	4.7×10^{-2}			
	($5.37 \times 10^{-6}/\text{hr}$)			

Table 1.2 Results of Coarse Screening Fire Analysis for POS 6
 (from a previous study - not results of this study)

Fire Area	Event Tree	Sequence	CDF*	Early or Late (E/L)	Containment Closed or Open (C/O)
1. Cable Vault and Tunnel	RHR	5	L	E	O
		8	M	E	O
3. Emergency Switch Gear Room	SB	5	L	E	O
		9	H	E	O
5. Control Room	SB	4	L	E	O
		7	H	E	O
15. Containment	RHR	4	L	E	O
		7	M	E	O
17. Auxiliary Building	RHR	3	M	E	O
		5	H	E	O
19. Safeguard Area	RHR	3	H	E	O
31. Turbine Building	RHR	5	L	E	O
		8	M	E	O

* Sequence CDF ranking, L=low, M=medium, H=high

Table 1.3 Surry Fire Initiating Event Frequencies for Full Power Operation (/yr), from NUREG/CR-4550

Fire Area	Mean	5th Percentile	50th Percentile	95th Percentile
Control Room	1.8E-3	1.2E-6	9.6E-4	7.4E-3
Cable Vault/Tunnel	7.5E-3	3.0E-6	1.8E-3	1.6E-2
Emergency Switchgear Room	8.0E-3	2.0E-5	2.4E-3	1.7E-2
Auxiliary Building	6.6E-2	2.7E-2	5.9E-2	1.6E-1
Pump Room	3.7E-3	(Lognormal EF = 3)		

Table 1.4 Surry Fire Area Full Power Core Damage Frequency, from NUREG/cr-4550

Fire Area	Core Damage Frequency (/yr) Mean
Emergency Switchgear Room	6.09E-6
Control Room	1.58E-6
Cable Vault/Tunnel	1.49E-6
Auxiliary Building	2.18E-6
Charging Pump Service Water Pump Room	3.92E-8
Total	1.13E-5

Table S.1 Summary of Results-Core-Damage Frequency by Initiating Event and Plant Operational States

	Initiating Event	IE Frequency	Core-Damage Frequency (per year)			
			R6	R10	D6	Total
1.	Loss of RHR					
	RHR2A-Over Draining	1.6E-02/Demand	1.8E-7	5.3E-8	2.6E-7	4.9E-7
	RHR2B-Failure to Maintain Level	1.2E-05/hr	2.1E-08	2.0E-8	2.9E-8	7.0E-8
	RHR3-Non-Recoverable Loss of RHR	4.1E-06/hr	1.5E-7	8.4E-9	3.0E-7	4.6E-7
	RHR4-Non-Recoverable Loss of Operating Train of RHR	5.3E-06/hr	7.6E-9	1.2E-9	2.3E-8	3.2E-8
	RHR5-Recoverable Loss of RHR	2.1E-05/hr	4.0E-8	4.1E-09	9.3E-8	1.4E-7
2.	LOOP-Loss of Offsite Power	7.0E-06/hr				
	L1-Both 1H and 1J Energized	6.2E-06/hr	3.3E-7	7.0E-8	7.6E-7	1.2E-6
	L2-1H and 2H energized, not 1J	7.4E-07/hr	1.0E-7	1.3E-8	1.7E-7	2.9E-7
	L3-1H energized, not 1J, unit 2 blackout	3.8E-08/hr	4.2E-8	1.3E-8	9.9E-8	1.5E-7
	B1-Unit 1 Black Out	2.0E-08/hr	4.8E-8	1.1E-8	1.7E-7	2.3E-7
	B2-2 Unit Blackout	3.2E-09/hr	3.8E-8	4.2E-8	1.1E-7	1.9E-7
3.	4KV-Loss of 4kv Bus	2.1E-05/hr	1.4E-7	1.9E-8	2.4E-7	4.0E-7
4.	VITAL-Loss of Vital Bus	5.6E-06/hr	2.8E-8	5.1E-9	7.3E-8	1.1E-7
5.	AIR-Loss of Outside Instrument Air	2.1E-6/hr	7.9E-10	-	3.2E-9	4.0E-9
6.	CCW-Loss of CCW	3.8E-06/hr	6.3E-8	1.1E-10	2.1E-7	2.7E-7
7.	SWGR-Loss of Emergency Switchgear Room Cooling	1.8E-08/hr	3.6E-8	1.2E-8	7.4E-8	1.2E-7
8.	ESFAS-Inadvertent Safety Feature Actuation	1.1E-04/hr	2.7E-7	2.7E-8	6.8E-7	9.8E-7
9.	Dilute-Boron Dilution (estimated CDF)	2.0E-07/hr				6.8E-08
TOTAL			1.5E-6	3.0E-7	3.3E-6	5.1E-6*

* Not including boron dilution

2. METHODOLOGY OVERVIEW

A more detailed discussion of certain aspects of the methodology and the results is presented in Chapters 3-10.

2.1 Fire Frequency Calculations

Fire frequency calculations were performed for important fire areas and for equipment found in these plant areas. Equipment classes were broken into subclasses, e.g. switchgear panels were divided up into bus panels, monitor control center (MCC) panels, uninterruptable power supply (UPS) panels, etc. Cable fires and transient fires were also considered. Large fires and small fires were calculated separately. Generic and Surry-specific fire events were obtained from the updated Sandia Fire data base¹, which considers events through 1989. These events were used to calculate Surry-specific fire frequencies in specific categories. These fire frequencies were then prorated to account for the fraction of fires in that category that occurs at a specific location.

2.2 Scenario Development

Fire areas in which important equipment is located were identified. The areas are such that a fire in a certain location within the area might cause an initiating event by disrupting RHR operation. Cable routing information within the area was also included in the analysis, both for power and control cables for important systems. Important systems are the ones which are identified in the internal PRA for providing alternate core cooling paths. Systems and components affected when the fire damages certain equipment and/or cable runs in a fire area location would result in an initiator and possibly degraded configuration of alternate core cooling paths. This information is eventually included in the event trees and fault trees from the internal PRA. Whether or not a certain cable would be damaged by a fire in a certain location would be decided by the fire growth calculations. The probability of damage would be determined by the fire suppression model.

2.3 Fire Growth Modeling

Once a certain critical location is identified (e.g., cables for important equipment pass nearby), the fire growth model is employed to determine if a fire in that location would damage the cable (which may be located a certain horizontal or vertical distance from the fire source). If damage does occur, the time to damage is also calculated.

The tool used for fire frequency calculations is the computer code COMPBRN-III². While this program is an important advance in the fire analysis, the results are only a rough representation of reality, as certain aspects are not modeled well and simplifying assumptions have to be made^{2,3}. For instance, the treatment of fire growth and the hot gas layer is such that ventilating the room will impede target damage (i.e., increase the time to damage). In contrast, the Surry Appendix R analysis⁴ states that ventilating the room will aid the fire growth as more oxygen is brought in and the products of combustion are taken out (certain fire suppressing agents will be diluted as well). For this reason (and also to prevent the fire from spreading to adjacent rooms), the ventilation to the affected area is cut off and the dampers and any sliding doors are closed once fire protection actuation occurs. In our analysis, to be conservative in accordance with the code modeling, the ventilation is cut off.

2.4 Fire Suppression and Damage Fraction Calculation

After a fire has initiated, and detection occurs, suppression efforts will start to bring it under control. The detection and suppression may consist of any combination of manual and automatic systems. These systems will act in such a way that a certain probability exists that the fire will be suppressed before damage to a critical cable occurs. (The time

Methodology Overview

to damage is input from the fire growth calculations above.) The probability of damage in a certain scenario is the damage fraction, and is input as a basic event representing damage to the particular component in our PRA model, given occurrence of fire in that location.

It should be noted that this analysis is a conservative simplification as, in reality, fire growth and suppression occur simultaneously (to a large extent) and there is interaction between them.

The suppression model uses transition rates among various states in the suppression path toward the eventual control of the fire^{5,6,7}. The transition rates and a particular combination of suppression steps relate to the probability of suppression in a certain time and in a plant area that contains the specified combination of detection and suppression equipment. A simplified, parametric approach has been developed⁷ to translate this transition model into a readily usable tool for calculating the non suppression probability (i.e., damage fraction). This suppression analysis is a more realistic approach than the one taken in the 1150 study^{8,9}, because it breaks down the suppression process into specific steps, and attempts to model options available at each step.

2.5 Fault Tree and Event Tree Modifications

The damage fraction calculated in 2.4 is input into the modified internal PRA model as a basic event representing a possible failure mode in a given component following a fire. The internal PRA model for a given initiator (caused by fire) is modified to account for additional equipment that may be damaged in a fire. Failure modes due to fire (e.g., spurious operation or power loss) are added to the internal failure modes of the component. Certain branches in the event tree will be prohibited, e.g., restoration of the 4 kV bus cannot be accomplished if the bus panel is destroyed in a fire.

The event tree will show core damage sequences given a fire in a certain location and given occurrence of the initiator by the fire.

2.6 Model Quantification

The quantification will proceed by multiplying the sequence probability by the location fire frequency and the conditional probability of the initiator to yield the sequence frequency. The latter two frequencies are sometimes combined into the scenario frequency.

The sequence frequencies are evaluated by IRRAS 5.0, the computer program used in the internal PRA quantification.

The modeling and quantification of human actions (for input into the PRA model) is done in two stages as in the internal PRA¹⁰. The high level human error probabilities (HEPs) are evaluated for each scenario (i.e., location-dependent fire event and its associated system impacts). The values are input into the system model, which is evaluated and yields sequence cutsets. The cutset-dependent recovery action HEPs are then applied to the most important sequence cutsets.

The quantification is performed with knowledge of IRRAS algorithm limitations at high failure probabilities. Compensatory steps are taken to account for that.

2.7 References

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9. M.P. Bohn, et al., "Analysis of Core Damage Frequency: Surry Power Station, Unit 1 External Events", NUREG/CR-4550, Vol. 3, Rev. 1, Part 3.
10. T-L Chu, Z. Musicki, P. Kohut, et al., " Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Surry Unit-1: Analysis of Core Damage Frequency from Internal Events During Mid-Loop Operations", NUREG/CR-6144, Volume 2, June 1994.

3. IMPORTANT FIRE AREAS ANALYZED

Table 3.1 shows Surry fire areas.

The fire areas described below are included in our fire risk assessment analysis. A fire in these areas could cause an initiator and damage important equipment and systems. The important areas are the emergency switchgear room (ESGR), the cable vault and tunnel (CVT), the containment (CT), the main control room (MCR), and the normal switchgear room (NSGR). Tables 3.2, 3.3, and 3.4 show the floor areas and the combustible loadings, fire protection features, and the volumes and ventilation rates, respectively, of these areas. Figures 3.1 and 3.2 show fire door locations in the ESGR and the CVT, respectively. Important equipment and cable locations are shown in Figures 3.3, 3.4, 3.5, and 3.6 for the ESGR, CVT, CT, and NSGR, respectively.

It should be noted that a fire in any area would show up on the fire panel in the main control room.

3.1 Unit 1 Emergency Switchgear Room (ESGR)

This room is located at level 9'6" of the Service Building (below the control room and the normal switchgear room). It is split into two compartments, the H (on the left) and the J; however, there are no doors between the two. The Unit 2 ESGR is right next to it and these two ESGRs are separated by a sliding door, which closes upon actuation (manual) of the Halon fire suppression gas system. All other doors are kept closed.

The fire protection system consists of smoke detectors, portable fire extinguishers, and a manually actuated Halon system.

This room contains various switchgear panels: the 4 kV 1H and 1J and associated stub buses (which contain RHR and component cooling water (CCW) breakers); the 480 V 1H, 1H1, 1J and 1J1 buses (and associated stepdown transformers); (MCCs) 1H1-1 and 1J1-1; the four UPSs. Important loads on these panels are shown in Tables 3.5-3.12. The pump motors and controls are usually connected to the bus breakers, whereas the valve motors and controls are usually connected to the MCCs. An exception to this is the charging pump cooling and service water pumps which are connected to MCC1H1-1 and MCC1J1-1. The important valves of concern in this study are connected to the MCCs in the CVT area, not the MCCs here. The auxiliary shutdown panel, used in case of an MCR fire is also located in the ESGR.

The J room is more vulnerable than the H room, because the control cables from the H side (as well as the J side) pass into the J room before going up into the control room. The control cables are routed from the respective bus breaker or the MCC cabinet to the lower part of the J room and up into the MCR. The power cables run from the bus/MCC into the CVT (usually) and then into the other areas and to the component in question. Power cables for charging pumps A and C and CC pump B run only a short distance in the CVT before entering the auxiliary building. Similarly, charging pump cooling and service water pump cables run only a short distance in the CVT from the ESGR. For purposes of this analysis, power cables for charging pumps A and C and CC pump B run directly into the auxiliary building. Similarly Charging Pump Cooling (CPC) and Charging Pump Service Water (CPSW) pump cables do not enter the CVT.

Any cables associated with a valve modeled in this study and found in the ESGR will be control, rather than power cables (because they will be coming down from the CVT MCCs). Most pump cables will be control, too, as the power cables usually just have a short spur from the respective bus before entering other areas (CVT, auxiliary building).

3.2 Cable Vault and Tunnel (CVT)

The CVT is located in the auxiliary building, between the containment, the safeguards building, and the ESGR. Its floor elevation is 13'0" and consists of three areas: narrow and long cable vault on the service building (i.e., ESGR) side, a long (40 ft) and narrow tunnel, and the high-ceiling containment penetrations vault.

Fire protection consists of smoke and heat detectors and an automatic CO₂ system, as well as open head and closed head sprinkler systems. Portable fire extinguishers are provided, too.

The door between the tunnel and the containment penetrations vault automatically closes upon actuation of the Cardox system; all other fire doors are kept closed.

The CT vault area contains four MCCs that power and control all valves of interest. The MCCs are arranged in groups of two, so MCC 1H1-2 consists of MCC 1H1-2-N and MCC 1H1-2-S, and likewise for the J side. Tables 3.13 and 3.14 present important loads on the MCCs. There is no physical barrier between the H and the J side, and in some areas there is not much separation between trains of some systems (e.g., the tunnel area, some containment and safeguards penetrations). The tunnel is the most vulnerable area here.

3.3 Containment (CT)

For our analysis, the important area is elevation 18'4". Near the RHR flats, the important elevation is -13'0". The containment is a large open area. Portable extinguishers are provided as well as fire detection. (At shutdown, there is also a lot of activity inside.) At power, the standpipe provided is dry; at shutdown it is pressurized. A lot of trash is generated inside and the welding frequency is high at shutdown. Any spilled oil would not be able to collect on the grated walkways.

For the cables of interest, there is no fire-initiating equipment nearby, except for the RHR pumps at the end of the run for the pump motor cables. The cables of interest are the RHR pump cables, as no other important system's cables are routed through this part of the containment (power cable for RHR MOV-1700 is within 1 ft of the pump cables, but this is not important as the valve is in the correct position). Significantly, the cables for the two RHR pumps are located in the same tray inside the containment. A fire at pump B (or anywhere along the way) would affect both cables. The RHR pumps contain about 6 gal of oil each.

3.4 Normal Switchgear Room (NSGR) (Unit 1)

This room is located above the ESGR. The Unit 1 and Unit 2 NSGRs are separated by a wall. The fire protection features include smoke and heat detectors, an automatic CO₂ system, and portable extinguishers.

This room contains many switchgear panels. The transfer buses D, E, and F, feeding both units' emergency buses, are located here, as are the normal buses 1A, 1B, and 1C, which can be used to power the emergency buses of both units via backfeed, if reserve station power or transfer buses are not available. (Normal buses 2A, 2B and 2C in Unit 2 NSGR can be used likewise; see Fig. 3.7 depicting the plant 4 kV distribution system.)

3.5 Fire Areas Not Analyzed

Safeguards building: This area contains low pressure injection (LPI) and Auxiliary Feed Water (AFW) equipment (cables were traced inside which showed both B trains in the same tray). However, a fire in this area would not disable the RHR and cause an initiator (unless it were to propagate through the penetrations, which is not an important scenario). Many other areas were screened for the same reason (e.g., Emergency Diesel Generator (EDG) rooms).

Charging pump service water pump room (CPSWPR) (also known as mechanical equipment room #4 or MER4) and mechanical equipment room #3(MER3): These rooms contain charging pump service water pumps, a necessary support system for the charging pumps. A fire cannot knock out both pumps as they are in separate rooms; if it did, a loss of charging would lead to a delayed recoverable loss of RHR (assuming the operator didn't isolate the letdown). This is a mild initiator (from internal PRA results) and loss of charging in this manner is not considered significant. Any intervening rooms (such as U2 ESGR) between the U1 ESGR and the CPSWPR or the MER3 through which the CPSW cables would pass were not considered for the same reason.

Turbine building (TB): This area contains the station service (SS) and the reserve station service (RSS) power cables that feed the plant electrical system and run between the transformers outside the TB and the NSGR. This was screened probabilistically, based on redundancy in the SS and RSS system, the fact that the trays are high above the floor (at least 21 ft), and there are no apparent fire sources in their vicinity.

Auxiliary building: This area contains charging system pumps and valves, component cooling pumps (also CC109A and B valves) and charging pump cooling pumps. The CPC system is not needed for water temperatures in question. The other systems' cables were traced inside the auxiliary building. The CCW system has four pumps, however, only two pumps' cables are coming from Unit 1. (These are collocated in the same tray for about 40 ft; charging pump C power cable is in the same tray, also.) The scenarios were screened out due to probabilistic arguments based on the short run of the tray in question, lack of fire sources, redundancy, in systems and equipment locations.

Figure 3.1 Unit 1 Emergency Switchgear Room Fire Doors

VIRGINIA ELECTRIC AND POWER COMPANY
SURRY POWER STATION
UNITS 1 & 2

FIRE DOORS
UNIT 1 ESGR
FIRE AREA 3

FIGURE NO
1-1

Figure 3.2 Unit 1 Cable Vault and Tunnel Fire Doors

Figure 3.3 Emergency Switchgear Room Equipment Layout and Cable Tray Locations

UNIT 1 ENERGY RELAY ROOM

15. FLOOD RISK

3 IN COATING ON
CONCRETE LEADS TO
DURABLE

3 MR COATING ON
COUNTS 1000-1
15181314 & 100001

3 IN COATING ON
CERAMIC
1578151

FILE DOWN
(1-VS-500-21)
807 EL 22-6

(24) 601 EL 12-15

6

WILLIAMS

— 1 —

1-55-40-9

3-6

Important Fire Areas Analyzed

Figure 3.5a Containment Layout at RHR Flats
Showing Critical Tray Locations

Figure 3.7 Surry Station 4 kV Electrical Distribution System

Table 3.1 Surry Power Station - Units 1 and 2

Identification of Fire Areas

Fire Area	Description
1 CVT-1	Unit 1 Cable Vaults and Tunnels
2 CVT-2	Unit 2 Cable Vaults and Tunnels
3 ESGR-1	Unit 1 Emergency Switchgear and Relay Rooms
4 ESGR-2	Unit 2 Emergency Switchgear and Relay Rooms
5 CR	Main Control Room
6 EDG-1	Emergency Diesel Generator Room 1
7 EDG-2	Emergency Diesel Generator Room 2
8 EDG-3	Emergency Diesel Generator Room 3
15 RC-1	Unit 1 Containment
16 RC-2	Unit 2 Containment
17 AB	Auxiliary, Fuel, and Decontamination Buildings, and Boron Recovery Room
18A FOPH-1	Fuel Oil Pump House Room 1
18B FOPH-2	Fuel Oil Pump House Room 2
19 SG-1	Unit 1 Safeguards Area
20 SG-2	Unit 2 Safeguards Area
28 INS	Intake Structure
31 TB	Turbine Building, including Machine Shop Building, Condensate Polishing Building, Office Building, and Service Building (including Cable Spreading Rooms, Normal Switchgear Rooms, MER 1 & 2 Personnel Facility Area, HP Area, Auxiliary Boiler)
45 MER-3	Mechanical Equipment Room #3
54 CPSWPR	Charging Pump Service Water Pump Room

Table 3.2 Combustible Loading Summary⁺

Description	Sq. Ft.	BTU	BTU/Sq. Ft.
01	1275	879,880,563	
Unit 1 Penetration Cable Vault	830	590,596,300	
Unit 1 Service Bldg. Cable Vault	1188	836,000	
Unit 1 MCC Rod Drive Room	3293	1,471,312,863	
Total			446,800
03		640,140,550	
A Unit 1 Emergency Switchgear Room	2670	655,024,400	
B Unit 1 Relay Room	1050	1,329,876,795	
Total	3720		333,302
05		236,144,000	
Control Room Complex	4800	236,144,000	
Total	4800		49,197
15		1,596,258,200	
Unit 1 Reactor Containment	11200	1,596,258,200	142,523
Total	11200		
31		197,649,375	
Unit 1 Normal Switchgear Room	3840		51,300

+ Appendix R for Surry gives a breakdown of combustibles in each fire area. Cable insulation contributes almost all of the combustible loading in the areas of interest except in the control room where there is a 50% contribution from class A combustibles and the containment with a 20% contribution from lube oil and grease.

* Only rooms of interest in a given fire area are shown, e.g. turbine building (fire area 31) has many different rooms.

Table 3.3A Surry Power Station - Unit 1

Existing Fire Protection Features by Important Fire Area

Fire Area	Detection	Suppression	Minimum Rating Fire Area Boundaries (hrs)	Fire Severity ¹
1 (CVT-1)	Smoke and Heat Detection	Total Flood CO ₂ , manual sprinkler system with closed head portion and open head portion	3	High
2 (ESGR-1)	Smoke Detection	Total Flooding Halon 1301 System	3	High
5 (CR)	Smoke Detection	None	3	Moderate
Unit 1 Normal SWG Room	Heat and Smoke Detection	Total flood CO ₂		

- 1 Low: 0-30 min equivalent fire severity (EFS)
 Moderate: 30-90 min EFS
 High: greater than 90 minutes EFS

Important Fire Areas Analyzed

Table 3.3B Miscellaneous Passive Fire Protection Items - Appendix R

A. Containment

1. Radiant Energy Shield
 - a. Units 1 and 2, between RHR pump motors, elev. (-) 13 ft - 0 in.
2. Solid Metal Cable Tray Cover
 - a. Units 1 and 2, on bottom of lowest horizontal cable tray in cable penetration area, and on top of all cable trays in cable penetration area; elev. 18 ft - 4 in between columns 6-9 (Unit 1), and 9-12 (Unit 2).
3. Cable Tray Firestops - various locations shown on plant drawings.

B. Auxiliary Building

1. Cable Tray Firestops
 - a. On elevation 13 ft 0 in, in cable tray C2-102 at the locations shown on drawing.

C. Emergency Switchgear Rooms

1. Fire Stops
 - a. Units 1 and 2 at various locations shown on plant drawings.

Table 3.4 Room Volume and Ventilation Rate for Select Rooms at Surry

Summary of HVAC Information

Room Description	Room Volume (Ft ³)	Ventilation Rate (CFM)	Air Changes Per Hour
Unit 1 Cable Vault & Tunnel	45,085	5,000*	6.7*
Unit 1 Normal Switchgear Room	73,260	30,000	24.6
Unit 1 Emer. Swgr. & Relay Rooms	64,953	9,400*	8.7*
Control Room Complex			
Unit 1 Control Cabinet	3,510	7,000	120
Control Room Annex	15,551	2,000	7.7
Unit 1 Computer Room	4,200	3,000	42.9
Unit 1 A.C. Room	2,925	10,000	205

*Has been upgraded to a higher level (with corresponding changes in fire detector locations) since this analysis was performed.

Important Fire Areas Analyzed

Table 3.5 Important Loads

4160 VAC Emergency Bus 1H, 11 Cabinets

Location: Emergency Switchgear Room

Source: Transfer Bus F, Breaker 15F3

Breaker	Load
15H3	Emergency Generator No. 1
15H4	St. General Auxiliary Fd. PP 3A
15H5	Charging PP 1-CH-P-1A
15H6	Charging PP 1-CH-P-1C
15H7	4160V/480V Emergency XFMR 1H and XFMR 1H-1
ISM8	Normal Feed from Transfer Bus F
4160V 1H Stub Bus	
15H9	4160V Bus 1H, Stub Bus Tie
15H10	Component Cooling PP 1-CC-O-1A
15H11	Residual Heat Removal PP 1-RH-P-1A

Important Fire Areas Analyzed

Table 3.6 Important Loads

480 VAC Emergency Bus 1H, 10 Cabinets

Location: Emergency Switchgear Room

Source: 4180 VAC Emergency Bus 1H, Breaker 15H7

Breaker	Load
14H3	Low Head Safety Inj. PP 1-S1-P-1A

Important Fire Areas Analyzed

Table 3.7 Important Loads

480 VAC Emergency Bus 1H1, 7 Cabinets

Location: Emergency Switchgear Room

Source: 4160 VAC Emergency Bus 1H, Breaker 15H7

Breaker	Load
14H13	MCC 1H1-2 Supply
14H14	MCC 1H1-1 Supply

Table 3.8 Important Loads**4160 VAC Emergency Bus 1J, 11 Cabinets**

Location: Emergency Switchgear Room

Source: Transfer Bus D, Breaker 1503

4160V Emer. Bus 1J	
Breaker	Load
15J2	Charging PP 1-CH-P-10
15J3	Emergency Generator No. 3
15J4	St. Gen. Aux. Fd. PP 3B
15J5	Charging PP 1-CH-P-1B
15J7	4160V/480V Emergency XFMR 1J and XFMR 1J-1
15J8	Normal Feed from Transfer Bus D
4160V 1J Stub Bus	
15J9	4160V Bus 1J, Stub Bus, Tie
15J10	Component Cooling PP 1-CC-P-1B
15J11	Residual Heat Removal PP 1-RH-P-1B

Important Fire Areas Analyzed

Table 3.9 Important Loads

480 VAC Emergency Bus 1J, 10 cabinets

Location: Emergency Switchgear Room

Source: 4160 VAC Emergency Bus 1J, Breaker 15J7

Breaker	Load
14J3	Low Head Safety Inj. PP 1-S1-P-1B

Table 3.10 Important Loads

480 VAC Emergency Bus 1J1, 7 Cabinets

Location: Emergency Switchgear Room

Source: 4160 VAC Emergency Bus 1J, Breaker 15J7

Breaker	Load
14J12	1J1-1A Supply EDG3
14J14	MXX 1J1-2 Supply
14J16	MCC 1J1-1 Supply

Important Fire Areas Analyzed

Table 3.11 Important Loads

MCC 1H1-1, 40 Cabinets

Location: Emergency Switchgear Room

Source: 480 VAC Emergency Bus 1H1, Breaker 14H14

Breaker	Load
1H1-1-11	MCC 1H1-1A Emerg. Gen Room #1 Feeder
1H1-1-13	1-SW-P-10A Chg Pump Service Water Pump
1H1-1-23	MOV-1867C Cold Leg Safety Injection
1H1-1-31	MOV-SW-102A CC Ht Exchange Inlet
1H1-1-33	MOV-1869A Chg Pump SI Stop Valve
1H1-1-43	●UPS-1A-1 Feeder
1H1-1-52B	●UPS-1A-2 Feeder Bypass
1H1-1-53	1-CC-P-2A Chg Pump Cool Water Pump

Important Fire Areas Analyzed

Table 3.12 Important Loads

MCC 1J1-1, 42 Cabinets

Location: Emergency Switchgear Room

Source: 480 VAC Emergency Bus 1J1, Breaker 14J16

Breaker	Load
1J1-124	MOV-SW-102B CC Ht Exch Inlet
1J1-142	1-SW-P-10B Chg Pump Serv Water Pump
1J1-143	1-EE-P-1C Emerg. Gen. Fuel Oil Pump
1J1-144	1-CC-P-2B Chg Pump Cooling Water Pump
1J1-153	UPS 1B-1 Feeder
1J1-174B	UPS 1B-2 Fdr. Bypass
1J1-183	MOV-1867D Cold Leg Safety Injection
1J1-191	MOV-1869B Chg Pump Safety Injection Stop

Table 3.13 Important Loads MCC 1H1-2

Location: Cable Vault

Source: 480 VAC Emergency Bus 1H1, Breaker 14H13

Breaker	Load
1H1-2-North, 44 cabinets	
1H1-211	MOV-FW-260A FW Cross Tie
1H1-212	MOV-1860A Lo Hd Safety Injection Suction
1H1-213	MOV-LCV-1115B Chg Pump Suction RWST
1H1-223	MOV-LCV-1115C Chg Pump Suction VCT
1H1-232	MOV-1862A LHSI Pump Suction RWST
1H1-242	MOV-1842 Alt High Hd Cold Leg
1H1-281	MOV-1890A Lo Hd SI to A Loop Hot Leg
1H1-291	MOV-1890C Lo Hd SI to Cold Leg
1H1-2101	MOV-1864A Lo Hd SI Pump Disch
1H1-2 South, 43 Cabinets	
1H1-212	MOV-FW-151A Aux FW Header
1H1-213	MOV-1720A RHR Outlet Isol
1H1-223	MOV-FW-151E Aux FW Header
1H1-224 (2D)	• UPS-1A-2 Feeder
1H1-233	MOV-FW-151C Aux FW Header
1H1-241	MOV-1270A Chg Pump Suction
1H1-251	MOV-1286A Chg Pump Disch
1H1-262	MOV-1286C Chg Pump Disch
1H1-282	MOV-1267B Chg Pump Suction
1H1-283	MOV-1700 RHR Inlet Isol
1H1-2103	• UPS-1A-1 Feeder Bypass

Important Fire Areas Analyzed

Table 3.14 Important Loads MCC 1J1-2

Location: Cable Vault

Source: 480 VAC Emergency Bus 1J1, Breaker 14J14

Breaker	Load
1J1-2 West, 37 cabinets	
1J1-212	MOV-FW-151D Aux Fd Water Header
1J1-213	MOV-1269A Chg Pump Suction
1J1-222	MOV-FW-151B Aux Fd Water Header
1J1-223	MOV-1269B Chg Pump Suction
1J1-232	MOV-FW-151F Aux Fd Water Header
1J1-233	MOV-1270B Chg Pump Suction
1J1-243	MOV-1286B Chg Pump Discharge
1J1-244A (4D-1)	UPS 1B-1 FDR. Bypass
1J1-252	MOV-1287B Chg Pump Discharge
1J1-271	MOV-1287C Chg Pump Disch
1J1-2101 (10A)	UPS 1B-2 Feeder
MCC 1J1-2 East, 40 cabinets	
1J1-2122	MOV-1862B LHSI Pump Suction RWST
1J1-2141	MOV-FW-260B Aux Fd Water Cross Tie
1J1-2151	MOV-LCV 1115D RWST Chg Pump Suction
1J1-2152	MOV-1860B LHSI Suction
1J1-2162	MOV-1864B LHSI Disch
1J1-2182	MOV-1890B LHSI B Loop Hot Leg
1J1-2101	MOV-1720B RHR Outlet Isol
1J1-2102	MOV-1701 RHR Inlet Isol

4. FIRE FREQUENCY CALCULATIONS

4.1 Methodology

Sandia Fire Data Base¹ was used to compile a list of possible fire events in the categories of interest and plant areas of interest. Certain criteria were applied as to the admissibility of events. Generic fire frequency distribution in various categories was obtained by applying a Bayesian updating scheme. The generic results were then updated with Surry-specific data to arrive at the Surry-specific frequency distributions. The mean of a distribution is used as a point estimate of fire frequency in that category. Fire frequencies were computed in three general areas: cable fires (both self-ignited and externally ignited), transient fueled fires (specialized to important plant fire areas), and equipment fires. The latter ones were subdivided into fire size categories (small, medium, large) and specialized to a particular type of equipment (e.g., MCC panel, RHR pump, etc.).

4.2 Sandia Fire Data Base

Pertinent fire events in various categories were compiled from the Sandia data base¹, both for Surry and for the nuclear industry as a whole.

While Phase 1A fire analysis used the older version of this data base (covering events reported through June 1985), this study had access to the just released latest version (including events through December 1989). The data base has a summary and a narrative part. The summary shows the plant and date of the event, the operating mode of the plant, the fire source and affected equipment, dollar loss and impact on plant operations, and time and method of suppression. The narrative goes into more detail on the circumstances of the fire but is usually only a few sentences long. Both parts have to be used in order to classify the fire for the purposes of this study. The events can be also grouped by plant and this feature was used to compile Surry-specific events. In some fraction of cases, certain important information is missing from the data fields or the narrative and assumptions have to be made.

4.3 Criteria for Inclusion/Exclusion of Events

Certain criteria were applied. Events that can happen only during power operation (e.g., Reactor Coolant Pumps (RCP) electrical fires, or oil coming in contact with hot piping) were thrown out.

By the same token, certain events can only happen at shutdown, and not in power operation. This is sometimes a gray area, and a judgement call occasionally had to be made. Such events were noted and a separate time period for frequency calculations was used for them.

Construction events were also excluded. The time period for inclusion of events was from initial criticality of the plant to its decommissioning or December 1989, whichever was sooner.

Data from dissimilar components of the same class was not used. For instance, fires in RCPs or Main Feedwater (MFW) pumps were not judged relevant for estimating the frequency of fires in RHR pumps. (CCW pumps were judged to be similar, however.)

Also disregarded were events in irrelevant fire areas, components or fuels (e.g., transformer yard fires, turbine generator fires, hydrogen fires). Diesel generator fires are irrelevant because such an event would not cause an initiator (meaning loss of RHR), unless the plant was already running on the EDG due to a prior loss of offsite power.

Fire Frequency Calculations

In the latter case, any diesel generator fires would be folded into the category "failure of the EDG to run for duration of mission time" which would be included in the analysis of loss of offsite power in the internal PRA.

Relevant events from all types of nuclear power plants were counted.

Fires that were too small or weak to cause damage were disregarded, e.g., smoldering fires, self-extinguishing fires, events where smoke but no flame was observed (or a burning smell but no open flame), or events where deenergizing equipment extinguished the fire. For surviving fires, classification into small, large and medium fires was performed depending on several factors: dollar amount of loss, if the unit had to be shut down, the extent of the damage, time to suppression and what type of extinguishing equipment was used. For example, if the fire was successfully suppressed in a short time by portable extinguishers only, it was judged to be a small fire. If the whole MCC panel or a transformer was destroyed, it was judged to be a "large fire".

4.4 Exposure Time at Power and Shutdown

In order to calculate frequency of fires, the exposure time of U.S. nuclear power plants and Surry has to be known. This time is calculated, for a particular plant, as the difference between the date of decommissioning or December 1989 (whichever was sooner) and the date of initial criticality of the plant. The table in Appendix A was used for that purpose. It shows the pertinent dates for each plant along with its exposure time. Most of the data comes from the data base (or was calculated). Some missing dates were taken from the latest world list of nuclear power plants in Nuclear News².

The resulting exposure time for all U.S. plants and for Surry are shown in Tables 4.1 and 4.2, respectively. The category "shutdown time only" is also shown. This is computed for all U.S. plants by assuming an average down time of 35%. For Surry, data was taken from the Phase 1A report³ on the frequency and duration of various types of shutdown configurations to calculate an average downtime fraction.

4.5 Pertinent Events from Data Base

Tables 4.3 and 4.4 list a summary of pertinent events in various categories for generic data and Surry-specific data.

4.6 Bayesian Updating Scheme

For calculating the fire frequency distribution, a Bayesian updating program was employed with a noninformative prior ($1/\lambda$) and the Poisson likelihood function. The number of events and number of plant years for each category was input. The resulting frequency distribution is shown in Table 4.5, along with the parameters of the lognormal distribution that would fit it and the number of observed events at Surry in that category. The lognormal distribution was input as a prior, along with Surry evidence and plant years in that category in a second Bayesian updating scheme. The resulting Surry-specific fire frequency distribution is shown in Table 4.6 and the point estimates used in Table 4.7. The frequencies for (operation + shutdown) and for (shutdown only) events are simply added to arrive at a frequency per shutdown year. Frequencies for cable self-ignited and externally ignited fires (which are approximately equal) are added together.

4.7 Component Based Fire Frequency

The fire frequency mean value from Table 4.6 was converted to component based frequencies by dividing by the number of components of that type (e.g., MCC panels, pumps etc.). It is assumed that all plants have the same number of components of the pertinent type per plant. The number of components and the corresponding component based fire frequency are shown in Table 4.8. The corresponding numbers for the cable and transient fires are shown in Tables 4.9 and 4.10. Note that in the equipment category, an event that never happened at a nuclear power plant was added: large switchgear equipment fire. This is postulated to be a large and smoky fire that disables not only the initiating component but also all the other switchgear in the room (medium voltage switchgear equipment is susceptible to arcing damage in a smoky environment). According to the Sandia cabinet fire test results⁴, most cabinet fires evolve large amounts of smoke.

The cable fire frequency is adjusted for the difference between Surry and an average plant in the number of cable tray feet. The average number of tray-feet per plant⁵, 85,000 tray-feet, was obtained from a sample of 32 plants started up since May, 1974. The Surry units have an average of about 25,000 cable tray feet, as shown in the breakdown in Table 4.11 (compiled from Appendix R data⁶). The Bayesian updating evidence for Surry was adjusted for the lower exposure in terms of tray-feet-years. The modified numbers are shown in Table 4.9 as well as the frequency per tray-foot-year. Note that the above analysis is somewhat nonconservative, as it assumes equal likelihood of fires in control cables vs. power cables; this may be true for externally ignited fires but not for the self-ignited ones. However, this nonconservatism will be offset by applying the total mix of control and power cable tray-footage to the tray-foot frequency number to arrive at the frequency of the scenario.

The transient fire frequency in Table 4.10 is calculated per square foot of the appropriate plant area. The CVT, ESGR and NSGR fall into the "switchgear room" type of areas and these were lumped together to arrive at this frequency for Surry.

We can distinguish between A and B types of combustibles. A is the regular trash type, whereas B is the liquid fuel (e.g., oil). It can be assumed that an A type fire will not lead to damage to nearby components. The frequency of B fires is then:

$$\lambda_{tr, area}^B = \lambda_{tr, area} * \phi$$

where ϕ is the fraction of transient fires involving B type fuels. The calculation of ϕ is shown in Appendix C (taken from Ref. 5) and the results for the plant fire areas of interest are given in Table 4.12. The ratio of large oil fires to small oil fires will be 30:70, i.e., the same as in the 1150 analysis^{7,8}; the same characteristics of the fuel source will be assumed. (See Chapter 6.) The frequency of fire for a particular scenario will be calculated by multiplying the values in Table 4.12 by the area of influence of the fire along the cable run.

The calculated frequencies in this chapter are per shutdown year, and in the scenario calculations are to be multiplied by the average fraction of time the plant spends in the mid-loop POS of interest (i.e., by 0.017 for R6, 0.015 for R10, and 0.035 for D6).

4.8 Insights

No prevalence of fires at shutdown in the data base was noticed, as compared to power operation fires (after the construction events are taken out). It is true that greater potential exists for fires in certain categories (e.g., transient or welding igniting cables or other equipment fires). It is also true that possibility of some types of fires is reduced (e.g. deenergized equipment, oil dripping on hot piping). A fire at shutdown is liable to be detected much sooner and extinguished in its early phases, because of increased floor traffic. (Credit is taken for this by disallowing events that were discovered in the smoking stage (without flames) or early enough such that deenergizing equipment extinguished the fire.) Increased vigilance by licensees may play a part in this also. At Surry, a fire watch is in place at welding operations; fire doors are kept closed.

One can compare the generated fire frequencies with several other sources, namely the 1150 full power fire analysis⁷, the Phase 1A study³ or the recently released EPRI FIVE report⁹. The first two studies give fire frequency per plant fire area, whereas the last reference also shows equipment based fire frequencies. The ESGR fire frequency in this Phase 2 study (when all the contributions from equipment, transients, and cables are added up) is about the same as that reported in the 1150; however, the CVT frequency is about 4 times lower. This may be due to disallowing construction events and instances where the initial fire intensity was too small. (One can argue there is less justification for the latter at power, as the fire may go undiscovered longer). The Phase 1A study containment fire frequency is about twice the one derived from data developed here; again, this may be due to the same reasons as above (the Phase 1A study was a scoping study and thus more conservative). The FIVE report equipment fire frequencies are also higher than the ones here; they seem to have counted all the events, even the ones where the fire severity was too small or no actual fire resulted (the methodology presented therein is supposed to be used for screening purposes).

4.9 References

1. Sandia Fire Data Base, updated version of "Nuclear Power Plant Fire Data Base, Based on NUREG/CR-4586, SAND86-0300 and EPRI NP-3179". The latest version contains events through December 1989.
2. "World List of Nuclear Power Plants", Nuclear News, August 1992.
3. T-L. Chu, et al., "PWR Low Power And Shutdown Accident Frequencies Program, Phase 1A - Coarse Screening Analysis", November 1991.
4. J.M. Chavez, S.P. Nowlen, "An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets, Part II: Room Effects Tests", NUREG/CR-4527 Vol. 2, Sandia National Laboratories, November 1988.
5. Memorandum from N. Siu to T-L. Chu and Z. Musicki, titled "Cable and Transient Fire Frequencies", dated July 31, 1992.
6. Virginia Power Company, "10CFR50 Appendix R Report, Surry Power Station - Units 1 and 2".
7. M.P. Bohn, J.A. Lambright, "Procedures for the External Event Core Damage Frequency Analyses for NUREG-1150", SAND88-3102, November 1990.
8. M.P. Bohn, et al., "Analysis of Core Damage Frequency: Surry Power Station, Unit 1 External Events", NUREG/CR-4550, Vol. 3, Rev. 1, Part 3.
9. Professional Loss Control, Inc., "Fire Induced Vulnerability Evaluation Methodology (FIVE) Plant Screening Guide", December 1991.

Fire Frequency Calculations

Table 4.1 Exposure Time, All U.S. Plants to 12/89

Mode of Operation	Exposure Time (y)
Power + Shutdown	1396
Shutdown Only	490

Table 4.2 Exposure Time, Surry Units

Unit	Exposure Time (y)
Surry 1	17.4
Surry 2	16.8
Surry Total	34.2
Surry Shutdown	13.7

**Table 4.3 Important Fire Events Initiated in Pertinent Equipment
from Sandia Fire Data Base Type of Equipment**

MCC

Small Fires			Medium Fires			Large Fires		
INO	Plant	Years	INO	Plant	Years	INO	Plant	Years
121	Trojan	14.0				14	Oyster Creek	20.6
138	Millstone 2	14.2						
185	Unknown BWR	12.6						
254	Unknown PWR	11.1						
268	Trojan	14.0						
404	Quad Cities 2	17.7						
415	Fermi 2	4.5						
Bus								
186	Unknown	11.5	437	Oconee 1	16.7	344	Unknown	11.5
235	Unknown PWR	11.1						
246	Unknown BWR	12.6						
256*	Unknown PWR	11.1						
324	Humboldt Bay	13.4						
342	Yankee Rowe	29.3						
385	Yankee Rowe	29.3						
401	Kewaunee	15.8						
429	Palo Verde 1	4.6						
Small			Transformer Medium			Large		

**Table 4.3 Important Fire Events Initiated in Pertinent Equipment
from Sandia Fire Data Base (continued)**

59	Turkey Point 3	17.2	396	Cook 1	14.9	56	Vermont Yankee	17.8
193	Fort St. Vrain	15.6						
444	LaSalle 2	5.8						
Pump								
269	Palisades	13.6						
358	Palisades	18.6						
392 ^s	Peach Bottom 3	15.3						
UPS								
157 ^s	Oyster Creek	20.6						
Relay								
159	Duane Arnold	15.8	156	Peach Bottom 3	15.3			
166	Peach Bottom 2	16.2						
169	Peach Bottom 3	15.3						
368	TMI-1	15.5						
388 ^s	Brunswick 1	13.2						
419 ^s	TMI-1	15.5						

^s The fire event can only occur at shutdown

Fire Frequency Calculations

Table 4.3A Important Cable and Transient Fire Events, Sandia Fire Data Base Cable Fires

Self-Ignited:		
INO	Plant (Area)	Years
7	San Onofre 1	22.5
8	San Onofre 1	22.5
51	Quad Cities 2	17.7
240	Browns Ferry 1	16.3
Externally Ignited:		
100	Browns Ferry 1 (CSR)	16.3
264	Unknown PWR	11.1
326	Oconee 3	15.2
	Transient Fires	
INO	Plant (Area)	Years
57 ^s	Point Beach 1 (TB)	19.1
80	Robinson 2 (CT)	19.2
87	Unknown PWR (TB)	11.1
105	Unknown PWR (?)	11.1
128	Browns Ferry 1 (CT)	16.3
137	Fort Calhoun (CT)	16.3
158	Brunswick 1 (TB)	13.2
270	Pilgrim (RB)	17.5
275 ^s	Ginna (RB)	20.1
288	Browns Ferry 1 (?)	16.3
309	San Onofre 1 (SWGR)	22.5
431 ^s	Wolf Creek (CB)	4.6
438 ^s	Dresden 3 (CT)	18.9

s = This fire event could only occur while the plant is shutdown.

Table 4.4 Pertinent Surry Fire Events

INO	Equipment/Type of Fire	Surry Unit (Fire Area)
73 ^s	RHR Pump (Small)	1 (CT)
238 ^s	Transient	2 (CT)

s = This fire event can only occur in shutdown

Fire Frequency Calculations

Table 4.5 Parameters of Generic Fire Frequency Distribution (/yr) and Its Lognormal Fit from the Bayesian Updating and for Various Fire Categories and Evidence for Surry Events in that Category

Type of Fire	5%	50%	Mean	95%	μ	σ	e
MCC Small	2.35-3	4.8-3	5.0-3	8.62-3	-5.4	0.395	0
MCC Large	3.83-5	5.12-4	7.17-4	2.27-3	-8.13	1.24	0
Bus Small	2.83-3	5.5-3	5.7-3	9.6-3	-5.26	0.371	0
Bus Large	2.6-4	1.2-3	1.4-3	3.7-3	-6.93	0.807	0
Bus Small, Shutdown Only	1.08-4	1.5-3	2.0-3	6.5-3	-7.08	1.24	0
Transformer, Small	5.98-4	1.9-3	2.15-3	4.59-3	-6.40	0.619	0
Transformer, Large	2.6-4	1.2-3	1.4-3	3.7-3	-6.93	0.807	0
Pump, Small	2.6-4	1.2-3	1.4-3	3.7-3	-6.93	0.807	0
Pump, Small Shutdown Only	1.1-4	1.5-3	2.0-3	6.5-3	-7.08	1.24	1
UPS Shutdown Only	1.1-4	1.5-3	2.0-3	6.5-3	-7.08	1.24	0
Relay, Small	9.8-4	2.6-3	2.9-3	5.7-3	-6.05	0.535	0
Relay, Medium	2.6-4	1.2-3	1.4-3	3.7-3	-6.93	0.807	0
Relay, Small Shutdown Only	7.3-4	3.5-3	4.1-3	1.0-2	-5.91	0.796	0
Cable, Self-Ignited	9.8-4	2.6-3	2.9-3	5.7-3	-6.05	0.535	0
Cable Externally Ignited	6.0-4	1.9-3	2.2-3	4.6-3	-6.40	0.619	0
Transient	3.3-3	6.2-3	6.4-3	1.0-2	-5.16	0.337	0
Transient, Shutdown Only	2.7-3	7.4-3	7.8-3	1.5-2	-5.06	0.521	1

Fire Frequency Calculations

Table 4.5A Parameters of Generic Fire Frequency Distribution (/yr) and Its Lognormal Fit from the Bayesian Updating and for Transients in Various Fire Areas+ and Evidence for Surry Events in that Category

Type of Fire	Fire Area	Number of Events	5%	50%	Mean	95%	μ	σ	e
Transient	CT/RB	5	1.4-3	3.4-3	3.6-3	6.7-3	-5.79	0.472	0
	TB	2	2.6-4	1.2-3	1.4-3	3.7-3	-6.93	0.807	0
	SWGR	2	2.6-4	1.2-3	1.4-3	3.7-3	-6.93	0.807	0
Transient, Shutdown Only	CT/RB	2	7.3-4	3.5-3	4.1-3	1.0-2	-5.91	0.796	1
	TB	2	7.3-4	3.5-3	4.1-3	1.0-2	-5.91	0.796	0
	SWGR	1	1.1-4	1.5-3	2.0-3	6.5-3	-7.08	1.24	0

+ CT/RB: containment/reactor building

TB: turbine building

SWGR: aggregate of switchgear rooms.

Fire Frequency Calculations

**Table 4.6 Parameters of Surry-Specific Fire Frequency Distribution (/yr)
from Bayesian Updating for Various Categories+**

Type of Fire (fire area)	5%	50%	Mean	95%
MCC Small	1.85-3	5.34-3	6.56-3	1.54-2
MCC Large	4.0-5	2.9-4	6.2-4	2.2-3
Bus Small	1.5-4	1.4-3	3.4-3	1.2-2
Bus Large	8.8-5	6.2-4	1.3-3	4.4-3
Bus Small, Shutdown Only	1.1-4	8.2-4	1.8-3	6.3-3
Transformer Small	5.5-4	2.1-3	2.9-3	8.1-3
Transformer Large	2.9-4	1.4-3	2.2-3	6.6-3
Pump Small	2.4-5	2.9-4	9.4-4	3.6-3
Pump Small, Shutdown Only	1.9-3	6.1-3	7.9-3	2.0-2
UPS, Shutdown Only	1.13-4	8.3-4	1.7-3	6.1-3
Relay Small	1.1-3	3.1-3	9.3-3	3.9-3
Relay Medium	3.9-5	2.9-4	6.2-4	2.2-3
Relay Small, Shutdown Only	1.6-3	5.0-3	6.4-3	1.6-2
Large, Large Switchgear	4.9-7	2.9-6	5.2-6	1.7-5
Cable, Self-Ignited	1.8-4	1.4-3	2.9-3	1.0-2
Transients (CT/RB)	1.5-4	1.2-3	2.4-3	8.7-3
Transients (TB)	8.4-5	6.1-4	1.3-3	4.5-3
Transients (SWGR)	9.2-5	6.4-4	1.3-3	4.4-3
Transients, Shutdown Only (CT/RB)	2.6-3	9.8-3	1.4-2	3.7-2
Transients, Shutdown Only (TB)	1.1-4	8.3-4	1.7-3	6.2-3
Transients, Shutdown Only (SWGR)	1.9-4	1.6-3	3.8-3	1.4-2

+ NOTE: All fire frequencies are per plant year, not per panel year or cabinet year, similarly for pumps.

Fire Frequency Calculations

Table 4.7 Point Values for Plant-Wide Fire Frequency (/sdy)

Category	Frequency (/sdy)
MCC Small	6.6-3
MCC Large	6.2-4
Bus Small	5.2-3
Bus Large	1.3-3
Transformer Small	2.9-3
Transformer Large	2.2-3
Pump Small	8.8-3
UPS	1.7-3
Relay Small	1.0-2
Relay Medium	6.2-4
Large, Large Switchgear	5.2-6
Cable	2.9-3
Transient, CT	1.6-2
Transient, TB	3.0-3
Transient, SWGR+	5.2-3

+ Aggregate of rooms containing important switchgear equipment.

Fire Frequency Calculations

Table 4.8 Component Based Frequency Derivation Point Estimates, Fire Frequency (/sdy)

Equipment	Frequency/ Plant	# Pieces*	Frequency/ Unit Eq't)
MCC Small Fire	6.6-3	34	1.9-4
MCC Large Fire	6.2-4	34	1.8-5
Bus Small Fire	5.2-3	20	2.6-4
Bus Large Fire	1.3-3	20	6.5-5
Transformer Small Fire	2.9-3	19 ¹	1.5-4
Transformer Large Fire	2.2-3	19	1.2-4
Pump Small Fire	8.8-3	4 ⁺	2.2-3
UPS	1.7-3	4	4.2-4
Relay Small Fire	1.0-2	10 ²	1.0-3
Relay Medium Fire	6.2-4	10 ²	6.2-5

* Panels, not individual cabinets for switchgear equipment;
there are about 40 cabinets/MCC, 7 cabinets/bus panel

+ 2RHR + 2CCW/Unit

¹ one per 480 V bus, two per UPS

² estimate

Fire Frequency Calculations

Table 4.9 Cable Fire Frequency Derivation per Tray-Foot Frequency (/sdy/ft)

Cable, total fire frequency(/sdy)	Average number of cable-tray-feet/plant	Cable frequency (/sdy/tray-ft)
2.9-3	85,000	3.4-8

Fire Frequency Calculations

Table 4.10 Transient Fire Frequency Derivation per Square Foot

Fire Area	Area-wide frequency	Floor area (Ft ²)	Fire frequency (/sdy/ft ²)
CT	1.6-2	11,200	1.4-6
SWGR ⁺	5.2-3	11,123	4.7-7

+ ESGR and CVT will be in this category.

Table 4.11 Cable Tray Length in Fire Areas Unit 1

Fire Area	Name	Cable Tray- Feet
01A	Penetration Cable Vault	2649
01B	Service Building Cable Vault	1632
03A	Emergency Switchgear Room	1838
03B	Relay Room	1697
08C	Diesel Generator #3	45
15	Containment	5082
17B	Auxiliary Building, 13'2"	400
17C	Auxiliary Building, 27'6"	907
17D	Auxiliary Building, 45'10"	135
17E	Fuel Building, 6'10"	120
17F	Fuel Building, 47'4"	470
28A	Intake Structure	239
31A	Turbine Building, 9'6"	3339
31B	Turbine Building 27'0"	4790
31C	Turbine Building, 58'6"	204
31H	Unit 1 Normal Switchgear Room	1125
31J	Mechanical Equipment Room #1	234
31K	Mechanical Equipment Room #2	141
31L	Administrative Offices	82
31R	Condensate Polishing Building	596
31S	Unit 1 Cable Spreading Room	1761
45	Mechanical Equipment Room #3	93
Total	Unit 1	27,579

Fire Frequency Calculations

Table 4.11A Cable Tray Length in Fire Areas Unit 2

Fire Area	Name	Cable Tray- Feet
02A	Penetration Cable Vault	2448
02B	Service Building Cable Vault	2444
04A	Unit 2 Emergency Switchgear Room	2422
04B	Relay Room	1503
16	Containment	5120
31D	Turbine Building, 9'6"	2861
31E	Turbine Building, 27'0"	3172
31F	Turbine Building, 58'6"	75
31I	Unit 2 Normal Switchgear Room	550
31T	Cable Spreading Room	1976
Total	Unit 2	22,571

Total Unit 1 + Unit 2 = 50,150 Tray Feet

Average per Unit = 25,075 Tray Feet

Fire Frequency Calculations

Table 4.12 Class B Fire Frequency

Fire Area	λ_{tr} (/sdy/ft ²)	ϕ	λ (/sdy/ft ²)	^B -Large λ_{tr} (/sdy/ft ²)
CT	1.4-6	0.38	5.3-7	1.6-7
SWGR	4.7-7	0.29	1.4-7	4.2-8

5. SCENARIO DEVELOPMENT

In this chapter, the analysis of scenarios is presented, along with quantification. Cable routing information in relation to important equipment in significant fire areas will be presented, along with impact of fire at various locations within a fire area.

5.1 Assumptions and Simplifications

Some cables are routed in conduit; others are in covered trays; the rest are in uncovered trays. For purposes of COMPBRN-IIIE, the uncovered trays are relatively easy to model. The covered trays and conduit cannot be realistically modeled (by COMPBRN). As there is some question as to how effective these barriers are for preventing cable damage, we assumed that they (the barriers) do not exist. Therefore, the results generated will be somewhat conservative (in addition to some conservative aspects of COMPBRN modeling).

For information, most trays in the ESGR are uncovered. Most trays in the CVT are covered. In the tunnel part, which is a critical location, the trays are stacked 8 deep on each side. The bottom 6 trays on the H side and 5 trays on the J side are covered. These trays carry mostly control cables for the valves (going from the vault MCCs down into the ESGR). The upper 2 trays on the H side and 3 trays on the J side are uncovered. The upper two trays on either side carry power cables for the pumps. In the containment (CT), most trays are covered; however, the covering is mostly on the top (possibly to prevent water collection especially after a spray actuation).

The cable in conduit cannot be traced from the engineering drawings used for this purpose (It would be very difficult to trace conduits, as apparently greater latitude was allowed in their placement). An assumption is made in this case that places the conduit in the worst location (within reason—see below); there are not many cases like this. Conduit tends to be used in the containment for the final spur between the cable tray and the component in question. Of the important systems considered and in the significant areas considered, conduit is used for LPI A pump power cable in the ESGR and the CVT (and on in the safeguards area); charging pump service water pump 10A power and control cables in the ESGR; AFW A pump in the ESGR and the CVT (and on in the safeguards area); and charging pump A in the auxiliary building.

The conservative assumption would be to place the conduit next to another train, and this was done when it seemed reasonable based on known information. For instance, charging pump A conduit was placed next to charging pump C cable, for a certain distance, in the auxiliary building (which is not an important area). However, in some other cases, it was believed reasonable that an 'A' train conduit would be placed in the H part of a fire area, not the J part (if the two areas are distinctly separate, e.g., in the tunnel). This assumption will not necessarily have a large impact on the core damage frequency, based on the scenarios considered.

Modeling of switchgear panel fires by COMPBRN showed that no damage would result to the cables nearby as long as the flames did not penetrate the panel casing. However, according to the Sandia cabinet fire test results¹, in a small fraction of fires, the flames were observed to shoot 50 cm horizontally from the cabinet. (The tests also show that the fire doesn't propagate between double walled cabinets of the type used at Surry.) COMPBRN results show that cables immersed in flames will suffer damage. (This seems to be almost a necessary and sufficient condition for cable damage). The panels are 7.5 to 8.5 ft high. Based on COMPBRN results, all the cables in the ESGR within the 50 cm horizontal distance of any panel are within reach of a small fire placed near the top of the cabinet. Therefore, the assumption is that a large panel fire (one that penetrates the casing) will damage all cables within the 50 cm horizontal distance from the panel. If a critical cable tray is not close to the panel, it is usually very far away such that propagation of fire along cable trays (from the burning panel) would lead to very long damage times and small damage fractions, hence, this kind of propagation can be screened out. Another assumption is that such a fire will destroy the

Scenario Development

whole panel (i.e., all cabinets within the panel). A small fire will destroy only the cabinet of origination and the rest of the panel and the cables nearby will be intact. (As for the CVT panels, i.e., the MCCs in the penetrations vault, the cable trays for systems not directly associated with these panels are horizontally outside the zone of influence of even a large panel fire).

A conservative assumption was made in the tunnel area where all combinations of cable fires were rolled into the worst case. The worst case is when the fire is initiated in the lowest tray; this causes damage to all the trays on both sides of the tunnel. However, a fire in an upper tray will not likely damage the trays below, but in order to limit the number of scenarios it was assumed that all initiation locations were equivalent. It should be noted that this is a relatively good assumption, as the upper two trays on either side carry pump power cables, while the lower trays carry valve control cables. Loss of pumps is irrecoverable, whereas most valves can be manually operated.

One explanation will help the reader better understand certain scenarios in the ESGR and certain aspects of tracing cables there. The important systems cables are pretty much grouped together (horizontally) within certain passageways (see Figure 5.1). The important trays within these passageways are stacked vertically, but in such a way that they are, for all systems, within reach of a large fire on the floor (except for some stretches of cable for occasional systems). Of course, as explained above, they are also within reach (vertically) of large panel fires within the critical horizontal distance. Some important systems' cables (e.g., both RHR pumps power) are also within reach of even a small oil fire on the floor. Since most ESGR trays are in this elevation band, conclusions can be reached for systems with unknown cable routing.

Certain systems were not included in the analysis and/or cable tracing:

- 1) EDG cables were not traced because this information is irrelevant; the EDGs would be used only in case of loss of power. If the loss of power was caused by a large fire in the ESGR, such a fire would destroy the originating bus panel, therefore recovery via EDG would be impossible. A small fire (i.e., in the supply breaker that would cause a demand for the EDG) would not damage any nearby cables.
- 2) Circulating Water (CW) condenser inlet/outlet valve cables were not traced because this information would be important only for a (LOOP) initiator. Such an initiator can only be caused by a large fire in the NSGR. This event will not damage (CW MOV) cables, which pass through the ESGR, 40 ft below.
- 3) Service air cable routing was not considered because this system is powered from the NSGR 480 V buses 1C2 (in Unit 1 NSGR) and 2A2 (in Unit 2 NSGR). (The outage compressors are also powered from the NSGR and there is a diesel compressor.) The backup instrument compressors are powered from the MCCs in the CVT. A single fire would not disable all these locations. Disregarded due to probabilistic concerns, system impact of likely initiators and system configuration. The likely fire-induced initiators in the NSGR (LOOP, loss of a bus) will already include (irrecoverable) loss of part of the system in their impact; the fact that a cable may have been damaged is immaterial.
- 4) The ESGR cooling system was not considered due to redundancy in the system.
- 5) Process instrumentation cables were not traced; however, as per discussion of ESGR cable layout above, one has a pretty good idea of scenario impact on this function. As all the trays in the tunnel scenario (the only one in the CVT) are damaged, the impact on instrumentation is known there also.

- 6) SG PORV control cables were not traced, also, the precise routing of supply to the semi-vital bus (controlling the PORVs) from the ESGR MCCs to the MCR is not known. In the earlier phase of this project the understanding was that the SG safeties are always open in mid-loop, so there was no need to trace the PORV cables. While this proved incorrect, the same comment as in 5) applies to this system. It was assumed that a fire in either H or J room and along the probable routing path will disable this system.
- 7) Relay fires were screened based on probability and system impact.
- 8) CC valve 109A and B cables were not traced as the information was not available at the time of analysis. It is expected that impact will be minimal.
- 9) Only one train of Unit 1 CCW, charging pump cooling and charging pump service water is usually operating in mid-loop. The assumption is that it is train A. Likewise, it is assumed that train A of RHR and charging is the operating train at the time of fire.
- 10) When the Reactor Water Storage Tank (RWST) suction MOVs to the charging system are disabled (due to damage to control or power cables to both MOVs), and if the control cables to charging pump A are damaged, this represents an irrecoverable failure of charging pump A.

Other assumptions and simplifications are described in Chapter 2.

5.2 Initiators Considered

The initiators considered are RHR3, RHR4, RHR5 (irrecoverable loss of RHR, irrecoverable loss of operating RHR train, recoverable RHR loss), L1 (type of loss of offsite power), B1 (Unit 1 blackout), 4 kV (loss of 1H bus) and VITAL (loss of vital bus). Others were screened out due to probabilistic concerns, or redundancy in widely separated systems or based on importance of initiator from the internal PRA.

5.3 Important Equipment and Cable Locations

Figures 5.1, 5.2, and 5.3 show the juxtaposition of important cables and equipment in the ESGR, CVT, and CT, respectively (See also the discussion in Chapter 2). Table 5.1 presents summarized cable routing information for important components, while Table 5.2 presents cable insulation information. Appendix D contains figures showing cable tray layout in the areas considered. It should be noted that the floor elevation in the ESGR is 9'6". COMPBRN predicts damage to cable trays up to elevation of 22'0" from a large fire and 20'6" from a small fire (and all trays above the initiating tray in a cable fire). The floor elevation of the CVT is 13'0". COMPBRN predicts damage to all cables in the tunnel from a large oil fire anywhere on the tunnel floor or a cable fire in the lowest tray. Important CT floor elevations are 18'4" and -13'0" (RHR flats). COMPBRN results for the ESGR also hold true here (with respect to the vulnerable tray elevation off the floor).

5.4 Types of Fire Damage to Components

A fire can damage control and/or power cables for valves and pumps. It can disable instrumentation. Certain electrical failures can propagate between panels.

Scenario Development

Spurious operation of components can happen due to hot shorts, when the fire occurs in the control room, at the MCC, or bus cabinet, or along the routing of the control cable. Isolation switches are provided to protect certain components from this phenomenon for fires in select locations. For instance, hot short switches are in the ESGR for protection against fires in the MCR.

Disabling a power cable for an MOV will not cause failure if the valve is in the correct position; e.g., MOV-1700 (RHR RCS isolation valve) is open while the RHR is running, so cutting off power to this valve will not disable the RHR system.

However, if the valve is not in the correct position for the intended operation of the system (e.g., charging suction from the RWST), damage to the power cable will disable the pump. This is recoverable, as the operator can manually operate the valve.

Damaging a valve control cable will disable it if it is not in the correct position. As before, this is recoverable, after power is disconnected from the motor.

If the control cable is for a valve that is in the correct position, there will likely be no change in the system status. However, in a certain fraction of cases, spurious operation of the valve due to hot shorts will result. This will disable the valve, recoverably as above.

For a pump, damage to the power cable will disable it irrecoverably. (Repair takes too long). Damage to the control cable will disable it irrecoverably if the pump is idle. (It cannot be started). If the pump is running, it will likely continue to run. However, in a certain fraction of cases, spurious operation (i.e., tripping) of the pump due to hot shorts results, and the pump is lost permanently.

The layout of control circuitry was considered in order to evaluate the probability of hot shorts causing spurious operation given damage to the control cable. The analysis is given in Appendix E. While the control circuitry for different valves may have slightly different arrangements, the result is that the conditional probability of hot short induced spurious operation is on the order of 0.1. The same is assumed to hold true for pumps. This is based on a combinatorial analysis alone and does not include other effects, e.g., the probability that the contact will be made or that it will be "good". The number derived will be used for spurious operation of all components.

In case of a loss of instrumentation cables, redundant process monitoring is provided at the remote monitoring panels outside the control room. These have cable routing independent of the ESGR and CVT.

At Surry, fire-induced electrical faults can propagate in certain situations. Appendix R analysis identifies lack of electrical coordination between the 480 V panels 1H (1J) or 1H1 (1J1) and the corresponding 4.16 kV bus 1H (1J) feeding them². This means that a fire at one of the 480 V buses which causes (or is caused by) an electrical short will cause the 4 kV bus supply breaker to open before the fault can be isolated at the 480 V level. Therefore, a loss of 4 kV bus will result.

5.5 Important Locations and Scenarios Within Fire Zones

5.5.1 ESGR

E1. Large fire at 4 kV 1H bus panel. The fire destroys the whole panel and nearby cables. Initiator: 4 kV (loss of 1H 4 kV emergency bus). No recovery is possible.

System impact: irrecoverable loss of all 1H loads, including RHR pump 1A and charging service water pump 10A. Possible spurious operation of MOV-1700 due to control cable damage would disable both RHR trains. SG PORVs are also assumed to be lost. Recoverable loss of LPI MOV 1890C (cold leg injection path). Loss of AFW pump 3A and valves 151A, C and E (control cable damage. Loss of recirculation spray train A, both inside and outside).

E2. Large fire at the 480 V panel 1H1 and 4 kV 1H stub bus. The fire destroys the whole panel and nearby cables. Initiator: 4 kV (loss of 1H 4 kV bus). This is caused by lack of coordination between the 480V 1H and 4 kV 1H buses; this allows an electrical fault to propagate to the 4kV bus, where the supply breaker will open to protect the upstream components. Unlike E1, this loss of 4 kV bus can be recovered.

System impact: irrecoverable loss of RHR train A, CC pump A, LPI pump A, charging pump 1A and 1C, and charging pump service water pump A. Possible spurious operation of MOV 1700 and 1720A. SG PORVs and LPI MOV 1890C are disabled. AFW valves 151A, C, and E are disabled. Recirculation spray train A (both inside and outside systems) are disabled.

E3. Large fire at the 480 V panel 1H. The fire destroys the whole panel and nearby cables.

Initiator: same as in E2, due to lack of electrical coordination between 480V bus 1H and 4 kV bus 1H.

System impact: same as in E2.

E4. Large fire at 480 V 1J1 panel and the 4 kV 1J stub bus. The fire destroys the whole panel and nearby cables. Initiator: RHR3 (irrecoverable loss of RHR). This is caused by loss of RHR B train in combination with other RHR failures (spurious operation of pump A, or MOV 1700, or MOV 1701, or loss of HCV-1758 instrumentation followed by failure of operators to control flow such that pump cavitation is prevented).

System impact: recoverable loss of 1J 4 kV bus due to the coordination problem. Permanent loss of CC pump B, LPI pump B, charging pump service water pump B, LPI pump A, charging pump B and C, and charging pump A (due to loss of RWST suction and damage to its control cable). Possible spurious operation of CC pump A. Possible spurious operation of the pressurizer block valves. Possible spurious operation of LPI RWST suction valves. SG PORVs disabled. Loss of process instrumentation forces the operators to rely on remote monitoring panels. All Unit 1 AFW is lost (pumps 3A and 3B and valves 151A, B, C, D, E, F are all disabled due to control cable damage).

E5. Large fire at 480 V 1J panel. The fire destroys the whole panel and nearby cables.

Initiator: RHR3 (irrecoverable loss of RHR). Caused by the same type of failures as in E5.

System impact: recoverable loss of the 4 kV 1J bus due to coordination problems. All methods of forced primary feed and bleed from Unit 1 are lost permanently. SG PORVs disabled. Possible spurious operation of pressurizer block valves. Loss of process instrumentation forces the operators to rely on remote monitoring panels. All Unit 1 AFW is lost as in E4.

E6. Large fire at MCC 1J1-1. The fire destroys the whole panel and nearby cables.

Initiator: RHR3 (irrecoverable loss of RHR). This is caused by loss of train B (due to control cable damage) in combination of various failures causing the loss of train A. These failures are: spurious closure of valve MOV-1700, spurious stopping of pump 1A, or operator failure due to loss of valve HCV-1758.

System impact: all important controls for the H division are lost. This means loss of charging pump C (possible spurious operation of pump A), LPI pump A, AFW pump A, and loss of H division valves for these systems. In addition, both charging pump service water pumps will be lost, as well as CPC pump 2B. This will indirectly cause loss of all charging. In addition, recirculation spray train A will be lost, and the pressurizer PORVs will be lost.

Scenario Development

E7. Large fire at UPS 1B-1. The fire destroys the whole panel and nearby cables.

Initiator: VB (loss of vital bus). This is caused by similar failures as in E6; in addition, spurious closure of MOV-1701, or simultaneous spurious closure of MOV-1720A and 1720B will also contribute to the initiator.

System impact: AFW pump 3A is lost (due to control cable damage) as are AFW valves 151B, D and F (for the same reason). Control is lost to the pressurizer PORVs, and the block valves may actuate spuriously. Recirculation sprays are lost. Charging pump cooling pumps 2A and 2B are lost (control cable damage) as is charging pump service water pump 10B. Charging MOVs 1115C and E are disabled.

E8. Very large fire at any of the panels causes loss of all switchgear equipment in both H and J compartment of the ESGR, due to interaction of smoke with switchgear.

Initiator: Unit 1 station blackout, without possibility of recovery, as 4 kV breakers are damaged, and neither the diesel generator nor the offsite power can be connected to either 4 kV bus.

System impact: All methods of cooling are permanently lost, except for Unit 2 charging cross-connect. Gravity feed can be recovered, but no recovery is possible post gravity feed. Possible loss of all process instrumentation forces the operators to use remote monitoring panels.

E9. Transient or cable fire in the H room, along the critical path.

Initiator: RHR4 (irrecoverable loss of RHR train A) due to spurious operation of pump A (control cable damaged), or RHR5 (recoverable loss of RHR) due to spurious operation of MOV 1700 (control cable damaged).

System impact: LPI pump A and charging pump C disabled (due to damage to control cables). SG PORVs disabled. LPI cold leg injection MOV-1890C disabled. Charging pump service water pump 10A disabled (power cable damage). Charging pump RWST suction MOV 1115B disabled. Possible spurious operation of charging A and/or CCW A pump. Possible spurious operation of charging pump suction and/or discharge MOVs (this disables charging train A irrecoverably). AFW pump 3A and MOVs 151A, C, and E are lost due to control cable damage. Train A of inside and outside recirculation sprays is lost.

E10. Transient or cable fire in the J room along the critical path.

Initiator: RHR3 (irrecoverable loss of both trains of RHR due to spurious operation of MOV 1700, or MOV 1701, both with loss of control cables for RHR pump A and B).

System impact: SG PORVs disabled; both LPI pumps disabled; charging pumps B and C disabled; CCW pump B disabled; charging RWST suction MOVs disabled. Charging pump A disabled (control cable damaged and RWST suction disabled). Possible spurious operation of CCW pump A. Possible spurious operation of pressurizer PORV block valves. Unit 1 AFW is lost due to control cable damage for pumps 3A and 3B and all six 151 MOVs.

E11. Small fire at 4 kV 1H stub bus panel; a fire at any of the three cabinets (one of which is supply to RHR pump A) will lead to irrecoverable loss of one train of RHR.

Initiator: RHR4

System impact: irrecoverable loss of CCW pump A.

E12. UPS fire (large fire at UPS-1A-1 or UPS-1A-2, both located in the H room, or a small fire at UPS-1B-1 located in the J room).

Initiator: VB (loss of vital bus)

No other impacts

E13A. Small fire in a 480 V cabinet in the H room.

Initiator: 4 kV (loss of 1H 4 kV bus). Recovery by diesel is possible. The bus is lost due to lack of electrical coordination.

System impact: Loss of all 1H loads. LPI pump A and inside and outside recirculation sprays train A are lost permanently.

E13B. Small fire in a 4kV cabinet in the H room.

Initiator: 4 kV (loss of 1H 4 kV bus). Recovery is not possible due to electrical fault.

System impact: Loss of all 1H loads.

5.2.2 CVT

CV1. A cable fire or a large transient fire in the tunnel/service building vault area destroys all the cables there (on both sides, i.e. both the H and J trains).

Initiator: RHR3 (irrecoverable RHR loss due to damage to pumps A and B power cables).

System impact: both trains of LPI disabled. Charging pump B disabled. CCW pump A disabled. SG PORVs disabled. Process instrumentation disabled, causing operators to rely on remote monitoring panels outside the control room (in the cable spreading room). MOVs for charging alignment to RWST disabled. Possible spurious operation of charging suction/discharge valves for all pumps. Possible spurious operation of pressurizer PORV block valves 1535 and 1536. All Unit 1 AFW is lost (pumps 3A and 3B have damage to the power cables, while valves MOV 151A, B, C, D, E, F are disabled due to control cable damage). Inside and outside recirculation sprays are lost.

Screened out due to low frequency: Large fire at MCC-1H1-2 that damages nearby cable trays and destroys the MCC (controlling A train valves). The trays are well outside the range (horizontally) of the casing-penetrating large fires observed in the Sandia cabinet fire tests.

Screened out due to low frequency: a cable fire in the safeguards penetration area knocks out RHR pump 1A and both LPI pumps. Similar reasoning applies to a fire in the containment penetrations area.

5.5.3 CT

CT1. A cable or a transient fire along the cable tray holding power cables for both RHR pumps.

Initiator: RHR3 (irrecoverable loss of RHR).

System impact: no other impacts, except for loss of power to RHR/RCS isolation MOVs.

CT2. A fire at one of the two RHR pumps. Such an event will likely just disable the pump, as the tray CA (carrying the final cable run to the pumps) is too high above the pumps. It is not known whether the cable from the tray to the pump is in a conduit; if it isn't, a fire can propagate along the cable to the cable tray, and possibly disable the other pump also. A fire at pump A (assumed to be the running pump), were it to reach the tray, would have to travel several feet along the tray in order to reach pump B cable. It should be noted that there is a radiant energy shield between the two pumps. A fire at pump B would much more easily disable pump B, assuming it reaches tray CA, as both pumps' cables are routed together in the vicinity of pump B. While a pump B fire would have a more serious impact, it would also have a lower frequency, as the pump is idle (There have been pump fires set by welding sparks, however). Conservatively, it is assumed that a fire at either pump (at the same RHR pump fire frequency) will disable both RHR trains.

Initiator: RHR3.

Scenario Development

System impact: none. The same HEPs as for the internal PRA will be used, hence the same conditional core damage probability will result.

5.5.4 NSGR

N1. Small fire at 4 kV transfer bus F, supply breaker for the 1H bus.

Initiator: 4 kV (loss of 4 kv 1H bus)

System impact: This will cause loss of 1H AND 2J (Unit 2) buses (under normal configuration). Recovery of 1H possible from EDG. Recovery from reserve station transformers is prohibited or from service transformers - same as E13.

N2. Large fire at 4 kV transfer bus F (destroys the whole panel).

Initiator: 4 kV (loss of 4 kV 1H bus)

System impact: this event causes loss of transfer bus F and normal bus 1A, so recovery via backfeed is prohibited, as well as from reserve station transformers. The loss caused would be to (Unit 1) 1H bus and (Unit 2) 2J bus. Recovery of 1H bus possible via EDG#1.

N3. Very large smoky fire in the NSGR disables all switchgear equipment there.

Initiator: Loss of offsite power (irrecoverable).

System impact: recovery of offsite power prohibited. However, recovery via diesel generator is allowed.

5.6 Scenario Quantification

Table 5.3 shows the results of fire scenario quantification (per plant year). These numbers include the mid-loop POS fraction. The values include the nonsuppression fraction (presented in Chapter 8). The scenario quantification (i.e., initiating event frequency) for each window and POS combination is given in Table 5.4. (These values also include the nonsuppression fraction.) Table 5.4 also includes quantification of scenarios in the main control room, developed in Chapter 9. These are scenarios M1-M13 and MA-MH

Note that development and quantification of fire scenarios in the control room is presented in Chapter 9.

Appendix K shows the algebraic expressions used in calculating the fire scenario initiating event frequencies and uncertainty distributions. Appendix L shows the fire scenario initiating event histograms (i.e. uncertainty distributions)

5.7 References

1. J.M. Chavez, "Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets, Part 1: Cabinet Effects Tests," NUREG/CR-4527-P1, Sandia National Labs, Nov. '86.
2. BNL Memorandum, dated July 9, 1991, from R.G. Fitzpatrick to T-L. Chu and N. Siu, titled "Review of Surry Appendix R Report (Chapter 9)."

Figure 5.1 Emergency Switchgear Room Equipment Layout and Cable Tray Locations

**Figure 5.2 Plan View of the Cable Vault and Tunnel
With the Cross Section of the Tunnel,
Showing Approximate Cable Tray Locations and the MCCs**

VIRGINIA ELECTRIC AND POWER COMPANY SURRY POWER STATION UNITS 1 & 2	
FIRE DOORS UNIT 1 CABLE VAULT/TUNNEL FIRE AREA 1	FIGURE NO. 1-3

Figure 5.3a Containment Layout at RHR Flats Showing Critical Tray Locations

Table 5.1 Room (Floor Elevation)

System	Component (train)	ESGR (9'6") ¹ tray height	CVT (13'0") ¹ tray height	CT (18'4", 13'0") ¹ tray height
RHR	HCV-1758 (instrument)	A17 18'7" 17'7" 18'7"	A1 17'9" A5 17'4"	A1 25'8" CND ² to- 11'6"
	RH-P-1A (H) (power)	B10 20'6"	B2 22'4" B1 23'4" 31'2"	B 28'8" 15'0" 1'0" 7'9"
	RH-P-1B(J) (power)	B10 19'7" 20'6"	B3 23'4" 32'10"	B 28'8" 15'0" 1'0" 9'9"
	RH-P-1A (H) Control	1a161 22'7" 1a16 21'7" 23'0"		
	RH-P-1B (J) Control	C11 19'7"		
	MOV-1700- (H) Power (also MOV 1720A power)		C14 23'4" 22'6" 23'0" C7 16'4" 25'4"	C 27'8" 15'0" 0'0" 8'9" CND 8'9" -1'6"
	MOV-1700 (H) Control	C10 23'6" 22'0" 1a16 21'7" 23'0"	C14 23'4" 22'6" C7 16'4"	
	MOV-1720A (H) Control	C10 23'6" 22'0" 1a16 21'7" 23'0"	C14 23'4" 22'6" C1 21'4"	
	MOV-1701 (J) (also MOV-1720B) (power)		C15 23'4" 21'4" C6 15'4" 25'4"	C6 63'6" CNDto 13'0"

Scenario Development

Table 5.1 Room (Floor Elevation) (continued)

System	Component (train)	ESGR (9'6") ¹ tray height	CVT (13'0") ¹ tray height	CT (18'4", 13'0") ¹ tray height
RHR	MOV-1701 (J) (also MOV 1720B) (control)	C10 23'6" 20'7" 24'0" 20'0"	C15 23'4" 21'4" C6 15'4" 16'4" 20'9" C8	
PPRS	MOV-1535 (H) Power		C14 22'6" 23'4" C7 16'4" 25'4"	C 27'8" CND to 61'3"
	MOV-1535 ⁺ (H) Control	C10 23'6" 20'7" 1a162 18'0" 1a161 22'7"	C14 23'2" 23'0" C7 16'4"	
	MOV-1536 (J) Power		C15 23'4" 21'4" C6 15'4" 25'4"	C2 30'8" 36'3" 43'0" CND to 61'3"
	MOV-1536 ⁺ (J) Control	C10 23'6" 20'7" 24'0" 20'0"	C15 21'4" 23'4" C6 16'4" C8 20'9"	
HPI ^A	MOV-1115D (J) & MOV-1115E Power		C15 23'4" 21'4"	
	MOV-1115D (J) Control	C10 23'6" 1a15 22'0"	C15 21'4" 23'4" C6 16'4" C8 20'9"	
	MOV-1115C (H) & MOV-1115B Power		C14 22'6" 23'4" 21'4" 23'0"	
	MOV-1115C (H) & MOV-1115B Control	C10 23'6" a16 23'0" 22'7" 23'0"	C14 23'0" C7 16'4"	

Table 5.1 Room (Floor Elevation) (continued)

System	Component (train)	ESGR (9'6") ¹ tray height	CVT (13'0") ¹ tray height	CT (18'4", 13'0") ¹ tray height
HPI	MOV-1115E (J) Control	C10 23'6" 20'7" 24'0" 20'0"	C15 21'4" 23'4" C6 16'4" C8 20'9"	
	MOV-1269A (J) Power ⁺⁺		C15 23'4" 21'4"	
	MOV-1269A (J) Control ⁺⁺	C10 23'6" 1a15 22'0"	C15 21'4" 23'4" C6 16'4" C4 20'4" C8 20'9"	
	MOV-1267A (H) Power*		C14 22'6" 23'4" 21'4" 23'0"	
	MOV-1267A (H) Control*	C10 23'6" 1a16 03'0" 22'7" 23'0"	C14 23'0" C7 16'4"	
	CH-P-1A (H) Control & CH-P-1C (H)	C10 23'6" 1a16 23'0"		
	CH-P-1B (J) Power		B5 22'4"	
	CH-P-1B (J) Power	C10 23'6" 1a15 22'0"		
HPI Cooling ^b	1-SW-p-10a (h) Power, control	CND		
	1-SW-P-10b (J) Power	1a15 25'3" 22'7" C101 19'6" 22'9"		
	1-SW-P-10b (J) Control	1a15 22'7" 21'7" 22'0"		

Scenario Development

Table 5.1 Room (Floor Elevation) (continued)

System	Component (train)	ESGR (9'6") ¹ tray height	CVT (13'0") ¹ tray height	CT (18'4", 13'0") ¹ tray height
LPI ^c	MOV-1862A (H) & MOV-1860A Power		C14 23'4"	
	MOV-1862A (H) & MOV-1860A Control	1a16 23'0"	C14 23'0" C7 16'4" C20 23'6" 20'7"	
	MOV-1860B (J) & MOV-1862B Power		C15 23'4" 21'4" C2 20'4" C1 31'2"	
	MOV-1860B (J) & MOX-1862B Control	C10 20'1" 20'0"	C15 23'4" 21'4" C6 16'4" C8 16'4" 20'9"	
	SI-P-1B (J) Power		B5 22'4" 32'0"	
	SI-P-1B (J) Control	C11 19'7"		
	SI-P-1A (H) Power	CND	CND	
	SI-P-1A (H) Control	1a16 23'0"		
CCW ^d	1-CC-P-1B Power	B10 20'6"		
	1-CC-P-1B Control	C11 19'7"		
	1-CC-P-1A Power	B10 20'6"	B2 22'4" B5 22'4"	
	1-CC-P-1A	1a16 20'7" 21'7" 23'0"		
AFW	TD MOV MS-102 Control		C14 23'4" C3 20'4"	

Table 5.1 Room (Floor Elevation) (continued)

System	Component (train)	ESGR (9'6") ¹ tray height	CVT (13'0") ¹ tray height	CT (18'4", 13'0") ¹ tray height
AFW	MS-102B PWR	A 172 16'7"	C8 20'9" C8 16'4" C7 16'4" C2 21'4" C2 20'4" C2 31'3" C12	
	MDP3B PWR		B2 22'4"	
	MDP3A PWR	CND	CND	
	MDP 3B Control	C10 20'7" C10 24'0" C11 19'7"		
	MDP3A Control	A16 20'7" 21'0" 23'0"		
	MOV 151B, D,F Power		C15 23'4" C6 15'4" C6 25'4"	C6 63'6" CND
	MOV 151B, D,F Control	C10 23'6" 24'0" 20'0" short Section	C6 15'4" C8 20'9"	
	MOV 151 A,C,E Power		C14 23'4" C7 16'4" C7 25'4"	C 27'8" CND
	MOV 151 A,C,E Control	C10 23'6" A16 22'7"	C7 16'4" CND C7 25'4"	

+ Note: Control cables for 'H' train components first run through the 'H' room in the ESGR, then through the 'J' room, whereas the 'J' train control cables are wholly contained in the 'J' room. Hence, tray C10 for MOV 1535 is in the 'H' room, whereas tray C10 for MOV 1536 is in the 'J' room.

a HPI routing in the auxiliary building not shown here

++ All other suction/discharge MOVs for CH-P-1B have the same cable routing.

* All other suction/discharge MOVs for CH-P-1A & CH-P-1C have the same cable routing.

Scenario Development

Table 5.1 Room (Floor Elevation) (continued)

- b Charging pump component cooling not needed for RWST water injection; cable routing through Unit 2 ESGR and beyond not shown here.
- c Cable routing through the safeguards building not shown here.
- d This table does not show routing into the auxiliary building.
- 1 Floor elevations of interest in the fire area.
- 2 CND is a conduit, indeterminate routing.

Table 5.2 Cable Insulation Types Used at Surry Unit 1 for Select Systems Cable Types⁺

System	Power		Control	
	Insulation (Mills)*	Total Cable Thickness (in)	Insulation (Mills)*	Total Cable Thickness (in)
AFW	45pei-45np	.58	45pei-80np	.90
	110pei-Alintlk	1.39	45pei-60np	.75
	110pei-60np	1.39		
CCW	110pei-Alintlk	1.48	45pei-80np	.90
RHR	110pei-Alintlk	1.39	25pei-45np	.375
	45pei-45np	.58	45pei-60np	.75
			45pei-80np	.90
PPRS	45pei-45np	.58	47 thw	
			45pei-80np	.90
Charging	45pei-45np	.58	45pei-80np	.90
	110pei-Alintlk	1.48	45pei-60np	.69
	47thw			
LPI	80pei-Alintlk	2.72	45pei-60np	.69
	80pei-65np	2.70	45pei-60np	.75

+ Explanation of symbols:

pei - polyethylene crosslinked
 np - neoprene
 thw - thermal wrap
 Alintlk - Aluminum intlk. armor

* the number preceding the symbol is the thickness of that layer in mills (innermost layer first).

Scenario Development

Table 5.3 Fire Scenario Quantification

Scenario	Initiator	Frequency ⁺ (/yr)
E1	4kV	2.8-6
E2	4kV	7.8-6*
E3	4kV	7.8-6*
E4	RHR3	6.0-6*
E5	RHR3	6.0-6*
E6	RHR3	5.3-7
E7	VB	8.0-6
E8	B1	3.4-7
E9	RHR4	2.8-7**
E10	RHR3	7.8-7**
E11	RHR4	7.4-6
E12	VITAL	8.8-5 ^a
E13A	4kV	5.5-5
E13B	4kV	1.7-5
N1	4kV	1.7-5
N2	4kV	8.4-6
N3	L1	3.4-7
CV1	RHR3	8.1-6 ^b
CT1	RHR3	1.2-5 ^c
CT2	RHR3	2.9-4

+ Multiply by 0.26 for R6, 0.23 for R10, 0.51 for D6.

* Stepdown transformer treated as a contributor

** Approximate length of cable ~40 ft. in either H or J room; 4 trays stacked in the H room, 11 trays in the J room. In either room the trays with RHR Cables are out of reach of a small oil fire. Zone of influence of large oil fire 3 ft on either side of the tray. Trash fires treated as oil fires. Probability of spurious operation is 0.1.

a Two transformers per UPS, treated as separate contributors.

b Trash fires treated as oil fires. Small fire scenario much milder and of much smaller frequency, so it was neglected.

- c Trash fires treated as oil fires. No credit for grating surface. Both small and large fires can reach a 51 ft section of cable tray. Fires cannot develop on one side of the tray, as the tray is next to the crane wall.

Table 5.4 Initiating Event Frequencies (/yr) for the Scenarios vs. Pos-Window Combinations

Windows-POS	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
Scenario										
W1D6	1.7-7	4.8-7	4.8-7	3.7-7	3.7-7	3.3-8	4.8-7	2.1-8	1.7-8	4.6-8
W1R6	1.2-8	3.3-8	3.3-8	2.5-8	2.5-8	2.2-9	3.3-8	1.4-9	1.2-9	2.9-9
W2D6	6.4-7	1.8-6	1.8-6	1.4-6	1.4-6	1.2-7	1.8-6	7.9-8	6.3-8	1.7-7
W2D6	3.7-7	1.1-6	1.1-6	8.1-7	8.1-7	7.1-8	1.1-6	4.6-8	3.7-8	1.0-7
W3D6	5.5-7	1.5-6	1.5-6	1.2-6	1.2-6	1.0-7	1.6-6	6.8-8	5.4-8	1.5-7
W3R10	1.0-8	2.9-8	2.9-8	2.2-8	2.2-8	1.9-9	2.9-8	1.3-9	1.0-9	2.7-9
W3R6	2.8-7	7.9-7	7.9-7	6.1-7	6.1-7	5.4-8	7.9-7	3.5-8	2.8-8	7.6-8
W4D6	1.1-7	2.9-7	2.9-7	2.3-7	2.3-7	2.0-8	3.0-7	1.3-8	1.0-8	2.8-8
W4R10	6.3-7	1.8-6	1.8-6	1.4-6	1.4-6	1.2-7	1.8-6	7.7-8	6.2-8	1.7-7
W4R6	2.3-8	6.6-8	6.6-8	5.1-8	5.1-8	4.5-9	6.6-8	2.9-9	2.3-9	6.3-9

Table 5.4 (Continued)

Initiating Event Frequencies (/yr) for the Scenarios vs. Pos-Window Combinations

Windows-POS	E11	E12	E13A	E13B	N1	N2	N3	CT1	CT2	CV1
Scenario										
W1D6	4.5-7	7.2-6	3.4-6	1.1-6	1.1-6	5.2-7	2.1-8	7.2-7	1.8-5	5.0-7
W1R6	3.1-8	4.9-7	2.3-7	7.2-8	7.2-8	3.5-8	1.4-9	4.9-8	1.2-6	3.4-8
W2D6	1.7-6	2.7-5	1.3-5	3.9-6	3.9-6	1.9-6	7.9-8	2.7-6	6.7-5	1.9-6
W2R6	9.9-7	1.6-5	7.3-6	2.3-6	2.3-6	1.1-6	4.6-8	1.6-6	3.9-5	1.1-6
W3D6	1.5-6	2.3-5	1.1-5	3.4-6	3.4-6	1.7-6	6.8-8	2.3-6	5.7-5	1.6-6
W3R10	2.7-8	4.3-7	2.0-7	6.3-8	6.3-8	3.1-8	1.3-9	4.3-8	1.1-6	3.0-8
W3R6	7.5-7	1.2-5	5.5-6	1.7-6	1.7-6	8.5-7	3.5-8	1.2-6	3.0-5	8.2-7
W4D6	2.8-7	4.4-6	2.1-6	6.5-7	6.5-7	3.2-7	1.3-8	4.4-7	1.1-5	3.1-7
W4R10	1.7-6	2.7-5	1.2-5	3.8-6	3.9-6	1.9-6	7.7-8	2.7-6	6.6-5	1.8-6
W4R6	6.2-8	9.9-7	4.6-7	1.4-7	1.4-7	7.1-8	2.9-7	9.9-8	2.5-6	6.8-8

Table 5.4 (Continued)

Initiating Event Frequencies (/yr) for the Scenarios vs. Pos-Window Combinations

Windows-POS	M1	M3	M4	M8	M13	MA	MC	MG	MH
Scenario									
W1D6	8.3-8	6.1-8	1.0-8	7.0-9	3.0-9	1.1-6	2.4-8	4.4-7	5.6-8
W1R6	5.7-9	4.2-9	6.8-10	4.8-10	2.1-10	7.5-8	1.7-9	3.0-8	3.8-9
W2D6	3.1-7	2.3-7	3.7-8	2.6-8	1.1-8	4.1-6	9.1-8	1.6-6	2.0-7
W2R6	1.8-7	1.3-7	2.2-8	1.5-8	6.6-9	2.4-6	5.3-8	9.5-7	1.2-7
W3D6	2.7-7	2.0-7	3.2-8	2.3-8	9.8-9	3.5-6	7.8-8	1.4-6	1.8-7
W3R10	5.0-9	3.6-9	6.0-10	4.2-10	1.8-10	6.5-8	1.5-9	2.6-8	3.3-9
W3R6	1.4-7	1.0-7	1.7-8	1.2-8	5.0-9	1.8-6	4.0-8	7.2-7	9.2-8
W4D6	5.1-8	3.7-8	6.2-9	4.3-9	1.9-9	6.7-7	1.5-8	2.7-7	3.4-8
W4R10	3.1-7	2.2-7	3.7-8	2.6-8	1.1-8	4.0-6	8.9-8	1.6-6	2.1-7
W4R6	1.1-8	8.3-9	1.4-9	9.6-10	4.2-10	1.5-7	3.3-9	6.0-8	7.6-9

6. FIRE GROWTH ANALYSIS

6.1 COMPBRN-IIIe Capabilities and Limitations

The COMPBRN-IIIe fire growth code¹ was used to calculate fire growth and cable damage. COMPBRN-IIIe is an updated version of COMPBRN-III² and is developed as a menu-driven interactive computer program. The physical models used in COMPBRN-IIIe are the same as that in COMPBRN-III, except for a few modifications related to radiation heat transfer. In addition to the point estimate analysis contained in COMPBRN, the updated version of IIIe has an uncertainty analysis module and can assist the users in performing a probabilistic fire risk analysis directly.

COMPBRN uses a quasi-static approach to simulate the process of fire growth in an enclosure. The enclosure is divided into two distinct homogeneous, stably stratified regions. The hot gases accumulating under the ceiling due to fire plume entrainment and buoyancy are defined as the upper layer. Elements in this layer are heated by convective heat flux from the hot gases. The lower region is assumed to be thermally inert and contains relatively quiescent cool air, which remains at ambient conditions at all times.

The burning rate of a fuel element is used to determine the heat output of the element, which is transferred to other objects via radiation. An element is considered damaged or ignited if its surface temperature exceeds the user-specified damage or ignition temperatures. The physical models of COMPBRN have been reviewed extensively.^{3,4} In general, the COMPBRN-IIIe is geared toward modeling relatively small fires in large enclosures. The hot gas layer is assumed to be formed within the first time step of simulation. Thus, the code's predictions are expected to be most reasonable for fire scenarios involving large fuel loads during their pre-flashover burning period.

The uncertainties of COMPBRN are associated with the physical property data for combustibles and model parameters. The property data are needed to define the physical behavior of the fuel, and the model parameters are needed to represent the uncertainties of the simplified physical models. A complete list of the physical properties required as input to the code is given in Table 6.1. Among the 14 property parameters, seven parameters are significant in the damage time assessment because they dominate the analysis results. The seven parameters are density, specific heat, thermal conductivity, heat value, damage temperature, specific burning rate constant, and reflectivity. The values used for cable and oil for the present analysis are included in Table 6.1. These values are selected based on references⁵⁻⁹ and recommendations from COMPBRN-IIIe. They represent a reasonable estimate of cables with polyethylene/neoprene type insulation and engine oil encountered in nuclear power plants.

The seven model parameters which are related to the physical modeling of doorway, heat transfer, enclosure wall, and flame/plume entrainment are listed in Table 6.2, together with the values suggested by COMPBRN-IIIe. These suggested values are used in the present analysis. Many of the suggested values were determined by comparisons with experiments such as SNL/UL Cable Tray Fire Experiments.² It should be noted that many of these experiments were performed under limited test conditions. The validity of these suggested values for nuclear power plants under accident conditions has not been fully demonstrated.

Probabilistic distributions can be specified for all the 14 property parameters and 7 model parameters to perform the uncertainty analysis. The COMPBRN-IIIe allows many distribution types: point value, uniform, normal, lognormal, shifted lognormal, negatively skewed lognormal, exponential, and negatively skewed exponential. Some of the distribution types require three values (point, low, and high) as input to run the uncertainty analysis. Thus, considerable experience and knowledge is required to perform a meaningful

Fire Growth Analysis

uncertainty analysis. Without this experience and knowledge, the uncertainty analysis itself could involve a large degree of uncertainty.

In addition to the simplified physical models used in the code, the code has several limitations to simulate fire accident in nuclear power plants. The following are some examples:

1. The code does not perform well when the fire source is too close to the ceiling, within the hot gas layer, or when a target is directly on top of a flame.
2. Only one doorway can be modeled and window openings can not. The location of a doorway cannot be specified.
3. The ventilation ports can only be located at the ceiling or on the floor. The fraction of flow entering or leaving each port is specified by users.
4. All rooms are treated as rectangular in shape. All objects, such as cable trays, must be oriented parallel to one of the axes.
5. Vertical or slanted burning objects cannot be modeled with accuracy.
6. The interference effect of several layers of objects, such as cable trays piled together with a small distance between them, cannot be modeled properly.

6.2 Modeling of Fires in Important Fire Areas

The important areas where critical cables are located and where potential fire could occur have been identified in Section 3 of this report. Since all these areas are much larger than the postulated fire size, it is expected that the COMPBRN results will not be affected by the selection of any specific room. Therefore, only the ESGR and CVT are selected as representatives for the present fire growth analysis. The results of this analysis would be applicable to other rooms.

6.2.1 ESGR

The Surry emergency switch gear room contains two sub-rooms, i.e., Rooms H and J. The height of each room is 15 ft and 6 in. The floor areas are about 1570 and 1480 ft² for Rooms H and J, respectively. In Room J, there are seven critical cable trays with elevations at 9, 10, 10.5, 11, 12.5, 13, and 13.5 ft above the floor. In Room H, there are 4 critical cable trays at elevations of 9, 11, 13, and 14 ft above the floor. Since both rooms are similar in size and Room J has more cable trays at various elevations, it is selected for the COMPBRN analysis. Room J also has many noncritical cable trays at elevations varying from 7 ft to 14 ft above the floor. In modeling fires in Room J of the ESGR, all the seven critical cable trays and one noncritical cable tray at 7 ft are included to simulate the responses of cables at different elevations.

Under normal conditions, the forced ventilation system provides a flow of about 9400 cfm for the ESGR. However, during a fire accident, it is assumed that the ventilation is turned off and is therefore not modeled in the base case of the analysis. The effect of ventilation is, however, included in the sensitive study presented in Section 6.4. The doorway between Rooms J and H is modeled in the analysis.

6.2.2 CVT

There are 16 cable trays located along the cable tunnel as shown in Figure 5-2. There are four critical cable trays (B1, B2, A5, and C7) and 4 noncritical cable trays (C1, C3, A1, and A3) on the left side of the tunnel. Similarly, there are four critical cable trays (B3, B5, C4, and C6) and four noncritical cable trays (C2, A2, A4, and A6) on the right side of the tunnel. The elevations of these trays vary from 1.2 ft to 8.4 ft and are modeled in the COMPBRN analysis. The width, height, and length of the cable tunnel are about 10 ft., 9 ft 4 in and 40 ft, respectively. In modeling the size of the room, the service building vault area is included so that the total floor area is about 830 ft². A door (2 ft 8 in by 6 ft 8 in) at the end of the tunnel is assumed open during the entire transient. Doors at the vault area are assumed closed. A forced ventilation with a flow rate at 6-7 room/hr is also included in the analysis.

6.3 Fire Analysis

6.3.1 Oil Fire

(a) ESGR Room J

Oil is one of the major transient fuel sources commonly found during maintenance. Only fires from a pool of oil spilled into an open surface is analyzed. The spray fire which is out of the scope of the COMPBRN code is not considered. The size of the oil pool in nuclear power plants is generally within one to 10 gal. Thus, three oil pool sizes were postulated in the analysis as shown below:

Pool Size	Gallon	Mass kg	Diameter m	Depth cm
Small	1	3.4	0.61	1.3
Medium	5	16.9	0.76	4.2
Large	10	33.8	0.91	5.8

The size, i.e., surface area of the pool, determines the oil burning rate and burning time for a given amount of oil mass. Using the input data given in Table 6.1, the fire would last approximately three, 10 and 14 minutes for the small, medium, and large fires, respectively.

In performing the COMPBRN analysis, the horizontal distance between the oil pool and cable tray was varied in order to estimate the shortest distance at which cables would not be damaged by fires from the oil pool. All oil fires are assumed to be located at the floor level. The results of the predicted cable damage time for fires in ESGR Room J are summarized in Table 6.3. It is seen that the distances beyond which cable would not be damaged are about 2, 3 and 5 ft for the small, medium, and large fires, respectively. When the fire source is within the critical distance, most of the cables at various elevations are damaged in a few minutes. However, no cable ignition is predicted for most of the cases except when a large fire source is located directly under or within 2 ft of the cable trays. For these two cases, cable ignition is predicted within minutes following the cable damage. There could be a large degree of uncertainty for the small fire case. For this case,

Fire Growth Analysis

the quantity of oil is only 3.4 kg and is exhausted in about three minutes. During this short burning time, many cable trays at higher elevations are at temperatures slightly less than the user-specified damage temperature. Hence the code predicts no damage for these cables. This prediction of no damage could be alternated by a minor change of the input parameters.

A limited scope of uncertainty analysis was performed for the small and large fires in Room J. Probabilistic distributions were specified only for a few property parameters as shown in Table 6.4. The predicted results are given in Table 6.5. The results are expected to depend strongly on the assumed distributions in Table 6.4.

(b) CVT

The three oil pools used for fire analysis for the ESGR were applied to the cable vault tunnel. Two fire locations were assumed. In the first case, the fire source is about 3 ft from the left wall, which is about 6 in to the cable trays on the left side (B1, B2, C1, C3, A1, A3, A5, and C7) and 4.5 ft from the cable trays on the right side (B3, B5, C2, C4, A2, A4, A6, and C6). In the second case, the fire is located at about 5 ft from the left wall (i.e., middle of the tunnel). In all cases, the fire is at the floor level.

The COMPBRN-predicted results are summarized in Table 6.6. It is seen that for the case of fire sources located at 3 ft from the left wall, cable trays on the left side of the tunnel are damaged in about two to three minutes due to the adjacency to the fire source. COMPBRN also predicts a rapid increase in temperatures beyond the user-specified ignition temperature. The ignition of cable trays at the left side of the tunnel causes a large fire which propagates to the right side and causes damage and ignition of these cables in about two min. Again, the predictions for the small fire case may involve a large degree of uncertainty because of the short burning time.

For the case in which the fire source is located at the middle of the tunnel, the damage time of cables on both sides is delayed by a few minutes. No cable ignition is predicted due to the relatively large distance between the cable trays and fire source.

6.3.2 Cable Fires

Cable fires are simulated in the CVT region. Fire is initially started at cable tray C7 which is located on the left side of the tunnel and is about 1.2 ft above the floor. The fire source covers a section of 2.5 ft of cables in C7. The COMPBRN-predicted results are given in Table 6.7. It appears that fire initiated at C7 immediately causes damage and ignition of cable trays located directly above the fire source. Within a few minutes the fire propagates to the right side of the tunnel and causes damage and ignition of cables on that side. In about 10 min, all trays in the tunnel region are ignited and burning. In this scenario it is assumed that none of the cable trays has metal cover. It is recognized that some of the cable trays in the tunnel region are covered by a metal sheet. The presence of a metal cover would serve as a radiation shield and therefore delay the potential damage time. The effect of a metal cover was not modeled in the present study.

An attempt was made to simulate cable fires initiated at a higher elevation. A section of 2.5 ft of cables in tray C3 was selected as the fire source. The C3 tray is located at about 5.2 ft above the floor. For this case, COMPBRN predicted the damage and ignition of cable trays located directly above the fire source at about 2 minutes. The cable trays are C1, B2, and B1. No damage and ignition of other trays is predicted for a time

period of 15 minutes. Since the fire source is located in the upper section of the room, it appears that the COMPBRN code has difficulty in properly simulating the hot gas layer and ventilation flow through the doorway. Interpretation of these predicted results must be cautious.

6.3.3 Cabinet Fire

The COMPBRN code was used to analyze the potential cabinet fire in the ESGR. The purpose of the analysis is to simulate the impact of fires in the MCCs and cabinet on critical cables located nearby. Since COMPBRN can not model the cabinet as an enclosure with venting holes on the sides or top of the cabinet, the scenario is simply simulated as a cable fire located at an elevation equivalent to the upper section of the cabinet. A steel barrier is put directly above the fire source to simulate the top cover of the steel cabinet. The cabinet is located below the critical cables at elevations of 10 and 11 ft, and is near the critical cables at 9, 11.5, and 13.5 ft elevation. In the first case, we assumed that the fire is enclosed within the cabinet and the flame cannot be seen by these critical cables above or near the cabinet. This is done by using the noncommunication option provided by the code. The results show that the cabinet fire does not damage any cables near the cabinet for a time period of 30 min. This case is apparently not conservative. Therefore, the non-communication option of the code was removed for the second case of our analysis. The removal of the noncommunication option implies that the flame could reach out and be seen by all critical cables nearby. The COMPBRN results for this case show that the cables at the 10 and 11 ft. elevation directly above the cabinet are damaged at 2 and 5 min, respectively. Within a period of 30 minutes of cabinet fire, neither damage nor ignition to another cable is predicted by the code.

6.3.4 Trash Fire

Trash fire is another transient fire source encountered during maintenance. Since trash fire consists of the burning of a solid fuel package, such as paper and cotton rags, there is a great deal of uncertainty in the anticipated behavior of a particular fuel package. Many experimental works have observed poor repeatability in many fuel packages because of the large variations of fuel configuration, packing density, and effective surface area. The existing fire model, such as the one used in COMPBRN, cannot accurately and reliably simulate the trash fire due to the lack of fundamental fuel properties to characterize the fire growth rate and heat release. Therefore, trash fire analysis is not performed in the present study. The impact of trash fire on cable damage probably could be estimated by considering an equivalent oil fire which has about the same heat content.

6.4 Sensitivity Study

6.4.1 Pool Fire Size

In Section 6.3.1, the diameter of the fire pool is assumed to be 2 ft and 3 ft for the small and large fires, respectively. In sensitivity studies, the pool size is extended to include 1 and 3 ft for the small fire, and 2 and 4 ft for the large fire. The surface of the pool has a direct effect on the fire burning rate and burning time based on the COMPBRN model as shown in Table 6.8. In the analysis, the fire source is assumed to be 1 ft from the cable trays for the small fire, and 3 ft for the large fire. The predicted cable damage time is summarized in Table 6.9. It appears that reducing the fire size reduces the potential for cable damage. When the fire size is increased, the cable damage time is hastened. COMPBRN also predicted cable ignition when

Fire Growth Analysis

the fire size is increased to 3 ft for the small fire and 4 ft for the large fire. Cable ignition is not predicted for these base cases.

6.4.2 Effect of Wall on Plume Entrainment

The presence of a wall could affect the air entrainment when the fire source is near the wall or at a corner. This wall effect is considered in COMPBRN. The user's manual¹ suggests that the plume entrainment coefficient be changed from 2.0 to 1.5 for pool fire next to a wall, and to 1.25 for a fire at a corner. The potential for a fire occurring near a wall is simulated by considering the fire pool located next to the back wall of Room J in the ESGR. It is assumed that the pool fire is near the three cable trays at elevations of 7, 9, and 10 ft above the floor. The horizontal distances from the cable trays are 1 ft for the small fire and 3 ft for the large fire. The COMPBRN results show that the presence of the wall has no apparent effect on the large fire and the predicted damage times remain the same as for the base case. However, the wall does have a stronger effect on the small fire. The sensitivity study shows that only the cable tray at 7 ft is damaged at 2 min and no damage is predicted for the other two trays at higher elevations. In the base case, the two cable trays at elevations of 9 and 10 ft are also damaged at 3 min just before the oil is exhausted.

6.4.3 Forced Ventilation

The fire scenario discussed in Section 6.3 assumes that forced ventilation in the ESGR is turned off but that doors remain open during a fire accident. In the sensitivity study, the potential of failure to turn off the ventilation system is examined. It is assumed that the fresh air enters Room J from ports on the floor and discharges at the ceiling. A flow rate of 4700 cfm is used in the analysis. For the case in which a small fire is located 1 ft from the cable trays, COMPBRN predictions show no change in the cable damage time. For the case in which a large fire is located 3 ft from the cable trays, COMPBRN predicts a delay of cable damage time by about 1 min.

6.4.4 Forced Ventilation and Doorway Opening

The fire scenario considered for the cable vault/tunnel region assumes that the forced ventilation is maintained and the door at the end of the tunnel is open throughout the fire accident. Since the ventilation flow tends to delay the cable damage time, the effect of no ventilation is considered for the sensitivity study. It is also considered that the doorway is closed as the forced ventilation is turned off.

For oil fires, the COMPBRN predictions show that the potential for cable damage appears to be higher when the ventilation is turned off and doors are closed. For the case in which a small fire is initiated at 3 ft from the left wall of the tunnel, cable trays A5 and C7 are predicted to be damaged at about 3 min. No damage is predicted for these two trays in the base case. For the case of a large fire initiated in the middle of the tunnel, cable ignition is predicted for all cables at about 5 to 6 min. The base case predicts no cable ignition.

The effects of ventilation and doorway are also examined for cable fires initiated at cable tray C7, which is located near the left side of the tunnel. For this case, there is no significant change in cable damage and ignition times. The times are alternated by only 1 or 2 min for some cable trays.

The above results may depend on the location of ports where air intake and discharge takes place. In the analysis, it is assumed that fresh air enters from ports on the floor and discharges from the ceiling. No change of the ports' location was included in the sensitivity study.

6.5 References

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Table 6.1 Physical Property Parameters

Property Parameters	Values Used for Present Analysis	
	Cable	Oil
Density, Kg/m ³	1710	900
Specific Heat, J/Kg/K	1040	2100
Thermal Conductivity, w/m/k	0.092	0.145
Heat Value, MJ/Kg	20.6	46.7
Pilot Ignition Temperature, K	773	400
Spontaneous Ignition Temperature, K	776	486
Damage Temperature, K	623	-
Ventilation Control Burning Rate Constant	0.11	0.11
Specific Burning Rate Constant, Kg/m ² /J	0.0043	0.061
Surface Control Burning Rate Constant, Kg/J	0.18×10^{-6}	0.2×10^{-6}
Combustion Efficiency	0.7	0.9
Fraction of Flame Heat Released as Radiation	0.4	0.45
Absorption Coefficient for Flame Gases, 1/m	1.4	1.4
Reflectivity	0.2	0.35

Table 6.2 Model Parameters

Model Parameters	Suggested Value
Heat Transfer Coefficient for Heat Transfer in a Flame, $\text{w/m}^2/\text{K}$	22
Convective Heat Transfer Coefficient Outside of Hot Gas Layer, $\text{w/m}^2/\text{K}$	10
Coefficient of Inflow Air through Doorway	0.6
Coefficient of Discharge for Doorway	0.7
Absorption Coefficient of Hot Gas	1.3
Heat Transfer Coefficient for Ceiling and for Objects in the Hot Gas Layer, $\text{w/m}^2/\text{k}$	10
Buoyant Plume entrainment Coefficient*	2.0

* The buoyant plume entrainment coefficient

= 2.0 for pool fire unaffected by enclosure

= 1.5 for pool fire next to a wall

= 1.25 for pool fire at a corner

Fire Growth Analysis

**Table 6.3 Cable Damage Time for Oil Fires in ESGR Room J
(Time in Minutes)**

Cable Elevation Ft	Fire Source Distance from Cable, Ft									
	Small Fire		Medium Fire		Large Fire					
	1	2	2	3	0	2	3	4	4.5	5
7	2	-	2	-	1	2	3	5	10	-
9	3	-	3	-	1	2	3	7	-	-
10	3	-	5	-	1	2	4	-	-	-
11	3	-	8	-	1	2	5	-	-	-
11.5	-	-	-	-	1	2	5	-	-	-
12.5	-	-	-	-	-	4	9	-	-	-
13.5	-	-	-	-	3	4	-	-	-	-

- Note:
1. Cable at 7 ft is non-critical
 2. - No damage predicted
 3. Cable ignition is predicted for large fires at 0 and 2 ft from the cable tray.

Table 6.4 Probabilistic Distributions Assumed for Uncertainty Analysis

	Distribution	Point Value	Low Value	High Value
Cables				
Heat Value J/Kg	Normal	2.06(7)	1.85(7)	2.31(7)
Pilot Ignition Temperature, K	Neg-log	773	750	780
Spontaneous Ignition Temperature, K	Neg-log	773	750	780
Damage Temperature, K	Normal	623	598	643
Specific Burning Rate Constant, Kg/m ² /s	Neg-log	4.3(-3)	1(-4)	7.5(-3)
Reflectivity	Normal	0.2	0.1	0.3
Oil				
Specific Burning Rate Constant, Kg/m ² /s	Normal	6(-2)	5.1(-2)	7.1(-2)
Combustion Efficiency	Uniform	0.9	0.85	0.95

Note: Point values are assumed for all other property parameters

Fire Growth Analysis

Table 6.5 Results of Uncertainty Analysis

	Cable Elevation, Ft		
	9	11.5	13.5
Small Fire, 1 ft Away from Cables			
Probability of No Damage before 10 min	0.22	0.95	0.96
Probability of Damage within 10 min	0.78	0.05	0.04
Large Fire, 4 ft away from Cables			
Probability of No Damage before 30 min	0.22	0.63	0.86
Probability of Damage within 30 min	0.78	0.37	0.14

Table 6.6 Cable Damage and Ignition Time for Oil Fire in Cable Vault Tunnel
(Time in Minutes)

Cable No.	Small Fire		Medium Fire		Large Fire	
	Damage	Ignition	Damage	Ignition	Damage	Ignition
Fire starts at 3 ft from the left wall						
B1	-	-	3	5	2	3
B2	-	-	2	5	2	3
C1	-	-	2	5	2	3
C3	-	-	2	5	2	3
A1	3	-	2	5	2	3
A3	3	-	2	5	2	3
A5	-	-	3	7	2	3
C7	-	-	3	7	2	4
B3	-	-	6	7	4	5
B5	-	-	6	7	4	5
C2	-	-	6	7	4	5
C4	-	-	6	7	4	5
A2	-	-	6	7	4	5
A4	-	-	6	7	4	5
A6	-	-	7	8	5	5
C6	-	-	7	8	5	6
Fire starts at 5 ft from the left wall						
B1	-	-	-	-	3	-
B2	-	-	7	-	3	-
C1	-	-	5	-	3	-
C3	-	-	5	-	3	-
A1	-	-	5	-	3	-
A3	-	-	6	-	3	-

Fire Growth Analysis

Table 6.6 Cable Damage and Ignition Time for Oil Fire in Cable Vault Tunnel
(Time in Minutes) (continued)

Cable No.	Small Fire		Medium Fire		Large Fire	
	Damage	Ignition	Damage	Ignition	Damage	Ignition
A5	-	-	-	-	3	-
C7	-	-	-	-	6	-
B3	-	-	-	-	3	-
B5	-	-	7	-	3	-
C2	-	-	5	-	3	-
C4	-	-	5	-	3	-
A2	-	-	5	-	3	-
A4	-	-	6	-	3	-
A6	-	-	-	-	3	-
C6	-	-	-	-	6	-

Table 6.7 Cable Damage and Ignition Time for Cable Fires in the Vault/Tunnel Region
(Time in Minutes)

Tray No.	Damage	Ignition	Tray No.	Damage	Ignition
B1	5	5	B3	8	8
B2	5	5	B5	8	8
C1	5	5	C2	8	8
C3	2	3	C4	8	8
A1	2	3	A2	8	8
A3	2	3	A4	8	8
A5	2	3	A6	9	9
C7	0	0	C6	9	10

Fire Growth Analysis

Table 6.8 Effect of Oil Pool Size on Combustion Characteristics

Small Fire (1 Gal)			
Pool Size, ft	1	2	3
Area, m ²	0.073	0.29	0.6567
Depth, m	0.05	0.013	0.0058
Burning Rate, Kg/s	0.0044	0.0175	0.0394
Burning Time, s	771	193	86
Large Fire (10 Gal)			
Pool Size, ft	2	3	4
Area, m ²	0.29	0.657	1.167
Depth, m	0.13	0.058	0.0325
Burning Rate, Kg/s	0.0175	0.0394	0.071
Burning Time, s	1930	858	476

Note: Burning rate and time are based on 100% efficiency.

Table 6.9 Effect of Oil Pool Size on Cable Damage Time

	Pool Size, Ft.		
Small Fire (1 Gal)			
Cable Elevation, Ft	1	2	3*
7	-	2	1
9	-	3	1
10	-	3	1
11	-	3	1
11.5	-	-	1
13.5	-	-	3
Large Fire (10 Gal)			
Cable Elevation, Ft	2	3	4*
7	-	3	2
9	-	3	2
10	-	4	2
11	-	6	2
11.5	-	5	2
13.5	-	-	3

* Cable ignition predicted

7. FIRE SUPPRESSION MODELING

The suppression model is different than the 1150 model where a mean suppression time was used^{1,2}. The conditional probability of nonsuppression in the 1150 model is given by:

$$f_{ns} = \exp(-t_d/t_s) \quad (7.1)$$

where f_{ns} is the nonsuppression fraction, t_d is the predicted time to damage (corresponding to τ_G below, in section 7.1) and t_s is the mean suppression time, equaling 42 minutes according to Reference 2.

The suppression model used in this study is somewhat more sophisticated. The nonsuppression fraction will depend on the type of suppression and detection equipment available in a particular fire area. The mean time to suppression will have a finer granularity, too (and will be only implicitly present in the model); it is broken down into stages in the suppression process, with each stage having a success/failure decision box attached to it, and the stages connected by branches representing transition rates. The nonsuppression fraction will have a different distribution (supported by numerical calculations) than the one in equation (7.1). The parameters of this model will be calculated from field data (nuclear and non-nuclear) and specialized to each type of fire area and fire severity.

7.1 Transition Diagram of Fire Detection and Suppression

Successful suppression will prevent damage to a component if the fire started nearby. The conditional probability of damage to a component given a fire event is then equal to the probability that suppression will not extinguish the fire before damage. (In case of electrical cables, damage is defined as reaching a certain critical temperature of the insulation).

A more detailed explanation of the suppression model is given in Appendix F, taken from reference 3. The nonsuppression probability is the fraction of cases where the time to detect and control the fire (hazard time, t_H) is greater than the time needed to damage the component (growth time, t_G), i.e.:

$$f_{ns} = \text{Fr}(t_G < t_H) \quad (7.2)$$

As explained in Appendix F, t_G can be replaced by its mean value, τ_G , and equation (7.2) becomes:

$$f_{ns} = \text{Fr}(\tau_G < t_H) \quad (7.3)$$

$$= 1 - F|t_H(\tau_G) \quad (7.4)$$

where $F|t_H$ is the cumulative probability function for t_H .

The suppression analysis in this study is based on the transition diagram model of suppression described elsewhere^{3,4,5}. Figure 7.1 shows the suppression model. The suppression process in a particular case progresses between the states in Figure 7.1, starting with detection, according to the conditional probabilities of the branches (ϕ_K 's and ψ_K 's) and the transition rates (λ_{ij} 's) along the branches (i.e., between the states). K are the state designators, whereas ij are the branches' identifiers (as per Figure 7.1).

7.2 Calculation of Parameters for f_{ns}

The parameters of the model (ϕ 's, ψ 's and λ 's) for a particular type of fire area are calculated, in Appendix F, from available data on suppression in nuclear power plants, and elsewhere. The types of fire areas (from suppression standpoint) are distinguished based on availability of detectors, special systems (e.g., CO₂, Halon, sprinklers), and manual or automatic actuation of such systems. The types of fire areas encountered are given in Table 1.8, Appendix F.

For the areas of interest here, the ESGR is in category IV (has detectors but the Halon system is manually actuated), the CVT (particularly the tunnel area) is category V (detectors with automatic actuation of Cardox, plus a manually actuated sprinkler system), whereas the CT is in category II (detectors, no special systems except for standpipe). (The MCR suppression is described in Chapter 9). This is shown in Table 7.1.

Once the parameters of the transition model are known (shown in Tables 1.4 and 1.5 of Appendix F), it is possible to calculate the nonsuppression probability for a given growth time and for a particular distribution of time along the particular path taken in a particular case. This involves integration over all possible paths and all possible time allotments of time to various stages along the suppression path.

A simplification of the above procedure is developed in Appendix F, where it is shown that the distribution in t_H is approximately Weibull:

$$F|t_H(t|\gamma_C, \xi_C) = 1 - \exp[-(t/\xi_C)^{\gamma_C}] \quad (7.5)$$

where the parameters (γ_C , ξ_C) can be determined from the mean and variance of t_H using the following equations:

$$\Gamma(1 + 2/\gamma_C) = \{1 + \text{Var}(t_H|C)/[E(t_H|C)]^2\}[\Gamma(1 + 1/\gamma_C)]^2 \quad (7.6)$$

$$\xi_C = E(t_H|C)/\Gamma(1 + 1/\gamma_C) \quad (7.7)$$

The mean and variance of hazard time and for a particular class of rooms, $E(t_H|C)$ and $\text{Var}(t_H|C)$, are calculated in Appendix F and shown in Table 1.9 there. The "high severity" data in the "hazard time mean" and "hazard time variance mean" columns are used in this study. The parameters γ_C and ξ_C are calculated using these data in equations 7.6 and 7.7 and the calculated values are shown in Table 7.2 for various room classes of interest. These values will be applied in Chapter 8, using equations (7.5) and (7.4), to calculate f_{ns} for cases of interest.

7.3 References

1. M.P. Bohn et al., "Analysis of Core Damage Frequency: Surry Power Station, Unit 1 External Events", NUREG/CR-4550 Vol. 3, Rev. 1, Part 3, December 1990.
2. J.A. Lambright et al., "Fire Risk Scoping Study: Investigation of Nuclear Power Plant Fire Risk, Including Previously Unaddressed Issues", NUREG/CR-5088, January 1989.
3. Pickard, Lowe and Garrick, Inc. (PLG, Inc.), "Beznau Risk Analysis Plant with NANO", prepared for Nordostschweizerische Kraftwerke AG, PLG-0511, December 1989.

4. Nathan Siu and George Apostolakis, "Modeling The Detection And Suppression of Fires in Nuclear Power Plants", from International ANS/ENS Topical Meeting on Probabilistic Safety Methods and Applications, February 24-March 1, 1985.
5. N. Siu and George Apostolakis, "A Methodology for Analyzing the Detection and Suppression of Fires in Nuclear Power Plants", in Nuclear Science And Engineering 94, pp. 213-226 (1986).

Figure 7.1 Fire Suppression Model

Table 7.1 Classification of Fire Areas into Suppression Categories
of Table 1.8, Appendix F

FIRE AREA	ESGR	CVT	CT
Suppression Category	IV	V	II

Table 7.2 Parameters ξ_c and γ_c for Fire Areas

FIRE AREA	ESGR	CVT	CT
ξ_c	17.5	21.7	18.6
γ_c	.5	.575	.55

8. DAMAGE FRACTION CALCULATIONS

The damage fractions are calculated from equations (7.4) and (7.5), using data in Table 7.2. The resulting damage fractions (i.e., f_{ds} in equation (7.4)) are given in Tables 8.1, 8.2, and 8.3 for the ESGR, CVT, and CT, respectively, and for the damage times of interest.

8.1 ESGR

In the ESGR, the damage times of interest are 3 min for a small fire (used for switchgear panel fires that reach out through the casing) and 5 min, 2 min and 1 min for large fires within 3, 2, and 0 ft (center to edge) of the cable tray, respectively. This is based on Table 6-3 showing the tray elevation-horizontal displacement-damage time relationship and Table 5.1 showing critical cable tray elevations. (The elevations in Table 6-3 are relative to the 9'6" floor elevation, whereas elevations in Table 5.1 are absolute.) The RHR cables (whose damage is needed in order to have an initiator) are generally in higher trays. Therefore, the damage fraction (from Table 8.1) is .66 for a switchgear panel fire; .59 for a large oil fire centered in the swath between 2.5 and 3 ft from the tray; .71 for a large oil fire centered in the swath between 1.5 ft and 2.5 ft from the tray; .94 for a large oil fire centered within 2.5 ft on either side from the tray centerline. (The tray is 2 ft wide.) The aggregate damage fraction is then 0.84 for a large oil fire, 0.66 for a small oil fire, and 0.66 for a switchgear fire.

For cable fires in the ESGR, growth time results from cable fires in the CVT (see below) were conservatively used. For a short stack of trays (4-5 trays above the initiating tray), the damage will propagate within 2 min to all the trays (damage will be immediate in the initiating tray). For a tall stack (10-11 trays above the initiating tray), half the trays will sustain damage within 2 min, the other half within 5 minutes (again, damage is immediate in the initiating tray). Therefore, keeping in mind that the RHR-cable-carrying trays are near the top in the ESGR, and that the H room contains a 4-tray stack, whereas the J room has an 11-tray stack, the aggregate damage fraction for cable fires (arising from all possible combinations) in the H room is .78 and in the J room it is .68.

8.2 CVT

In the CVT, the Chapter 6 results for a sensitivity analysis of the growth time, subsection 6.4.4, are used instead of the base case. This is due to the base case (for CVT) keeping the doors open and ventilation on (an optimistic case for COMPBRN modeling). When the ventilation is turned off and the doors are closed, a large oil fire on the tunnel centerline will cause damage to all the trays within 3 min; a cable fire starting in a bottom tray will propagate to the top tray within 5 min, and to the other side of the tunnel within 7 min. Then, using Table 8.2, the damage fractions are .73 for a large oil fire and .65 for a cable fire.

8.3 CT

In the CT, the connecting cable tray between the two RHR pumps is too high to be directly damaged by a pump fire; however, propagation along the vertical pump cable (assuming it is not in a conduit) to the tray is probable; such an event cannot be modeled by COMPBRN. The damage fraction will be conservatively assumed to be 1, as not enough is known about the propagation time of a fire along a vertical cable.

For the transient fire in scenario CT1, the 45' section of tray reachable by an oil fire (large or small) is at a relative elevation of 10'4". The results of Table 6-3 are used, as they apply for a large room. The results will

Damage Fraction Calculations

be modified somewhat, as the ventilation option will make no difference due to the size of the containment. According to Subsection 6.4.3, damage time due to a large fire at a distance of 3 ft should be increased by 1 min, while other results are unchanged. Using these results, and applying the same reasoning as in section 8.1 (keeping in mind that the trays are anchored to the crane wall), results in a damage fraction of .84 for a large fire and .66 for a small fire, from Table 8.3. The aggregate damage fraction for transient fires is 0.71.

For the cable fires in scenario CT1, a 50.75' section contains 3 trays (below or at the RHR cables-carrying tray), a 31.2' section contains 2 such trays and a 19.7' section contains one tray. Applying the same logic as in 8.1 and Table 8.3, the 3-tray section will have a damage fraction of 0.81, the two-tray section will have a damage fraction of 0.86, and the one-tray section will have a damage fraction of 1. The aggregate damage fraction for cable fires is 0.86.

8.4 Results

Table 8.4 shows the results of damage fraction calculations for each room as described above. (As there are no cables involved, NSGR fire scenarios have a damage fraction of 1.)

Table 8.1 Nonsuppression Fraction, f_{ns} , vs. Time in ESGR

Time (Min)	1	2	3	4	5	7	10
f_{ns}	0.94	.71	.66	.62	.59	.53	.47

Table 8.2 NonSuppression Fraction, f_{ns} vs. Time in CVT

Time (Min)	1	2	3	4	5	7	10
f_{ns}	.95	.78	.73	.68	.65	.59	.53

Table 8.3 NonSuppression Fraction, f_{ns} , vs. Time in CT

Time (Min)	1	2	3	4	5	7	10
f_{ns}	.95	.75	.69	.65	.62	.56	.49

Table 8.4 Damage Fractions for Fire Scenarios

Room	Scenarios	Damage Fractions
ESGR	E1-E7	0.66
	E9	0.84 0.66 0.78 ¹
	E10	0.84 0.66 0.68 ¹
	E8	1
	E11-E13B	1
CVT	CV1	0.73 0.69 ²
CT	CT1	0.71 0.86 ²
	CT2	1
NSGR	N1-N3	1

¹ First number is for large oil fires, second number is for small oil fires, and third number is for cable fires² First number is for large oil fires, second number is for cable fires

9. CONTROL ROOM FIRE RISK ANALYSIS

The main control room (MCR) at Surry serves as the nerve center of controls for all plant operations. The MCR houses a multitude of the instrumentation and controls for various plant systems. Due to the close spatial arrangement of the controls (e.g., control switches, control wiring, circuit boards, controllers) in the MCR, occurrence of fires can simultaneously damage control capability of multiple pieces of equipment. Thus, fires are considered to be a potential risk contributor. The purpose of this section is to assess the risk of fires to the MCR at Surry during mid-loop. The scope of the analysis presented in this section is limited to the portion of the MCR that is dedicated to Unit 1 operations. Fire scenarios that can cause core damage are identified. These scenarios are then screened qualitatively. The occurrence frequency of the scenarios that survive the preliminary screening are then assessed.

The overall process in the control room fire risk analysis is inherently counteractive and must be balanced in a meaningful practical fire risk analysis. Ideally, all potential hazardous scenarios that can cause any conceivable damage would be identified to ensure that all locations and all possible hazards within the control room are fully examined. On the other hand, to most efficiently use available resources and to maintain a proper balance throughout the risk assessment process, only the relatively risk significant scenarios are analyzed in detail. This top-down approach to risk assessment minimizes the effort in quantifying the risk associated with unimportant scenarios. Therefore, the scenarios developed for the MCR should be as comprehensive as possible, but they remain at a manageable number for the subsequent frequency, core impact, and recovery action analyses.

A fire scenario in this section is defined at the location level. A scenario describes all possible fires that occur at or near a particular location and damage the components within that location. Each scenario has a unique combination of the fire sources, fire initiators, location and magnitude of the fires, their occurrence frequencies, and the damage (or impact) caused by the fires to the plant. Fire scenarios developed for the MCR are generally grouped into several impact categories (i.e., grouping the scenarios with the same damage impact). One of these impact categories, consisting of a large number of scenarios, is identified as "no impact on the shutdown risk". For example, fire-induced control failure of the main feedwater is important to the plant power operation but is not a risk contributor during mid-loop operation at plant shutdown. To streamline the effort in the identification of risk significant fire scenarios, the analysis approach is to focus on the fire scenarios that can potentially impact or degrade systems that are required to be operating during mid-loop operation at shutdown such as the residual heat removal system, component cooling system, or charging system. Therefore, this study begins with identifying the control locations for the equipment that is involved in the decay heat removal operation or supports the operation of RHR. In addition, control locations for the equipment that can be used for the mitigation of a loss of RHR event are also identified. This analysis conservatively assumes that fires occurring around the control locations would cause an adverse impact on the modeled function. For the postulated impact, all possible fires that could cause the same damage are considered in the occurrence frequency estimation of the scenario. The fire scenarios are then incorporated into the overall plant risk model as the fire-induced initiating events to determine their risk contribution (i.e., in terms of core damage frequency).

In summary, the control room fire analysis consists of the following major steps:

1. Generate a list of the equipment considered in providing the shutdown cooling or the mitigation of shutdown accidents.
2. Locate the controls for the above equipment.

Control Room Fire Analysis

3. Postulate fire scenarios based on impact on the shutdown cooling, the RCS inventory control functions, and the mitigation of loss of RHR events.
4. Screen the scenarios qualitatively according to effective fire sizes.
5. Estimate the scenario occurrence frequency.

The first three steps in this analysis are described in Section 9.1, fire scenario development. Section 9.2 discusses the fire scenario quantification process. The references cited in this section are listed in Section 9.3.

9.1 Fire Scenario Identification

The Surry MCR is a common area serving both Units 1 and 2. It is located on elevation 27'-0 of the Service Building. The main control boards for Unit 1 are completely independent of those for Unit 2. The control room is manned 24 hours continuously; and manual fire suppression is available with the fire extinguishers inside the control room and a hose station located in the turbine building. The potential fire sources in the control room are expected to be either the transient combustibles or the electrical equipment such as control cables. The fire induced by the transient combustibles that would damage the control equipment or cause a control room evacuation is unlikely because of the continuous presence of the operators and the easy access to the fire extinguishers. Furthermore, based on past industrial experience (Ref. 9-1), there has been no evidence of transient combustible induced fires in the control room area. Therefore, this analysis concentrates its effort in the cabinet cables-induced fires, and transient combustible induced fires are not considered.

In addition to the control features provided in the main control room, alternate control capabilities are available outside the control room such as the auxiliary shutdown panel (Ref. 9-2) and switchgear room. Table 5-2a of Reference 9-2 lists the plant equipment that can be controlled from the auxiliary shutdown panel in the event of evacuation from the main control room due to fires. In this analysis, credits can be taken for this type of equipment in the evaluation of control room fires that would impact the corresponding controls in the MCR.

A simplified layout of the control room is provided in Figure 9-1. As shown in the figure, the control room contains:

1. Benchboard sections 1-1 and 1-2
2. Vertical board sections 1-1, 1-2, 1-3, 1-4, 1-5, 1-6, and 1-7
3. Semi-vital bus and the associated transformer
4. Vital bus cabinets 1-II and 1-IV and terminal box for vital bus train B
5. 125V DC cabinets 1-1 and 1-2
6. 120V AC cabinet
7. Miscellaneous panels such as PAMC panel and junction boxes

The Benchboards and Vertical Boards (Ref. 9-3) contain controls for the reactor coolant system, engineered safeguards systems (i.e., High-Head Safety Injection system, Low-Head Safety Injection system, Containment

Spray system, and Recirculation Spray system), auxiliary systems (including Chemical and Volume Control System, Residual Heat Removal system, Component Cooling Water system, Charging Pump Cooling Water system) and secondary systems (e.g., Main Steam system, Steam Generator Feedwater system, Auxiliary Feedwater system, and Condensate system), emergency power system (Diesel Generators 1 and 3), and the power generation systems.

The semi-vital bus and its associated transformer (480V/120V) are located behind the Vertical Board section 1-1. This bus supplies power for the operation of the steam generator power-operated relief valves.

Vital buses II and IV and their associated terminal box are located on the west wall of the control room. These buses provide uninterruptible power supply to vital instruments and equipment.

The 125V DC and 120V AC cabinets distribute the required control power for solenoid-operated valves and control relays, and the power supply for indicating lights, monitors, recorders, and annunciators in the main control room.

The control devices (e.g., control switches) for the equipment in various systems are mounted on the front panel of the control boards or cabinets. In this analysis, the control associated components (such as control cables, fuses, contacts, etc.) are generally assumed to be installed inside a panel or board in the proximity of their associated control device.

Fire incidents occurring in the aforementioned boards, cabinets, or panels could lead to different impacts on plant safety depending on their location of occurrence and severity. For example, a small fire occurring on the left side of Benchboard section 1-1 could damage the controls of the shutdown accident mitigation equipment such as the low head safety injection pumps. Another fire with similar severity occurring at a place where the controls for the containment spray system are located might contribute much less to the shutdown risk because the containment integrity may not be maintained during plant shutdown. Thus a significant scenario induced by a small fire is possible only if it occurs near the controls for the equipment of concern. On the other hand, a fire with greater severity could cover a large area, and thereby cause a more severe impact but with less frequency. From the past nuclear industrial operating experience (Ref. 9-1), small fires generally cause minor impact but they may occur more frequently. Large fires (with higher severity) might occur at a lower occurrence frequency but result in a more severe impact due to a larger damage zone.

To analyze the control room fires that would contribute significantly to the risk during shutdown, only those could disrupt the operations of the RHR or the RCS inventory control are considered. These fires may or may not cause impacts on the shutdown accident mitigation equipment. Therefore, the controls for the shutdown accident mitigation equipment need to be located first and then fires with possible combinations of the initiating location and severity that could cover the controls for the equipment of interests are considered. In the following sections, the process of fire scenario identification is described.

9.1.1 Shutdown Accident Mitigation Equipment and Control Locations

As mentioned before, fire scenarios being analyzed are those fires that could possibly cause damages to the controls of the shutdown accident mitigation equipment. To postulate a significant fire scenario, information about the control location for the shutdown accident mitigation equipment is required. The shutdown accident mitigation equipment are taken from the basic events modeled in each of the fault trees developed for the event tree functional top events. These fault tree models include

Control Room Fire Analysis

1. RCS makeup at mid-loop,
2. Restoration of RHR,
3. Steam generator reflux cooling,
4. RCS feed and bleed, and
5. RCS gravity feed.

The basic events list is provided in Table 9-1. Also provided in the table is the basic event description. Because the description provides sufficient information to determine its associated equipment in most cases, the conversion of the basic events into equipment is not performed. Instead, only annotations in parentheses are added to those basic events that require more information for identifying the associated equipment. Also noted in this table, for the equipment with different failure modes modeled (e.g., component cooling water pump 1B fails to start on demand, designated as CCW-MDP-FS-CCP1B, and fails to run, CCW-MDP-FR-CCP1B), more than one basic event may be listed. A screening is first performed to exclude those basic events that are not of interest, such as human errors, common cause faults, maintenance and testing events, and equipment that is not equipped with a control feature in the main control room. This equipment includes check valve, manual valve, heat exchanger, strainer, tank, pipe segment, and air dryer.

The remaining basic events are thus used as the source of information for generating the list of potential shutdown accident mitigation equipment that can be controlled from the main control room.

The outline drawings (Ref. 9-3) for the control boards and panels are used to locate the controls for each piece of equipment listed in Table 9-1. The outline drawings provide information about the physical arrangement of the instrumentation and control (such as indicators, annunciators, controllers, recorders, control switches, etc.) on the front panels. The control location of the shutdown accident mitigation equipment identified in this review process is presented in Table 9-2. The location information in Table 9-2 is listed in terms of the control board and the subsection on the control board. For example, the controls for charging pumps 1A, 1B, and 1C are all located on the BenchBoard 1-1, subsection 3W, thus the location is identified as BB-1-1 (3W). Based on the control locations, the fire-induced impact on the controls of the shutdown accident mitigation equipment is postulated for the significant fire scenarios.

9.1.2 Significant Scenario Identification

To ensure plant safety during mid-loop operation at shutdown, the residual heat generated in the fuel must be removed and water inventory in the reactor coolant system is required to be controlled at a level where the mid-loop operation can be successfully performed. The RHR system is used to provide the residual heat removal function. The reactor coolant inventory control is maintained by the charging and letdown operations. If a fire event does not cause any perturbation to these two functions, the fire is not considered to be a significant risk contributor. For this reason, the significant fire scenarios in this study are defined as those that might potentially damage the controls for shutdown accident mitigation equipment and interrupt the heat removal or the inventory control function. Therefore, the critical control locations are identified from Table 9-2:

1. Subsections 3AE, 3V, 3W, and 3Z in Benchboard 1-1.
2. Subsections 3A, 3B, 3F, 3G, and 3H in Benchboard 1-2.
3. Subsections 3BC, 3BD, and 3B in Vertical board 1-1.

4. Subsection 3AQ in Vertical Board 1-2.
5. Diesel Generator 1 control panel in Vertical Board 1-6.
6. Diesel Generator 3 control panel in Vertical board 1-7.
7. 120V AC vital bus 1-II.

The failure modes resulting from control damage due to fires are also of interest in the scenario identification process. From the industry experience, the most common failures of the control equipment are open circuits or shorting to ground in the control circuitry. Hot shorts are addressed in several control room fire scenarios in which an undesired operation of the plant equipment is initiated. For example, fire-induced open circuits or shorting to ground in the control circuitry for the operating RHR pump would not have any adverse impact on the continued RHR operation, but a hot short in the circuitry could generate a spurious signal that causes the pump to trip. In this case, only fires with hot shorts are considered since the open circuits or grounding do not have any significant impact. For the postulated scenarios, control failure with open circuit or shorting to ground is generally assumed unless another failure mode is specified.

Fire scenarios are thus postulated by considering the fire-induced control damage in the critical control locations listed above. To provide insights for the scenario postulation, each of the fire scenarios identified is discussed as follows:

BB-1-1: Benchboard 1-1 subsection 3Z contains the controls for the RHR pumps 1A and 1B, the RHR heat exchanger flow control valve HCV1758, the heat exchanger bypass valve HCV1605, the hot leg suction isolation valves MOV1700 and MOV1701, the cold leg injection isolation valves MOV1720A and MOV1720B, and the RHR letdown flow control valve HCV1142. The RHR system provides shutdown cooling when the RCS is depressurized to below 450 psig and cooled to below 350 F. Loss of RHR decay heat removal function induced by fires is the key concern of this scenario. This scenario addresses several ways of failures that might lead to a loss of RHR, and they are

1. failures of both RHR pumps to operate
2. failure of MOV1700 or MOV1701 to remain open
3. failures of MOV1720A and MOV1720B to remain open
4. failure of FCV1605 to control heat exchanger bypass flow
5. failure of HCV1758 to control heat exchanger flow
6. failure of HCV1142 to control letdown flow

Most of the above failures require at least one hot short in the control circuitry.

Control Room Fire Analysis

BB-1-2: Benchboard 1-1 subsections 3W and 3V contain the controls for charging pumps 1A, 1B, and 1C, charging pump cooling pumps 2A and 2B, charging pump service water pumps 10A and 10B, RWST supply isolation valves MOV1115B and MOV1115D, and VCT supply isolation valves MOV1115C and MOV1115E. Operation of the charging pumps requires pump seal cooling from the charging pump cooling system and lube oil cooling from the charging pump service water system. Loss of charging flow and High Hat Safety Injection (HHSI) are considered in this fire scenario which can be induced by

1. failure of the three charging pumps
2. failure of the charging pump cooling pumps
3. failure of the charging pump service water pumps
4. failure of charging pump suction supplies

The above failures require at least one hot short in the control circuitry.

BB-1-3: Benchboard 1-2 subsections 3A and 3B contain the controls for feed breakers 15F1 and 15D1, which provide power from the reserve station service transformers C and A to 4 kV buses F and D, respectively. Buses F and D are the normal power supply to 4 kV buses 1H and 1J which provide the motive power to the charging pumps and the RHR and CCW pumps (via stub buses). Loss of normal power supply to 4 kV buses 1H and 1J is considered in this fire scenario. The above failures require at least one hot short in the control circuitry.

BB-1-4: This scenario addresses fires with a medium severity such that the damage zone covers subsections 3AE and 3Z on Benchboard 1-1. Subsection 3AE contains the controls for the motor-operated isolation valves (1867C and 1867D) at the charging pump discharge to the RCS cold leg, and the low head pressure injection (LHSI) pumps 1A and 1B and their associated valves. Fire-induced closure of these two valves would cause loss of HHSI through the RCS cold legs. The controls in subsection 3Z are as described in scenario BB-1-1. The impact of this scenario is considered as loss of RHR, HHSI through cold legs, and LHSI. The above failures require at least one hot shorts in the control circuitry.

BB-1-5: This scenario addresses fires with a large severity such that the damage zone covers subsections 3AE, 3Z, 3W, and 3V. The controls of interests in these subsections are as described in scenarios BB-1-1, BB-1-2, and BB-1-4. The fire-induced impact is considered as the combined impact of these three scenarios (i.e., loss of RHR, charging flow, HHSI, and LHSI.) The above failures require at least one hot short in the control circuitry.

BB-1-6: This scenario addresses fires with a large severity such that the damage zone covers subsections 3AE, 3Z, 3W, 3V, 3H, 3G, and 3F. Subsections 3H, 3G, and 3F contain the controls for the steam generator PORVs, main steam trip valves, and steam dump valves. The steam generator PORVs or the steam dump valves are required to provide the steam relief path in the event of a loss of RHR. Fire-induced failure of the controls is assumed to cause a loss of SG steam relief path. The controls of interests in subsections 3AE, 3Z, 3W, and 3V are as described in scenarios BB-1-1, BB-1-2, and BB-1-4. The fire-induced impact is considered as loss of RHR, charging flow, HHSI, LHSI, and SG steam relief path. The above failures require at least one hot short in the control circuitry.

- BB-1-7: This scenario addresses fires with a large severity such that the damage zone covers the entire benchboards 1-1 and 1-2. The controls of interests in these boards are as described in scenarios BB-1-1, BB-1-2, BB-1-4, and BB-1-6. The impact of this scenario is considered as the combined impact of the four scenarios (i.e., loss of RHR, charging flow, HHSI, LHSI, steam generator steam relief path, and normal power supply to 4 kV buses 1H and 1J). The above failures require at least one hot short in the control circuitry.
- BB-1-8: This scenario addresses fires with a medium severity such that the damage zone covers subsections 3Z, 3W, and 3V on benchboard 1-1. The controls located in these subsections are as described in scenarios BB-1-1 and BB-1-2. The fire-induced impact is considered as the combined impact of these two scenarios (i.e., loss of RHR, charging flow, and HHSI). The above failures require at least one hot short in the control circuitry.
- BB-1-9: This scenario addresses fires with a large severity such that the damage zone covers subsections 3Z, 3W, 3V, 3H, 3G, and 3F. The controls located in these subsections are as described in scenarios BB-1-1, BB-1-2, and BB-1-6. The fire-induced impact is considered as loss of RHR, charging flow, HHSI, and steam generator steam relief path. The above failures require at least one hot short in the control circuitry.
- BB-1-10: This scenario addresses fires with a large severity such that the damage zone covers subsections 3Z, 3W, 3V, 3H, 3G, 3F, 3B, and 3A in Benchboards 1-1 and 1-2. The controls of interest in these subsections are as described in scenarios BB-1-1, BB-1-2, BB-1-3, and BB-1-6. The impact of this scenario is considered as loss of RHR, charging flow, HHSI, steam generator steam relief path, and normal power supply to 4 kV buses 1H and 1J. The above failures require at least one hot short in the control circuitry.
- BB-1-11: This scenario addresses fires with a medium severity such that the damage zone covers subsections 3W, 3V, 3H, 3G, and 3F in Benchboards 1-1 and 1-2. The controls of interest in these subsections are as described in scenarios BB-1-2 and BB-1-6. The impact of this scenario is considered as loss of charging flow, HHSI, and steam generator steam relief path. The above failures require at least one hot short in the control circuitry.
- BB-1-12: This scenario addresses fires with a large severity such that the damage zone covers subsections 3W, 3V, 3H, 3G, 3F, 3B, and 3A in Benchboards 1-1 and 1-2. The controls of interest in these subsections are as described in scenarios BB-1-2, BB-1-3, and BB-1-6. The impact of this scenario is considered as loss of charging flow, HHSI, steam generator steam relief path, and normal power supply to 4 kV buses 1H and 1J. The above failures require at least one hot short in the control circuitry.
- BB-1-13: This scenario addresses fires with a large severity such that the damage zone covers subsections 3H, 3G, 3F, 3B, and 3A in Benchboard 1-2. The controls of interest in these subsections are as described in scenarios BB-1-3 and BB-1-6. The impact of this scenario is considered as loss of steam generator steam relief path and normal power supply to 4 kV buses 1H and 1J. The above failures require at least one hot short in the control circuitry.

Control Room Fire Analysis

- VB-1-1: Vertical Board 1-1 subsection 3BH contains the controls for CCW return headers A and B trip valves TV109A and TV109B. The CCW system provides cooling water to the RHR heat exchangers for decay heat removal and the RHR pump seal coolers. Fire-induced closure of both valves would block the CCW return flow which, in turn, fails the CCW system. The failures described in this scenario does not require a hot short.
- VB-1-2: Vertical Board 1-1 subsections 3BD and 3BC contain the controls for the charging pump suction and discharge isolation valves (MOV1267A and MOV1286A for pump 1A, MOV1269A and MOV1286B for pump 1B, and MOV1270A and MOV1286C for pump 1C). Failure of the suction isolation valves or the pump discharge isolation valves to remain open would cause loss of charging flow and HHSI which is considered in this fire scenario. The above failures require at least one hot short in the control circuitry.
- VB-1-3: Vertical Board 1-2 subsection 3AQ contains the control for CCW pumps 1A and 1B. RHR shutdown cooling requires heat removal by the CCW system. Loss of the CCW system is the key concern of this fire scenario. The above failures require at least one hot short in the control circuitry.
- VB-1-4: This scenario addresses fires with a medium severity such that the damage zone covers subsections 3BH, 3BD, and 3BC on the Vertical Board 1-1. The controls located in these subsections are as described in scenarios VB-1-1 and VB-1-2. The fire-induced impact is thus the combined impact of these two scenarios (i.e., loss of CCW, charging flow, and HHSI). The above failures require at least one hot short in the control circuitry.
- VB-1-5: This scenario addresses fires with a medium severity such that the damage zone covers subsections 3AQ, 3BD, and 3BC in Vertical Boards 1-1 and 1-2. The controls of concern located in these subsections are as described in scenarios VB-1-2 and VB-1-3. The fire-induced impact is thus the combined impact of these two scenarios (i.e., loss of CCW, charging flow, and HHSI). The above failures require at least one hot short in the control circuitry.
- VB-1-6: This scenario addresses fires with a large severity such that the damage zone covers subsections 3AQ, 3BD, 3BC, and 3BH in Vertical Boards 1-1 and 1-2. The controls of concern located in these subsections are as described in scenarios VB-1-1, VB-1-2 and VB-1-3. The fire-induced impact is thus the combined impact of these three scenarios (i.e., loss of CCW, charging flow, and HHSI). The above failures require at least one hot short in the control circuitry.
- VB-6-DG1: The diesel generator No. 1 control panel in Vertical Board 1-6 contains the controls for diesel generator No. 1, the feed breakers (ACB 15H8 from the normal supply 4 kV bus F and ACB 15H3 from the emergency supply) to the 4 kV bus 1H, and the tie breaker 15H1 (from 4 kV bus 1J). Fire-induced failure of the controls could cause a loss of 4 kV bus 1H which, in turn, fails the power supply to one train of the charging, RHR, and CCW pumps. The above failures require at least one hot short in the control circuitry.
- VB-7-DG3: The emergency diesel generator 3 control panel in Vertical Board 1-7 contains the controls for diesel generator 3, which is shared with Unit 2, and the feed breakers (ACB 15J8 from the normal supply and ACB 15J3 from the emergency supply). Failure of these controls induced by fires may lead to a loss of 4 kV bus 1J which would cause the loss of power supply to one

train of the charging, RHR, and CCW pumps. However, this train is assumed to be the standby train.

VBC-1-II-1: The 120V AC vital bus 1-II supplies control power for the CCW return header B trip valve TV109B. Failure of this vital AC bus causes closure of the valve which can lead to a loss of CCW cooling to the RHR heat exchanger in service. The failures described in this scenario does not require hot short.

Fire scenario involving individual failure of the controls in subsection 3AE in benchboard 1-1 or subsections 3H, 3G, and 3F in Benchboard 1-2 is not included in the above list because the impact does not cause any disturbance to the RHR or charging systems. However, the control damages are evaluated with some other control failures that would cause a loss of RHR (e.g., scenario BB-1-4).

Fires in the 125V DC cabinets 1-1 and 1-2 and the 120V AC cabinet 1-1 located inside Vertical Board 1-2 are not evaluated in this analysis. This is based on a review of the loads that are supplied by the cabinets (load list in Ref. 9-3). This leads to a conclusion that no significant impact due to fires can be resulted.

The identified MCR fire scenarios are summarized in Table 9-3. A preliminary screening is performed to exclude those fire scenarios that are judged to be highly unlikely or insignificant. The screening is based on the following observations:

1. The voltage of the electrical equipment in the MCR is relatively low (e.g., 120 V, 24 V, etc.), thus the likelihood of a severe fire that could cause a large damage zone in a short period of time is deemed to be extremely low.
2. Fires inside the MCR cabinets are expected to generate smoke and odors that would catch the attention of the operators immediately which would prevent the fires from further progression to cause severe damage.
3. Fires are assumed not to spread and damage any components outside the cabinet. This assumption is based upon the cabinet configurations within the Surry MCR and the cabinet fire test results in Reference 9-4.

Thus, only fires that occur within a cabinet are considered. Furthermore, of the 451 actual fire events in the industrial fire event data base (Reference 9-1), there is no evidence of cabinet-to-cabinet fire propagation, and for the actual fire events, none of the cabinet fires that has a fire damage zone with a radius greater than 5 feet. For these reasons, a severe fire that would cover several control subsections (or clusters) is judged to be unlikely. To accommodate the uncertainty about this issue, it is conservatively assumed any fires with a fire radius more than 8 feet are excluded from this analysis. Another qualitative evaluation is based on the scenario impact which screened out fire scenario VB-7-DG3 due to no initiating event involved. The results of this preliminary screening are summarized in the third column of Table 9-3.

9.2 Fire Scenario Quantification

The control room fire scenarios are defined at the location level, i.e., each scenario includes fires that occur near or around a particular subsection in a control board and damage the components in that subsection. Once accounted by the fires, all components are assumed to fail in the subsection being considered. Therefore, the occurrence frequency for each scenario is the expected frequency of all possible fires that occur

Control Room Fire Analysis

within or around the components prescribed by the scenario and damage those components. Thus, the origin of fires may not be limited to the location where the components prescribed by a particular scenario are, it may also include other locations where fires, with significant severity, can propagate from their origins to damage the components. Moreover, only fires that occur within a cabinet are considered in fire propagation analysis and these fires are assumed not to spread and damage any components 8 ft beyond the fire origin or outside the cabinet. This assumption is based upon the cabinet configurations within the Surry MCR and the cabinet fire tests results in Reference 9-4. Furthermore, of the 451 actual fire events in the industrial fire events data base (Reference 9-1), there is no evidence of cabinet-to-cabinet fire propagation. Therefore, the occurrence frequency of the scenarios is limited to fires initiated within a control room cabinet, and fires occur within one section of a cabinet and propagate to another section in the cabinet.

The objective of the scenario frequency assessment is to quantify the Surry-plant-specific MCR fire occurrence frequency for each scenario with the following considerations:

1. The scenario frequency must consistently account for actual empirical industry data and any Surry-plant-specific experience in control room related fires.
2. The scenario frequency must provide a conservative upper bound for the actual frequency of more detailed event scenarios that may eventually be developed for the location. In other words, the total scenario frequency may be consistently subdivided to more realistically represent any specific event scenario in the location, if it is necessary to develop more detailed models for the location.

The MCR fire scenario occurrence frequency assessment is performed according to the following steps:

1. Collect plant information.
2. Specialize empirical industrial fire events data base.
3. Apply Bayesian update to obtain Surry-plant-specific MCR fire frequency.
4. Apportion the MCR fire frequency to individual cabinets.
5. Assess occurrence frequency for each fire scenario.

Descriptions of the above steps and their results are presented in the following sections.

9.2.1 Control Room Walkdown

The Surry MCR was visited by a fire risk analysis team member at the beginning of the analysis. The purposes of the visit included:

1. to familiarize himself with the configuration of the MCR,
2. to examine plant-specific features that might affect the basis for and assumptions of the frequency assessment,
3. to evaluate the traffic level and transient fuel loadings inside the MCR,

4. to identify combustible fuels outside the MCR and assess the possibility of fire propagation from these fuels into the MCR, and
5. to observe the back side of each control panel inside the MCR and assess a relative weight ratio of the amount of combustible fuels within each section of the panels observed.

The control room visit resulted in the following observations:

1. Relay cabinets were not found in the MCR, and there was no specific plant features that deviate the Surry MCR from a typical nuclear power plant control room.
2. Although the traffic levels and transient combustible loadings at the MCR during shutdown were considerably higher than during normal operation, all activities within the MCR were closely supervised by the operators. Any fire precursors would be suppressed before a more severe situation could develop. Therefore, the increase in traffic is not expected to significantly increase the frequency of transient fires in the MCR during shutdown.
3. There was no significant amount of transient and in-situ combustibles outside the MCR that have the severity of damaging components within the MCR, if ignited, and affect the operability of the MCR.
4. The first three columns of Table 9-4 summarize the relative weight ratio of combustibles (mainly cables and circuit boards) as observed from the back of the panels during the plant visit. (Note that the rest of Table 9-4 contains materials to be presented in the following sections.)

9.2.2 Industrial Fire Events Specialization

One important step in the fire occurrence frequency assessment for events that lack sufficient plant specific experience is to apply relevant empirical industrial experience of similar situations. Since there have not been any MCR fires at Surry during the past years of its operation, the revised Sandia generic fire event data base (Ref. 9-1) is used as a basis for the Bayesian update process. The data base contains 451 actual fire events that occurred in U.S. nuclear power plants. Only a portion of these events is relevant to the Surry control room operations; therefore, the data base has to be reviewed thoroughly to select only the relevant events to develop a "specialized" generic data base for the Surry MCR. The data base should account for design features of the Surry MCR and characteristics of the hazard sources that can be found in the MCR during shutdown.

In order to be consistent with the fire frequency assessment performed for the rest of the plant areas at Surry, a "one-stage" Bayesian approach is taken and the specialized data base is developed accordingly. Two pieces of information are required for the formation of the specialized data base: (1) the number of relevant control room fire incidents, and (2) the number of years that the nuclear industry has accumulated for the control room experience.

Fire events that occurred in control rooms were first selected from the empirical database provided in Reference 9-1 and their event summaries were reviewed to determine their applicability to the analysis. Fire

Control Room Fire Analysis

events that are classified to occur in control buildings in Reference 9-1 were also screened for their applicability to the Surry control room. This was to ensure the completeness of the fire event data search and to avoid any possible misclassification of fire location in Reference 9-1 since control room is a compartment in a control building.

Several control room related fire events and all control building related fire events were screened out and were not included in the specialized database. This may be because of one the following reasons:

1. the event denotes a fire precursor condition only and no adjacent components were affected,
2. the events involves only component failures and such failures have been accounted for in the component failure database,
3. the event denotes a fire occur in a control building but outside of a control room,
4. the event relates to components or operations that are not present in the Surry MCR,
5. the event resulted from a sabotage or arson attempt,
6. the event describes a fire scenario due to violation of procedures, or
7. the event describes a fire scenario that occurred during construction and would not occur in the Surry MCR during shutdown.

After the empirical database was screened, seven control room events were included in the specialized database. It is noted that although some events occurred during normal power operation, it is judged that such events are also likely to occur during shutdown and, therefore, are included in the database. Table 9-5 summarized the events selected for the specialized database.

In order to account for the number of years of control room experience that the nuclear industry has accumulated, the age of all U.S. commercial nuclear power plants are accumulated. The age is defined as the time between first criticality and the end of december 1989 (or date of decommissioning). Unlike other plant areas where plant operation during shutdown and at power may be different (in terms of combustible loadings), the control room at Surry is considered to have the same characteristics with respect to cabinet fires during both at power and shutdown. Therefore, there is no discount factor for the control room age even only the plant period during shutdown is the focus of this analysis. The fraction of time that the plant in shutdown mode will be considered in the subsequent fault tree and event tree analyses.

It is noted that some of the power plants have more than one reactor unit but are equipped with only one control room, the amount of equipment included in such multiple unit control rooms is significantly higher than those with a single reactor unit. For instance, Surry has 2 reactor units but with only one control room. On the other hand, Beaver Valley has 2 control rooms for its 2 reactor units and Plant Trojan has one control room for its single unit reactor. Therefore, the age of control room experience must be carefully adjusted for on a site-to-site basis for the purpose of control room age estimation. Since most control room fires are

assumed to be originated within control cabinets and control rooms that handle multiple reactor units must have dedicated control cabinets for each unit, those control rooms that handle multiple units are counted as two individual control rooms in terms of control room experience accumulation.

For example, Surry 1 achieved criticality on 7/1/72 which gives 17.51 years - time elapsed between 7/1/72 to 12/31/89 - for its control room age. Surry 2 achieved criticality on 3/7/73, even though it shares the control room with Unit 1, Surry 2 has its dedicated control cabinets. The age of the Surry 2 control room is then equal to the time elapsed between March 3, 1973 and December 12, 1989, which is 16.83 years. Thus, as a site, Surry accumulated a total of 34.34 years of control room experience. This approach is more realistic than the overly conservative approach which only counts the control room age of Surry 1 which would be 17.51 years, even though its control room has twice the amount of equipment than a typical one-unit-one-control-room plant.

Table 9-6 summarizes the control room age estimation. The data included in the table is provided by Reference 9-1. Tables 9-5 and 9-6 form the specialized industrial fire event data base for the Surry control room. There have been 7 relevant control room fire events within 1341.87 adjusted years of control room operation experience. It is also noted that control room experience at Surry 1 is not counted toward the total generic control room age. This data base provides the basis for the industry experience input to the hazard frequency analysis.

9.2.3 Control Room Fire Frequency Assessment

Following the similar approach used in the fire occurrence frequency assessment for other plant areas, a one-stage Bayesian update is used to assess the posterior control room fire frequency. From the specialized data base, there have been seven events in 1341.87 years of control room operation experience. A noninformative lognormal prior is assumed. The industrial experience is entered as the median of the lognormal prior into the RISKMAN Data Analysis Module. The range factor of this generic prior is assumed to be seven. Table 9-7 displays the main characteristics of such prior. The characteristic values of the prior frequency are

Mean	= 1.05E-02 per year
5th percentile	= 7.03E-04 per year
50th percentile	= 5.09E-03 per year
95th percentile	= 3.55E-02 per year

The Surry-plant-specific experience on control room fires is zero fires in 17.51 years for the Unit 1 portion of the shared control room. Such plant specific information is used to update the prior and form the posterior distribution as shown in Table 9-8. The characteristic values of the posterior frequency for the Surry control room are

Mean	= 7.66E-03 per year
5th percentile	= 6.18E-04 per year
50th percentile	= 3.92E-03 per year
95th percentile	= 2.00E-02 per year

9.2.4 Control Room Fire Frequency Apportionment

The fire frequency obtained in the previous section denotes the frequency of fires, at any size, occur within anywhere in the control room area that houses Unit 1 equipment. To assess the occurrence frequency of fires in different locations within the MCR, the control room fire frequency must be apportioned consistently to different areas.

Because the control room is 24-hour manned, any transient combustible-initiated fire precursors or exposed cable fire precursors will be detected and extinguished immediately; thus, no damage to the vital equipment will be expected. Furthermore, control room cabinet fire test results (Ref. 9-4) and past industrial experience (Ref. 9-1) indicated that (1) fires occurring in a cabinet are very unlikely to propagate and damage components in other cabinets, (2) fires have only occurred in electrical cabinets, and (3) transient combustible-initiated fires have never occurred in the control room area. Therefore, the fire frequency is conservatively apportioned only to the control cabinets in the MCR.

Assuming that the density of combustible loadings (cables, circuit boards) within each cabinet is approximately the same and the equipment within a control board is uniformly distributed and is located in the front and back of the panels only, and the occurrence frequency of fire is directly proportional to the amount of combustibles (cables and circuit boards) inside each cabinets, the control room frequency is first apportioned into the different cabinets based on the panel surface areas. Miscellaneous panels and junction boxes that are not being considered in the scenarios are conservatively assumed to have 10% of the total MCR cabinet surface area. Fire occurrence frequency of individual cabinets is then equal to the product of its normalized surface area ratio to the MCR total fire frequency ($7.66E-3/\text{yr}$). Table 9-9 summarizes the apportionment of the control room fire frequency into different cabinets based on the panel surface area ratios. Because of the additional information regarding the weight ratio (see the first three columns in Table 9-4) of the combustible loadings within Benchboards 1-1 and 1-2, and Vertical Boards 1-1 and 1-2, the frequencies of these boards are combined and then apportioned based on the combustible loading distributions observed during the control room visit. Table 9-4 presents the additional frequency apportionment of the individual sections within Benchboards 1-1 and 1-2, and Vertical Boards 1-1 and 1-2. Since the weight ratios obtained from the walkdown were taken for group subsections of the boards, the fire frequency for each group of panel subsections in Table 9-4 is further apportioned to each individual panel subsection. Following the assumption that the density of combustible loadings within each subsection in a panel section is approximately the same, the subsection frequency can then be obtained using normalized subsection length and the total fire frequency of the panel since all subsections have the same height. Tables 9-10 and 9-11 present the results of the fire frequency apportionment for each panel subsection in Benchboards 1-1 and 1-2, and Vertical Boards 1-1 and 1-2.

9.2.5 Scenario Frequency Quantification

The frequencies presented in Tables 9-9 through 9-11 are the fire occurrence frequencies at each panel subsection. These fire occurring frequencies are then used to assess the occurrence frequency for the scenarios postulated in the previous section with the consideration of the severity of fires occurred at or near the panel subsection of the scenario interested.

The occurrence frequency of a fire scenario in this analysis is defined as the sum of the frequencies of all possible fires that occur in the subsection prescribed by the scenario, and fires that occur in other subsections in the same panel with significant severity that can damage the components in the subsection prescribed by the scenario. Thus, the occurrence frequency of scenario i in control panel board j , $\lambda_{i,j}$, can be expressed as:

$$\lambda_{i,j} = \lambda_{MCR} F_j F_{GS}(i, j)$$

where

- λ_{MCR} = the annual frequency of fire of any severity in the control room
= 7.66E-3 per year (see Table 9-8)
- F_j = the conditional probability of fire of any severity occurring in control board j given a control room fire has occurred, i.e., the normalized ratio of each cabinet presented in Table 9-9
- $F_{GS}(i, j)$ = the conditional frequency, given a fire has occurred in control board j , of having an impact on the area of interest of scenario i .

The conditional frequency $F_{GS}(i, j)$ can be expressed as

$$F_{GS}(i, j) = \sum_k f_g(i, j, k) f_s(i, j, k)$$

where "k" represents a unique set of subsections in control board j for scenario i . The panel subsections included in "k" are those that if a fire occurs in those subsections, it will be severe enough to damage only the panel subsection prescribed by scenario i but not so severe as to affect the adjacent panel subsections whose damage is modeled in other scenarios. The two factors f_g and f_s are generally known as the geometry factor and the severity factor of the subsections included in "k."

The geometry factor and severity factor are interrelated (Ref. 9-5). If the scenario involves the whole control panel, the combined geometry and severity factor, F_{GS} , is 1.0. The geometry factor is used to model the fraction of fires that can be initiated within a specific area, say area m , within the control panel j given that a fire has occurred within j . Thus, the product $\lambda_{MCR} F_j f_g(i, j, k)$ denotes the fire occurrence frequency of panel subsection k in control board j in the MCR, and k is a subsection that can damage the panel subsection prescribed by scenario i . The geometry factor in this analysis is obtained by assessing the normalized length ratio of a subsection to the whole panel.

The severity factor is used to model the fraction of fires at different levels of severity that can occur at subsection k , given a fire occurs at panel subsection k . Severity factors of different fire sizes are obtained from analyzing the fire sizes and damage levels of past actual control cabinet fire incidents reported in Reference 9-6. The severity factor is the probability of fires that can grow and propagate to certain fire sizes,

Control Room Fire Analysis

which is usually measured in terms of fire radius, without being mitigated. Figure 9-2 illustrates the severity factor function developed for control cabinet fires. Since the MCR at Surry is 24-hour manned, any fires should be detected and suppressed immediately, thus the severity function shown in Figure 9-2 is considered to be overly conservative when applied to the Surry MCR. For instance, it is very unlikely that a fire would be allowed to grow and propagate to a distance of more than 5 ft without being interfered with and extinguished. Therefore, the severity factor presented in Figure 9-2 is adjusted by conservatively assuming that the probability of fires with fire radius of over 8 ft is essentially zero.

The following example illustrates the application of the geometry factor and severity factor in the assessment of scenario occurrence frequency:

Scenario BB-1-1-1 postulates failure of RHR pumps A and B control in subsection 3Z of bBenchboard 1-1. Any fires within the benchboard with an appropriate severity that can damage components in subsection 3Z are included. It is conservatively assumed that all fires occurring in a cabinet will spread radially along the length of the cabinet with equal distance, and if a fire can propagate to subsection 3Z, regardless of the actual magnitude of the fire, subsection 3Z is declared to be damaged. To facilitate the analysis, it is further assumed that the center of a fire occurs in a panel subsection at the midpoint of the panel subsection.

The set of fire origin subsections that can damage 3Z is a unique set. If a fire can damage not only 3Z but also subsections 3AE or 3W/3V, such subsection fire will not be included in the unique set for 3Z but will be included in scenarios BB-1-4 or BB-1-8. For example, in order for a fire originating at subsection 3AD to damage subsection 3Z, the fire size must have a fire radius of at least 3.8 ft (midpoint to midpoint distance between panel subsections 3Z and 3AD measured in Ref. 9-3.) With such fire sizes, subsection 3AE will also be damaged. Therefore, fire originating at 3AD, regardless of fire sizes, cannot be included in the unique set of fire origins for subsection 3Z in scenario BB-1-1. For subsection 3AB, the minimum fire size for a fire originating at 3AB in order to damage 3Z will be fires with radius of at least 2.1 ft from midpoint of subsection 3AB. However, if the fires originating at 3AB are allowed to grow and propagate radially, when the fire size reaches a radius of 3.0 ft or more, subsection 3AE will also be damaged. Thus, the effective fire radius for a fire originating in subsection 3AB to damage subsection 3Z is between 2.1 ft and 3.0 ft. Therefore, the conditional probability of fires with a radius of 2.1 ft to 3.0 ft., given the fires occurring in subsection 3AB, must be used. Severity factor $f_s(2.1 \text{ ft})$ denotes the probability of fires with a radius of larger than 2.1 ft before being suppressed eventually, severity $f_s(3.0 \text{ ft})$ denotes the probability of fires with a radius of larger than 3.0 ft before being suppressed eventually.

Similarly, the unique set of subsection fires that can damage subsection 3Z in scenario BB-1-1 includes the following fires:

1. Fires initiating in subsection 3Z with an effective fire radius of 0.0 ft to 4.4 ft,
2. Fires initiating in subsection 3AB with an effective fire radius of 2.1 ft to 3.0 ft,
3. Fires initiating in subsection 3AA with an effective fire radius of 0.9 ft to 4.1 ft, and
4. Fires Initiating in subsection 3Y with an effective fire radius of 1.2 ft to 3.3 ft

The severity factors for each possible subsection fire in this unique set ($k = 3Z, 3AB, 3AA, 3Y$) are then assessed. Using Figure 9-3 and the notation in the above expressions, the severity factor for fires originating in subsection 3AB to damage 3Z in scenario BB-1-1 is:

$$f_s(i=BB-1-1, j=BB\ 1-1, k=3AB) = f_s(2.1\text{ ft.}) - f_s(3.0\text{ ft.}) = 0.23 - 0.08 = 0.153.$$

Table 9-12 summarizes the fire origin identification, effective fire radius estimation, and severity factor assessment for all scenarios retained from the preliminary screening. It is noted that the effective fire radius for the fires being considered cannot be greater than 8.0 ft.

Once the unique set of subsection fires is identified for scenario BB-1-1, the geometry factor for each subsection (3Z, 3AB, 3AA, and 3Y) included in the unique set is required. The geometry factor for subsection 3Z is the fraction of fires that can occur at 3Z, given a fire has occurred in benchboard 1-1. This geometry factor is equal to the normalized ratio presented in Table 9-10, i.e., the geometry factor $f_g(i=BB-1-1, j=BB\ 1-1, k=3AB)$ is 0.613. The product of the total MCR fire frequency and the geometry factor of 3AB gives the frequency of fires occurring at subsection 3AB.

The product of the geometry factor and severity factor for scenario BB-1-1, $f_g f_s(i=BB-1-1, j=BB\ 1-1, k=3AB)$ denotes the frequency of fires occurring at subsection 3AB and damaging subsection 3Z only before being suppressed. The total of such frequency for all panel subsections included in the unique set k (3Z, 3AB, 3AA, and 3Y) is the frequency of subsection 3Z being damaged in a configuration denoted by scenario BB-1-1.

Since at least one hot short in the circuitry within subsection 3Z is required for the damage of the control of RHR pump A or other RHR system valves, the probability of hot short must be accounted for in scenario BB-1-1. In some scenarios, more than one hot short may be required to disable the control; it is conservatively assumed that only one hot short is needed to upper bound the hot short failure mode required for the fire scenario to occur. Using the hot short probability assessed in Appendix E, a failure mode factor of 0.1 is multiplied to the combined severity and geometry factor/fire frequency of scenario BB-1-1 to obtain the scenario occurrence frequency ($2.04E-5$ per year). For scenarios that do not require a hot short to disable the control described in the scenarios, the failure mode factor is essentially equal to one.

Similarly, the scenario occurrence frequency for other scenarios is assessed, and the summary of the scenario occurrence frequency assessment is presented in Table 9-12. It is noted that these scenario occurrence frequencies are on a yearly basis, the fraction of such frequencies applied to mid-loop are considered in the subsequent fault tree/event tree analysis.

9.3 References

1. "Nuclear Power Plant Fire Data Base," based on NUREG/CR-4586, SAND86-0300, and EPRI NP-3179, updated, June 1992.
2. 10 CFR 50 Appendix R Report, Surry Power Plant - Units 1 and 2, Revision 7, October 1990

Control Room Fire Analysis

3. Outline Drawing 11448-RE-25A, Benchboard Section 1-1, Rev 15
Outline Drawing 11448-RE-25B, Benchboard Section 1-2, Rev 11
Outline Drawing 11448-RE-25C, Main Control Board Vertical Section 1-1, Rev 16
Outline Drawing 11448-RE-25D, Main Control Board Vertical Section 1-2, Rev 14
Outline Drawing 11448-RE-25E, Benchboard Section 1-3, Rev 3
Outline Drawing 11448-RE-25F, Benchboard Section 1-4, Rev 3
Outline Drawing 11448-RE-25G, Benchboard Section 1-5, Rev 1
Outline Drawing 11448-RE-25H, Benchboard Section 1-6, Rev 8
Outline Drawing 11448-RE-25J, Benchboard Section 1-7, Rev 2
Loading Table 11448-FE-11AD, Bus Distribution Panel AC 1-1, Rev 3
Loading Table 11448-FE-11AE, Bus Distribution Panels DC 1-1 & DC 1-2, Rev 4
4. J.M. Chavez, "An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets, Part I - Cabinet Effects Tests," NUREG/CR-4527, Sandia National Laboratories, April 1987.
5. Pickard, Lowe and Garrick, Inc., "Seismic and Fire Risk Analysis for A Typical Japanese 4-Loop PWR Plant," PLG-0642, July 1988
6. PLG, Inc., "Database for Probabilistic Risk Assessment of Light Water Nuclear Power Plants - Fire Data," Volume, PLG-0500, Revision 0, October 1990.

Figure 9.1 Surry Unit 1 Main Control Room Equipment Arrangement

Figure 9.2 $F_s(r)$ for Control Room Fires
9-20

Figure 9.3 Illustration of Five Severity Factor Calculations for Scenario BB-1-1

Control Room Fire Analysis

Table 9.1 List of Surry Unit 1 Shutdown PRA Basic Events for Equipment with Controls in Main Control Room

Basic Event Designator	Comp. ID	Basic Event Description
ACP-BAC-ST-V1111	V1111	VITAL BUS 1111 BUSWORK FAILURE
ACP-BAC-ST-VB11	VB11	VITAL BUS 11 BUSWORK FAILURE
ACP-BAC-ST-VB111	VB111	VITAL BUS 111 BUSWORK FAILURE
ACP-CRB-CO-14H1	14H1	AC CIRCUIT BREAKER 14H1 TRANSFERS OPEN (480V BUS 1H FEED BKR)
ACP-CRB-CO-14H13	14H13	AC CIRCUIT BREAKER 14H13 TRANSFERS OPEN (480V MCC 1H1-2 FEED BKR)
ACP-CRB-CO-14H14	14H14	AC CIRCUIT BREAKER 14H14 TRANSFERS OPEN (480V MCC 1H1-1 FEED BKR)
ACP-CRB-CO-14H15	14H15	AC CIRCUIT BREAKER 14H15 TRANSFERS OPEN (480V BUS 1H1 FEED BKR)
ACP-CRB-CO-14J1	14J1	AC CIRCUIT BREAKER 14J1 TRANSFERS OPEN (480V BUS 1J FEED BKR)
ACP-CRB-CO-14J11	14J11	AC CIRCUIT BREAKER 14J11 TRANSFERS OPEN (480V BUS 1J1 FEED BKR)
ACP-CRB-CO-14J14	14J14	AC CIRCUIT BREAKER 14J14 TRANSFERS OPEN (480V BUS 1J1-2 FEED BKR)
ACP-CRB-CO-14J16	14J16	AC CIRCUIT BREAKER 14J16 TRANSFERS OPEN (480V BUS 1J1-1 FEED BKR)
ACP-CRB-CO-15H7	15H7	AC CIRCUIT BREAKER 15H7 TRANSFERS OPEN (4KV BUS 1H TO 4KV/480V XFMR BKR)
ACP-CRB-CO-15H8	15H8	AC CIRCUIT BREAKER 15H8 TRANSFERS OPEN (BUS 1H FEED BKR, FROM BUS F)
ACP-CRB-CO-15H9	15H9	AC CIRCUIT BREAKER 15H9 TRANSFERS OPEN (4KV BUS 1H TO STUB BUS BKR)
ACP-CRB-CO-15J7	15J7	AC CIRCUIT BREAKER 15J7 TRANSFERS OPEN (4KV BUS 1J TO 4KV/480V XFMR BKR)
ACP-CRB-CO-15J8	15J8	AC CIRCUIT BREAKER 15J8 TRANSFERS OPEN (BUS 1J FEED BKR, FROM BUS D)
ACP-CRB-CO-15J9	15J9	AC CIRCUIT BREAKER 15J9 TRANSFERS (4KV BUS 1J TO STUB BUS BKR)
ACP-CRB-CO-1135	1135	VITAL BUS 11 AC CKT BREAKER 35 TRANSFERS OPEN
ACP-CRB-CO-111	111	AC CIRCUIT BREAKER TO 111 TRANSFERS OPEN
ACP-CRB-CO-FE9AE	FE9AE	AC CIRCUIT BREAKER FE9AE TRANSFERS OPEN
ACP-CRB-CO-FE9AF	FE9AF	AC CIRCUIT BREAKER FE9AF TRANSFERS OPEN
ACP-CRB-CO-FE9AJ	FE9AJ	AC CIRCUIT BREAKER FE9AJ TRANSFERS OPEN
ACP-CRB-CO-FE9AK	FE9AK	AC CIRCUIT BREAKER FE9AK TRANSFERS OPEN
ACP-CRB-CO-FE9BE	FE9BE	AC CIRCUIT BREAKER FE9BE TRANSFERS OPEN
ACP-CRB-CO-FE9BJ	FE9BJ	AC CIRCUIT BREAKER FE9BJ TRANSFERS OPEN
ACP-CRB-CO-FE9BK	FE9BK	AC CIRCUIT BREAKER FE9BK TRANSFERS OPEN
ACP-CRB-CO-11135	11135	VITAL BUS 1111 AC CKT BRKR 35 TRANSFERS OPEN
CCW-AOV-OC-109A		CC-TV-109A TRANSFERS CLOSED (CCW RETURN HEADER A TCV)
CCW-AOV-OC-109B		CC-TV-109B TRANSFERS CLOSED (CCW RETURN HEADER B TCV)
CCW-MDP-FR-CCP1A	CCP1A	1-CC-P-1A FAILS TO RUN
CCW-MDP-FR-CCP1B	CCP1B	MDP CC-P1B FAILS TO RUN
CCW-MDP-FS-CCP1B	CCP1B	MDP CC-P1B FAILS TO START ON DEMAND
CPC-AOV-FT-108B	108B	AOV TV-CC-108B FAILS TO OPEN
CPC-AOV-FT-108C	108C	AOV TV-CC-108C FAILS TO OPEN
CPC-ICC-FA-SWPBS	SWPBS	NO ACTUATION SIGNAL TO START SW PUMP 10B
CPC-MDP-FR-CC2A	CC2A	MDP CC2A FAILS TO RUN AS LONG AS CHRNG PUMPS (HPI PUMP COOLING WATER PUMP A)
CPC-MDP-FR-CC2B	CC2B	MDP CC2B FAILS TO RUN FOR 24 HOURS (HPI PUMP COOLING WATER PUMP B)
CPC-MDP-FR-SW10A	SW10A	MDP SW10A FAILS TO RUN AS LONG AS PUMPS (HPI PUMP COOLING SERVICE WATER PUMP A)
CPC-MDP-FR-SW10B	SW10B	MDP SW10B FAILS TO RUN FOR 24 HRS (HPI PUMP COOLING SERVICE WATER PUMP B)
CPC-MDP-FS-CC2B	CC2B	MDP CC2B FAILS TO START (HPI PUMP COOLING WATER PUMP B)
CPC-MDP-FS-SW10B	SW10B	MDP SW10B FAILS TO START (HPI PUMP COOLING SERVICE WATER PUMP B)
DCP-BDC-ST-BUS1A	BUS1A	125V DC BUS 1A BUSWORK FAILURE
DCP-BDC-ST-BUS1B	BUS1B	125V DC BUS 1B BUSWORK FAILURE
DCP-CRB-CO-19	19	DC CIRCUIT BREAKER 19 TRANSFERS OPEN
DCP-CRB-CO-20	20	DC CIRCUIT BREAKER 20 TRANSFERS OPEN
DCP-CRB-CO-23	23	DC CIRCUIT BREAKER 23 TRANSFERS OPEN
DCP-CRB-CO-24	24	DC CIRCUIT BREAKER 24 TRANSFERS OPEN
HPI-MDP-FR-1A6HR	1A6HR	CHARGING PUMP CH1A FAILS TO RUN FOR 6 HOURS
HPI-MDP-FR-1B6HR	1B6HR	CHARGING PUMP CH1B FAILS TO RUN FOR 6 HOURS
HPI-MDP-FR-1C12H	1C12H	CHARGING PUMP CH1C FAILS TO RUN FOR 12 HOURS
HPI-MDP-FS-CH1B	CH1B	CHARGING PUMP CH1B FAILS TO START ON DMD
HPI-MDP-FS-CH1C	CH1C	CHARGING PUMP CH1C FAILS TO START ON DMD
HPI-MOD-FT-101B		MOTOR OPERATED DAMPER MOD-101B FAILS TO OPEN

Table 9.1 List of Surry Unit 1 Shutdown PRA Basic Events for Equipment with Controls in Main Control Room (continued)

Basic Event Designator	Comp. ID	Basic Event Description
HPI-MOD-FT-101C		MOTOR OPERATED DAMPER MOD-101C FAILS TO OPEN
HPI-MOV-FT-1115B	1115B	HPI MOV 1115B FAILS TO OPEN ON DEMAND (RWST SUPPLY TO HPI PUMP ISOL VLV)
HPI-MOV-FT-1115C	1115C	HPI MOV 1115C FAILS TO CLOSE (VCT SUPPLY TO HPI PUMP ISOL VLV)
HPI-MOV-FT-1115D	1115D	HPI MOV 1115D FAILS TO OPEN ON DEMAND (RWST SUPPLY TO HPI PUMP ISOL VLV)
HPI-MOV-FT-1115E	1115E	HPI MOV 1115E FAILS TO CLOSE (VCT SUPPLY TO HPI PUMP ISOL VLV)
HPI-MOV-FT-1867C	1867C	HPI MOV 1867C FAILS TO OPEN ON DEMAND (HPI PUMP DISCH TO COLD LEGS ISOL VLV)
HPI-MOV-FT-1867D	1867D	HPI MOV 1867D FAILS TO OPEN ON DEMAND (HPI PUMP DISCH TO COLD LEGS ISOL VLV)
HPI-MOV-PG-1269A	1269A	MOTOR OPERATED VALVE 1269A PLUGGED (HPI PUMP B SUCTION ISOL VLV)
HPI-MOV-PG-1270A	1270A	MOTOR OPERATED VALVE 1270A PLUGGED (HPI PUMP C SUCTION ISOL VLV)
HPI-MOV-PG-1286B	1286B	MOTOR OPERATED VALVE 1286B PLUGGED (HPI PUMP B DISCH ISOL VLV)
HPI-MOV-PG-1286C	1286C	MOTOR OPERATED VALVE 1286C PLUGGED (HPI PUMP C DISCH ISOL VLV)
IAS-AOV-FT-TV126		IA-TV-126 FAILS TO OPEN
IAS-AOV-PG-TV125		IA-TV-125 PLUGGED
IAS-CPS-FR-IAC-1		TURBINE BUILDING IA COMPRESSOR IA-C-1 FAILS TO RUN
IAS-CPS-FS-IAC-1		TURBINE BUILDING IA COMPRESSOR IA-C-1 FAILS TO START
LPI-MDP-FR-1A1HR	1A1HR	LPI MDP SI1A FAILS TO RUN FOR 1 HOUR
LPI-MDP-FR-1B1HR	1B1HR	LPI MDP SI1B FAILS TO RUN FOR 1 HOUR
LPI-MDP-FS-SI1A	SI1A	LPI MDP SI1A FAILS TO START ON DEMAND
LPI-MDP-FS-SI1B	SI1B	LPI MDP SI1B FAILS TO START ON DEMAND
LPI-MOV-CC-1890C		LPI MOV- 1890C FAILS TO OPEN (LPI PUMP DISCH TO COLD LEGS ISOL VLV)
LPI-MOV-PG-1862A	1862A	LPI MOTOR OPER VALVE 1862A PLUGGED (LPI PUMP A SUCTION ISOL VLV)
LPI-MOV-PG-1862B	1862B	LPI MOTOR OPER VALVE 1862B PLUGGED (LPI PUMP B SUCTION ISOL VLV)
LPI-MOV-PG-1864A	1864A	LPI MOTOR OPERATED VALVE 1864A PLUGGED (LPI PUMP A DISCH TO COLD LEGS ISOL VLV)
LPI-MOV-PG-1864B	1864B	LPI MOTOR OPERATED VALVE 1864B PLUGGED (LPI PUMP B DISCH TO COLD LEGS ISOL VLV)
MSS-AOV-FC-101A	101A	SG A PORV BLOCKED
MSS-AOV-FC-101B	101B	SG B PORV BLOCKED
MSS-AOV-FC-101C	101C	SG C PORV BLOCKED
MSS-AOV-FT-101A	101A	SG A PORV FAILS TO OPEN
MSS-AOV-FT-101B	101B	SG B PORV FAILS TO OPEN
MSS-AOV-FT-101C	101C	SG C PORV FAILS TO OPEN
MSS-NRV-FT-101A		NRV FAILS TO OPEN (MAIN STEAM NON-RETURN VLV A)
MSS-NRV-FT-101B		NRV FAILS TO OPEN (MAIN STEAM NON-RETURN VLV B)
MSS-NRV-FT-101C		NRV FAILS TO OPEN (MAIN STEAM NON-RETURN VLV C)
MSS-STV-FT-101A		MSTV FAILS TO OPEN (MAIN STEAM TRIP VLV A)
MSS-STV-FT-101B		MSTV FAILS TO OPEN (MAIN STEAM TRIP VLV B)
MSS-STV-FT-101C		MSTV FAILS TO OPEN (MAIN STEAM TRIP VLV C)
OEP-BAC-ST-FDRD	FDRD	RESERVE STATION SERVICE FEEDER D BUSWORK FAILS (BKR 15D1, RSS XFMR TO BUS D)
OEP-BAC-ST-FDRF	FDRF	RESERVE STATION SERVICE FEEDER F BUSWORK FAILS (BKR 15F1, RSS XFMR TO BUS F)
OEP-CRB-FT-15H3	15H3	DIESEL GEN #1 CKT BRKR 15H3 FAILS TO CLOSE (BUS 1H FEED BKR, FROM DG 1)
OEP-CRB-FT-15J3	15J3	DIESEL GEN #3 CKT BRKR 15J3 FAILS TO CLOSE (BUS 1J FEED BKR, FROM DG 3)
OEP-DGN-FC-DG3U2	DG3U2	DIESEL GEN #3 UNAVAIL, ALIGNED TO UNIT 2
OEP-DGN-FR-DG01	DG01	DG 1 FAILS TO RUN 1 HR
OEP-DGN-FR-DG03	DG03	DG 3 FAILS TO RUN 1 HR
OEP-DGN-FS-DG01	DG01	DIESEL GENERATOR #1 FAILS TO START
OEP-DGN-FS-DG03	DG03	DIESEL GENERATOR #3 FAILS TO START
PCS-AOV-FT-BYPA	BYPA	A BYPASS VALVE FAIL TO OPEN TCV 107/8A
PCS-AOV-FT-BYPB	BYPB	B BYPASS VALVE FAIL TO OPEN TCV 107/8B
PCS-AOV-FT-MSTVA	MSTVA	A BYPASS VALVE TCV 105/6A FAILS TO OPEN
PCS-AOV-FT-MSTVB	MSTVB	B BYPASS VALVE TCV 105/6B FAILS TO OPEN
PCS-AOV-PG-BYPA		A BYPASS TCV 107/8A PLUGGED
PCS-AOV-PG-BYPB		B BYPASS TCV 107/8B PLUGGED
PCS-AOV-PG-MSTVA	MSTVA	A BYPASS VALVE TCV 105/6A PLUGGED

Control Room Fire Analysis

Table 9.1 List of Surry Unit 1 Shutdown PRA Basic Events for Equipment with Controls in Main Control Room (continued)

Basic Event Designator	Comp. ID	Basic Event Description
PCS-AOV-PG-MSTVB	MSTVB	B BYPASS VALVE TCV 105/6B PLUGGED
RHR-AOV-CO-1758		AOV 1758 OPENS SPURIOUSLY (RHR HX FCV)
RHR-AOV-OC-1758	1758	HCV-1758 FAILS SHUT (RHR HX FCV)
RHR-AOV-OO-1605	1605	FCV-1605 TRANSFERS FULLY OPEN AND REMAINS OPEN (RHR HX BYPASS FCV)
RHR-MDP-FR-A24HR	A24HR	RHR MDP 1A FAILS TO RUN 24 HOURS
RHR-MDP-FR-B24HR	B24HR	RHR MDP 1B FAILS TO RUN FOR 24 HOURS
RHR-MDP-FS-RHR1A	RHR1A	RHR MDP 1A FAILS TO START ON DEMAND
RHR-MDP-FS-RHR1B	RHR1B	RHR MDP 1B FAILS TO START ON DEMAND
SAS-CPS-FR-1SAC1		SERVICE AIR COMPRESSOR 1-SA-C-1 FAILS TO RUN
SAS-CPS-FR-2SAC1		SERVICE AIR COMPRESSOR 2-SA-C-1 FAILS TO RUN
SEMI-VIT-BUS		FAILURE OF SEMI-VITAL BUS
SP-SI-CLSI-HE		SPURIOUS SI/CLSI SIGNAL
SW-AOV-FT-SW263		1-SW-263 FAILS CLOSED ON LOSS OF OFFSITE POWER

Control Room Fire Analysis

Table 9.2 Control Locations for Surry Unit 1 Shutdown Accident Mitigation Equipment

Location of Control	Basic Event Designator	Comp. ID	Basic Event Description
BB 1-1 (3AE)	HPI-MOV-FT-1867C	1867C	HPI MOV 1867C FAILS TO OPEN ON DEMAND (HPI PUMP DISCH TO COLD LEGS ISOL VLV)
BB 1-1 (3AE)	HPI-MOV-FT-1867D	1867D	HPI MOV 1867D FAILS TO OPEN ON DEMAND (HPI PUMP DISCH TO COLD LEGS ISOL VLV)
BB 1-1 (3AE)	LPI-MDP-FR-1A1HR	1A1HR	LPI MDP S11A FAILS TO RUN FOR 1 HOUR
BB 1-1 (3AE)	LPI-MDP-FR-1B1HR	1B1HR	LPI MDP S11B FAILS TO RUN FOR 1 HOUR
BB 1-1 (3AE)	LPI-MDP-FS-S11A	S11A	LPI MDP S11A FAILS TO START ON DEMAND
BB 1-1 (3AE)	LPI-MDP-FS-S11B	S11B	LPI MDP S11B FAILS TO START ON DEMAND
BB 1-1 (3AE)	LPI-MOV-CC-1890C		LPI MOV- 1890C FAILS TO OPEN (LPI PUMP DISCH TO COLD LEGS ISOL VLV)
BB 1-1 (3AE)	LPI-MOV-PG-1862A	1862A	LPI MOTOR OPER VALVE 1862A PLUGGED (LPI PUMP A SUCTION ISOL VLV)
BB 1-1 (3AE)	LPI-MOV-PG-1862B	1862B	LPI MOTOR OPER VALVE 1862B PLUGGED (LPI PUMP B SUCTION ISOL VLV)
BB 1-1 (3AE)	LPI-MOV-PG-1864A	1864A	LPI MOTOR OPERATED VALVE 1864A PLUGGED (LPI PUMP A DISCH TO COLD LEGS ISOL VLV)
BB 1-1 (3AE)	LPI-MOV-PG-1864B	1864B	LPI MOTOR OPERATED VALVE 1864B PLUGGED (LPI PUMP B DISCH TO COLD LEGS ISOL VLV)
BB 1-1 (3AE)	SP-SI-CLSI-HE		SPURIOUS SI/CLSI SIGNAL
BB 1-1 (3V)	CPC-ICC-FA-SWPBS	SWPBS	NO ACTUATION SIGNAL TO START SW PUMP 10B
BB 1-1 (3V)	CPC-MDP-FR-CC2B	CC2B	MDP CC2B FAILS TO RUN FOR 24 HOURS (HPI PUMP COOLING WATER PUMP B)
BB 1-1 (3V)	CPC-MDP-FR-SW10B	SW10B	MDP SW10B FAILS TO RUN FOR 24 HRS (HPI PUMP COOLING SERVICE WATER PUMP B)
BB 1-1 (3V)	CPC-MDP-FS-CC2B	CC2B	MDP CC2B FAILS TO START (HPI PUMP COOLING WATER PUMP B)
BB 1-1 (3V)	CPC-MDP-FS-SW10B	SW10B	MDP SW10B FAILS TO START (HPI PUMP COOLING SERVICE WATER PUMP B)
BB 1-1 (3W)	CPC-MDP-FR-CC2A	CC2A	MDP CC2A FAILS TO RUN AS LONG AS CHRGNG PUMPS (HPI PUMP COOLING WATER PUMP A)
BB 1-1 (3W)	CPC-MDP-FR-SW10A	SW10A	MDP SW10A FAILS TO RUN AS LONG AS PUMPS (HPI PUMP COOLING SERVICE WATER PUMP A)
BB 1-1 (3W)	HPI-MDP-FR-1A6HR	1A6HR	CHARGING PUMP CH1A FAILS TO RUN FOR 6 HOURS
BB 1-1 (3W)	HPI-MDP-FR-1B6HR	1B6HR	CHARGING PUMP CH1B FAILS TO RUN FOR 6 HOURS
BB 1-1 (3W)	HPI-MDP-FR-1C12H	1C12H	CHARGING PUMP CH1C FAILS TO RUN FOR 12 HOURS
BB 1-1 (3W)	HPI-MDP-FS-CH1B	CH1B	CHARGING PUMP CH1B FAILS TO START ON DMD
BB 1-1 (3W)	HPI-MDP-FS-CH1C	CH1C	CHARGING PUMP CH1C FAILS TO START ON DMD
BB 1-1 (3W)	HPI-MOV-FT-1115B	1115B	HPI MOV 1115B FAILS TO OPEN ON DEMAND (RWST SUPPLY TO HPI PUMP ISOL VLV)
BB 1-1 (3W)	HPI-MOV-FT-1115C	1115C	HPI MOV 1115C FAILS TO CLOSE (VCT SUPPLY TO HPI PUMP ISOL VLV)
BB 1-1 (3W)	HPI-MOV-FT-1115D	1115D	HPI MOV 1115D FAILS TO OPEN ON DEMAND (RWST SUPPLY TO HPI PUMP ISOL VLV)
BB 1-1 (3W)	HPI-MOV-FT-1115E	1115E	HPI MOV 1115E FAILS TO CLOSE (VCT SUPPLY TO HPI PUMP ISOL VLV)
BB 1-1 (3W)	SP-SI-CLSI-HE		SPURIOUS SI/CLSI SIGNAL
BB 1-1 (3Z)	RHR-AOV-CO-1758		AOV 1758 OPENS SPURIOUSLY (RHR HX FCV)
BB 1-1 (3Z)	RHR-AOV-OC-1758	1758	HCV-1758 FAILS SHUT (RHR HX FCV)
BB 1-1 (3Z)	RHR-AOV-OO-1605	1605	FCV-1605 TRANSFERS FULLY OPEN AND REMAINS OPEN (RHR HX BYPASS FCV)
BB 1-1 (3Z)	RHR-MDP-FR-A24HR	A24HR	RHR MDP 1A FAILS TO RUN 24 HOURS
BB 1-1 (3Z)	RHR-MDP-FR-B24HR	B24HR	RHR MDP 1B FAILS TO RUN FOR 24 HOURS
BB 1-1 (3Z)	RHR-MDP-FS-RHR1A	RHR1A	RHR MDP 1A FAILS TO START ON DEMAND
BB 1-1 (3Z)	RHR-MDP-FS-RHR1B	RHR1B	RHR MDP 1B FAILS TO START ON DEMAND
BB 1-2 (3A)	OEP-BAC-ST-FDRF	FDRF	RESERVE STATION SERVICE FEEDER F BUSWORK FAILS (BKR 15F1, RSS XFMR TO BUS F)
BB 1-2 (3B)	OEP-BAC-ST-FDRD	FDRD	RESERVE STATION SERVICE FEEDER D BUSWORK FAILS (BKR 15D1, RSS XFMR TO BUS D)
BB 1-2 (3F)	MSS-AOV-FC-101B	101B	SG B PORV BLOCKED
BB 1-2 (3F)	MSS-AOV-FC-101C	101C	SG C PORV BLOCKED
BB 1-2 (3F)	MSS-AOV-FT-101B	101B	SG B PORV FAILS TO OPEN
BB 1-2 (3F)	MSS-AOV-FT-101C	101C	SG C PORV FAILS TO OPEN
BB 1-2 (3G)	MSS-AOV-FC-101A	101A	SG A PORV BLOCKED

Control Room Fire Analysis

Table 9.2 Control Locations for Surry Unit 1 Shutdown Accident Mitigation Equipment (continued)

Location of Control	Basic Event Designator	Comp. ID	Basic Event Description
BB 1-2 (3G)	MSS-AOV-FT-101A	101A	SG A PORV FAILS TO OPEN
BB 1-2 (3G)	MSS-STV-FT-101B		MSTV FAILS TO OPEN (MAIN STEAM TRIP VLV B)
BB 1-2 (3G)	MSS-STV-FT-101C		MSTV FAILS TO OPEN (MAIN STEAM TRIP VLV C)
BB 1-2 (3H)	MSS-STV-FT-101A		MSTV FAILS TO OPEN (MAIN STEAM TRIP VLV A)
BB 1-2 (3H)	PCS-AOV-FT-BYPA	BYPA	A BYPASS VALVE FAIL TO OPEN TCV 107/8A
BB 1-2 (3H)	PCS-AOV-FT-BYPB	BYPB	B BYPASS VALVE FAIL TO OPEN TCV 107/8B
BB 1-2 (3H)	PCS-AOV-FT-MSTVA	MSTVA	A BYPASS VALVE TCV 105/6A FAILS TO OPEN
BB 1-2 (3H)	PCS-AOV-FT-MSTVB	MSTVB	B BYPASS VALVE TCV 105/6B FAILS TO OPEN
BB 1-2 (3H)	PCS-AOV-PG-BYPA		A BYPASS TCV 107/8A PLUGGED
BB 1-2 (3H)	PCS-AOV-PG-BYPB		B BYPASS TCV 107/8B PLUGGED
BB 1-2 (3H)	PCS-AOV-PG-MSTVA	MSTVA	A BYPASS VALVE TCV 105/6A PLUGGED
BB 1-2 (3H)	PCS-AOV-PG-MSTVB	MSTVB	B BYPASS VALVE TCV 105/6B PLUGGED
VB 1-1 (3BC)	HPI-MOV-PG-1270A	1270A	MOTOR OPERATED VALVE 1270A PLUGGED (HPI PUMP C SUCTION ISOL VLV)
VB 1-1 (3BC)	HPI-MOV-PG-1286C	1286C	MOTOR OPERATED VALVE 1286C PLUGGED (HPI PUMP C DISCH ISOL VLV)
VB 1-1 (3BD)	HPI-MOV-PG-1269A	1269A	MOTOR OPERATED VALVE 1269A PLUGGED (HPI PUMP B SUCTION ISOL VLV)
VB 1-1 (3BD)	HPI-MOV-PG-1286B	1286B	MOTOR OPERATED VALVE 1286B PLUGGED (HPI PUMP B DISCH ISOL VLV)
VB 1-1 (3BH)	CCW-AOV-OC-109A		CC-TV-109A TRANSFERS CLOSED (CCW RETURN HEADER A TCV)
VB 1-1 (3BH)	CCW-AOV-OC-109B		CC-TV-109B TRANSFERS CLOSED (CCW RETURN HEADER B TCV)
VB 1-1 (BACK)	SEMI-VIT-BUS		FAILURE OF SEMI-VITAL BUS
VB 1-2 (3AQ)	CCW-MDP-FR-CCP1A	CCP1A	1-CC-P-1A FAILS TO RUN
VB 1-2 (3AQ)	CCW-MDP-FR-CCP1B	CCP1B	MDP CC-P1B FAILS TO RUN
VB 1-2 (3AQ)	CCW-MDP-FS-CCP1B	CCP1B	MDP CC-P1B FAILS TO START ON DEMAND
VB 1-2 (3AS)	MSS-NRV-FT-101A		NRV FAILS TO OPEN (MAIN STEAM NON-RETURN VLV A)
VB 1-2 (3AS)	MSS-NRV-FT-101B		NRV FAILS TO OPEN (MAIN STEAM NON-RETURN VLV B)
VB 1-2 (3AS)	MSS-NRV-FT-101C		NRV FAILS TO OPEN (MAIN STEAM NON-RETURN VLV C)
VB 1-6	ACP-CRB-CO-15H8	15H8	AC CIRCUIT BREAKER 15H8 TRANSFERS OPEN (BUS 1H FEED BKR, FROM BUS F)
VB 1-6	OEP-CRB-FT-15H3	15H3	DIESEL GEN #1 CKT BRKR 15H3 FAILS TO CLOSE (BUS 1H FEED BKR, FROM DG 1)
VB 1-6	OEP-DGN-FR-DG01	DG01	DG 1 FAILS TO RUN 1 HR
VB 1-6	OEP-DGN-FS-DG01	DG01	DIESEL GENERATOR #1 FAILS TO START
VB 1-7	ACP-CRB-CO-15J8	15J8	AC CIRCUIT BREAKER 15J8 TRANSFERS OPEN (BUS 1J FEED BKR, FROM BUS D)
VB 1-7	OEP-CRB-FT-15J3	15J3	DIESEL GEN #3 CKT BRKR 15J3 FAILS TO CLOSE (BUS 1J FEED BKR, FROM DG 3)
VB 1-7	OEP-DGN-FC-DG3U2	DG3U2	DIESEL GEN #3 UNAVAIL, ALIGNED TO UNIT 2
VB 1-7	OEP-DGN-FR-DG03	DG03	DG 3 FAILS TO RUN 1 HR
VB 1-7	OEP-DGN-FS-DG03	DG03	DIESEL GENERATOR #3 FAILS TO START
VB Cab 1-II	ACP-BAC-ST-VB1II	VB1II	VITAL BUS 1II BUSWORK FAILURE
VB Cab 1-II	ACP-CRB-CO-1II	1II	AC CIRCUIT BREAKER TO 1II TRANSFERS OPEN
Not in MCR	ACP-BAC-ST-V1III	V1III	VITAL BUS 1III BUSWORK FAILURE
Not in MCR	ACP-BAC-ST-VB1I	VB1I	VITAL BUS 1I BUSWORK FAILURE
Not in MCR	ACP-CRB-CO-1I35	1I35	VITAL BUS 1I AC CKT BREAKER 35 TRANSFERS OPEN
Not in MCR	ACP-CRB-CO-1II35	1II35	VITAL BUS 1III AC CKT BRKR 35 TRANSFERS OPEN

**Table 9.2 Control Locations for Surry Unit 1 Shutdown Accident Mitigation
Equipment (continued)**

Location of Control	Basic Event Designator	Comp. ID	Basic Event Description
Not in MCR	ACP-CRB-CO-14H1	14H1	AC CIRCUIT BREAKER 14H1 TRANSFERS OPEN (480V BUS 1H FEED BKR)
Not in MCR	ACP-CRB-CO-14H13	14H13	AC CIRCUIT BREAKER 14H13 TRANSFERS OPEN (480V MCC 1H1-2 FEED BKR)
Not in MCR	ACP-CRB-CO-14H14	14H14	AC CIRCUIT BREAKER 14H14 TRANSFERS OPEN (480V MCC 1H1-1 FEED BKR)
Not in MCR	ACP-CRB-CO-14H15	14H15	AC CIRCUIT BREAKER 14H15 TRANSFERS OPEN (480V BUS 1H1 FEED BKR)
Not in MCR	ACP-CRB-CO-14J1	14J1	AC CIRCUIT BREAKER 14J1 TRANSFERS OPEN (480V BUS 1J FEED BKR)
Not in MCR	ACP-CRB-CO-14J11	14J11	AC CIRCUIT BREAKER 14J11 TRANSFERS OPEN (480V BUS 1J1 FEED BKR)
Not in MCR	ACP-CRB-CO-14J14	14J14	AC CIRCUIT BREAKER 14J14 TRANSFERS OPEN (480V BUS 1J1-2 FEED BKR)
Not in MCR	ACP-CRB-CO-14J16	14J16	AC CIRCUIT BREAKER 14J16 TRANSFERS OPEN (480V BUS 1J1-1 FEED BKR)
Not in MCR	ACP-CRB-CO-15H7	15H7	AC CIRCUIT BREAKER 15H7 TRANSFERS OPEN (4KV BUS 1H TO 4KV/480V XFMR BKR)
Not in MCR	ACP-CRB-CO-15H9	15H9	AC CIRCUIT BREAKER 15H9 TRANSFERS OPEN (4KV BUS 1H TO STUB BUS BKR)
Not in MCR	ACP-CRB-CO-15J7	15J7	AC CIRCUIT BREAKER 15J7 TRANSFERS OPEN (4KV BUS 1J TO 4KV/480V XFMR BKR)
Not in MCR	ACP-CRB-CO-15J9	15J9	AC CIRCUIT BREAKER 15J9 TRANSFERS (4KV BUS 1J TO STUB BUS BKR)
Not in MCR	ACP-CRB-CO-FE9AE	FE9AE	AC CIRCUIT BREAKER FE9AE TRANSFERS OPEN
Not in MCR	ACP-CRB-CO-FE9AF	FE9AF	AC CIRCUIT BREAKER FE9AF TRANSFERS OPEN
Not in MCR	ACP-CRB-CO-FE9AJ	FE9AJ	AC CIRCUIT BREAKER FE9AJ TRANSFERS OPEN
Not in MCR	ACP-CRB-CO-FE9AK	FE9AK	AC CIRCUIT BREAKER FE9AK TRANSFERS OPEN
Not in MCR	ACP-CRB-CO-FE9BE	FE9BE	AC CIRCUIT BREAKER FE9BE TRANSFERS OPEN
Not in MCR	ACP-CRB-CO-FE9BJ	FE9BJ	AC CIRCUIT BREAKER FE9BJ TRANSFERS OPEN
Not in MCR	ACP-CRB-CO-FE9BK	FE9BK	AC CIRCUIT BREAKER FE9BK TRANSFERS OPEN
Not in MCR	CPC-AOV-FT-108B	108B	AOV TV-CC-108B FAILS TO OPEN
Not in MCR	CPC-AOV-FT-108C	108C	AOV TV-CC-108C FAILS TO OPEN
Not in MCR	DCP-BDC-ST-BUS1A	BUS1A	125V DC BUS 1A BUSWORK FAILURE
Not in MCR	DCP-BDC-ST-BUS1B	BUS1B	125V DC BUS 1B BUSWORK FAILURE
Not in MCR	DCP-CRB-CO-19	19	DC CIRCUIT BREAKER 19 TRANSFERS OPEN
Not in MCR	DCP-CRB-CO-20	20	DC CIRCUIT BREAKER 20 TRANSFERS OPEN
Not in MCR	DCP-CRB-CO-23	23	DC CIRCUIT BREAKER 23 TRANSFERS OPEN
Not in MCR	DCP-CRB-CO-24	24	DC CIRCUIT BREAKER 24 TRANSFERS OPEN
Not in MCR	HPI-MOD-FT-101B		MOTOR OPERATED DAMPER MOD-101B FAILS TO OPEN
Not in MCR	HPI-MOD-FT-101C		MOTOR OPERATED DAMPER MOD-101C FAILS TO OPEN
Not in MCR	IAS-AOV-FT-TV126		IA-TV-126 FAILS TO OPEN
Not in MCR	IAS-AOV-PG-TV125		IA-TV-125 PLUGGED
Not in MCR	IAS-CPS-FR-IAC-1		TURBINE BUILDING IA COMPRESSOR IA-C-1 FAILS TO RUN
Not in MCR	IAS-CPS-FS-IAC-1		TURBINE BUILDING IA COMPRESSOR IA-C-1 FAILS TO START
Not in MCR	SAS-CPS-FR-1SAC1		SERVICE AIR COMPRESSOR 1-SA-C-1 FAILS TO RUN
Not in MCR	SAS-CPS-FR-2SAC1		SERVICE AIR COMPRESSOR 2-SA-C-1 FAILS TO RUN
Not in MCR	SW-AOV-FT-SW263		1-SW-263 FAILS CLOSED ON LOSS OF OFFSITE POWER

Control Room Fire Analysis

Table 9.3 Scenario Description and Preliminary Screening Results

Scenario Designator	Scenario Impact	Retained for Frequency Assessment?	Hot Short Required?
BB-1-1	Small fires in Benchboard 1-1, around subsection 3Z, fail RHR pumps A and B	Yes	Yes
BB-1-2	Small fires in Benchboard 1-1 or 1-2, around subsections 3W and 3V, fail HHSI pumps A, B, and C	Yes	Yes
BB-1-3	Small fires in Benchboard 1-2, around subsections 3B and 3A, fail feed breakers from RSS transformers to 4 kV buses F and D	Yes	Yes
BB-1-4	Medium fires in Benchboard 1-1, covering subsections 3AE and 3Z, fail (a) RHR pumps A and B, (b) HHSI pump discharge to the cold leg isolation valves, (c) LHSI pumps A and B, (d) recirculation sprays	Yes	Yes
BB-1-5	Large fires in Benchboard 1-1, covering subsections 3AE, 3Z, 3W, and 3V, fail (a) RHR pumps A and B, (b) HHSI pumps A, B, and C, (c) LHSI pumps A and B, (d) recirculation sprays	Yes	Yes
BB-1-6	Large fires in Benchboard 1-1, covering subsections 3AE, 3Z, 3W, 3V, 3H, 3G, and 3F, fail (a) RHR pumps A and B, (b) HHSI pumps A, B, and C, (c) LHSI pumps A and B, (d) steam generator steam relief path, (e) recirculation sprays	No	Yes
BB-1-7	Large fires in Benchboard 1-1 or 1-2, covering subsections 3AE, 3Z, 3W, 3V, 3H, 3G, 3F, 3B, and 3A, fail (a) RHR pumps A and B, (b) HHSI pumps A, B, and C, (c) LHSI pumps A and B, (d) SG steam relief path, (e) feed breakers from RSS transformers to 4 kV buses F and D, (f) AFW system, (g) recirculation sprays	No	Yes
BB-1-8	Medium fires in Benchboard 1-1, covering subsections 3Z, 3W, and 3V, fail (a) RHR pumps A and B and (b) HHSI pumps A, B, and C	Yes	Yes
BB-1-9	Large fires in Benchboard 1-1 or 1-2, covering subsections 3Z, 3W, 3V, 3H, 3G, and 3F, fail (a) RHR pumps A and B, (b) HHSI pumps A, B, and C, and (c) steam generator steam relief path	Yes	Yes

Table 9.3 Scenario Description and Preliminary Screening Results (continued)

Scenario Designator	Scenario Impact	Retained for Frequency Assessment?	Hot Short Required?
BB-1-10	Large fires in Benchboard 1-2, covering subsections 3Z, 3W, 3V, 3H, 3G, 3F, 3B, and 3A, fail (a) RHR pumps A and B, (b) HHSI pumps A, B, and C, (c) steam generator steam relief path, (d) feed breakers from RSS transformers to 4 kV buses F and D, (e) AFW system	No	Yes
BB-1-11	Medium fires in Benchboard 1-1 or 1-2, covering subsections 3W, 3V, 3H, 3G, and 3F, fail (a) HHSI pumps A, B, and C and (b) steam generator steam relief path	Yes	Yes
BB-1-12	Large fires in Benchboard 1-2, covering subsections 3W, 3V, 3H, 3G, 3F, 3B, and 3A, fail (a) HHSI pumps A, B, and C, (b) steam generator steam relief path, (c) feed breakers from RSS transformers to 4 kV buses F and D, (d) AFW system	Yes	Yes
BB-1-13	Large fires in Benchboard 1-2, covering subsections 3H, 3G, 3F, 3B, and 3A, fail (a) steam generator steam relief path, (b) feed breakers from RSS transformers to 4 kV buses F and D, (c) AFW system	Yes	Yes
VB-1-1	Small fires in Vertical Board 1-1, around subsection 3BH, fail CCW return headers A and B TCVs	Yes	No
VB-1-2	Small fires in Vertical Board 1-1 or 1-2, around subsections 3BD and 3BC, fail suction and discharge isolation valves of HHSI pumps A, B, and C	Yes	Yes
VB-1-3	Small fires in Vertical Board 1-2, around subsection 3AQ, fail CCW pumps 1A and 1B	Yes	Yes
VB-1-4	Medium fires in Vertical Board 1-1, covering subsections 3BH, 3BD, and 3BC, fail (a) CCW return headers A and B TCVs and (b) suction and discharge isolation valves of HHSI pumps A, B and C	Yes	Yes
VB-1-5	Medium fires in Vertical Board 1-2, covering subsections 3AQ, 3BC, and 3BD, fail (a) suction and discharge isolation valves of HHSI pumps A, B, and C and (b) CCW pumps 1A and 1B	No	Yes

Control Room Fire Analysis

Table 9.3 Scenario Description and Preliminary Screening Results (continued)

Scenario Designator	Scenario Impact	Retained for Frequency Assessment?	Hot Short Required?
VB-1-6	Large fires in Vertical Board 1-1 or 1-2, covering subsections 3AQ, 3BC, 3BD, and 3BH, , fail (a) suction and discharge isolation valves of HHSI pumps A, B, and C (b) CCW pumps 1A and 1B, and (c) CCW return headers A and B TCVs	No	Yes
VB-6-DG1	Fires in Vertical Board 1-6 fail diesel generator 1 and normal power supply to 4 kV bus 1H	Yes	Yes
VB-7-DG3	Fires in Vertical Board 1-7 fail diesel generator 3 and normal supply to 4 kV bus 1J	No	No
VBC-1-II-1	Fires in 120 V AC vital bus 1-II cabinet fail the cabinet	Yes	No

Note: The terms "small", "medium", and "large" fires in the scenario impact description are used only for distinguishing purposes and are not intended to quantitatively define the fire magnitudes.

Table 9.4 Summary of Control Room Walkdown Observations and Frequency Apportionment for Benchboards 1-1 and 1-2, and Vertical Boards 1-1 and 1-2

Location	Panel Subsection ¹	Weight Ratio	Normalized Weight Ratio	Fire Frequency ² (/yr)
Benchboard 1-1	3V, 3W and 3X	3.0	0.07	2.98E-04
Benchboard 1-1	3Y, 3Z and 3AA	3.0	0.07	2.98E-04
Benchboard 1-1	3AB and 3AC	3.0	0.07	2.98E-04
Benchboard 1-1	3AD	1.5	0.03	1.49E-04
Benchboard 1-1	3AE	1.0	0.02	1.01E-04
Benchboard 1-2	3A and 3B	1.5	0.03	1.49E-04
Benchboard 1-2	3C, 3D and 3E	1.5	0.03	1.49E-04
Benchboard 1-2	3F, 3G and 3H	1.8	0.04	1.80E-04
Benchboard 1-2	3J and 3K	1.5	0.03	1.49E-04
Vertical Board 1-1	3BC through 3BF	6.0	0.14	5.96E-04
Vertical Board 1-1	3BG, 3BH and 3BJ	6.0	0.14	5.96E-04
Vertical Board 1-2	3AQ, 3AR and 3AS	7.2	0.16	7.14E-04
Vertical Board 1-2	3AT, 3AU and 3AV	7.2	0.16	7.14E-04
Sum		44.2	1.00	4.39E-03

Note:

- 1 Fire frequency for individual subsection within each row is assumed to be linearly proportioned
- 2 Total fire frequency for Benchboards 1-1 and 1-2, and Vertical Boards 1-1 and 1-2 is $7.96\text{E-}4 + 3.58\text{E-}3 = 4.38\text{E-}3/\text{yr}$. (See Table 9.9.)

Table 9.5 Empirical Data Base Specialization

Event No.	Plant Unit	Event Date	Location	Operation Mode	Initiated Component	General Description	Comment
188	Unknown	7/4/78	Control Building	Power Operation	Diode	Fire involved in the RPS located in the control building. Operator noticed smoke coming from the RPSCIP panel.	Not included. Component failure only. Component not in MCR.
225	Three Mile Island 2	7/12/79	Control Room	Cold Shutdown	Resistor	A small fire occurred in the radiation monitoring readout panel for the Aux. Bldg. waste gas system monitor. The cause was suspected to be an overheated resistor.	Included in the Surry MCR fire data base.
263	Unknown	11/21/80	Control Building	Construction		While putting up new wall outside the control room, sparks from metal plate welding ignited flashing and nailer board.	Not included. Construction event occurred outside control room.
271	Watts Bar 1	3/7/81	Control Building	Construction	Computer	Fire in a digital computer system in communications room of the facilities control building.	Not included. Unit never reached critical. Component not in MCR.
318	Salem 1	11/9/82	Control Room	Power Operation	Relay	Operator observed a fire in fire detection instrumentation panel. The fire was resulted from the failure of the panel alarm buzzer relay.	Included in the Surry MCR fire data base.
323	McGuire 2	2/19/83	Control Building	Hot Shutdown	Fan	Household fan caught on fire. Approx. 2 ft cable tray damaged.	Not included. Fan is not used in Surry MCR.
331	Surry 1	9/9/83	Control Building	Power Operation (100%)	Motor	With unit 1 at power, while attempting to energize "A" control room air conditioning chiller, the local control panel caught fire. Service water from a blown condenser zinc plug shorted the motor starter contact at the local chiller control panel.	Not included. Component not in MCR. Event occurred in control building outside control room.
368	Three Mile Island 1	9/27/82	Control Building	Power Operation	Relay	Coil failure led to burning of relay due to either end-of-life or undefined mechanical failure.	Not included. Component failure only.

Table 9.5 Empirical Data Base Specialization (continued)

Event No.	Plant Unit	Event Date	Location	Operation Mode	Initiated Component	General Description	Comment
372	Hatch 1	3/30/83	Control Room	Power Operation	Relay	Smoke observed from a scram discharge volume high level RPS relay in the control room. The fire was extinguished by portable extinguisher.	Included in Surry MCR fire data base.
374	Three Mile Island 1	4/9/83	Control Building	Power Operation	Relay	Coil failure led to burning of relay due to either end-of-life or undefined mechanical failure.	Not included. Component failure only.
375	Three Mile Island 1	4/19/83	Control Building		Relay	Coil failure led to burning of relay due to either end-of-life or undefined mechanical failure.	Not included. Component failure only.
379	Hatch 1	8/9/83	Control Room	Power Operation	Relay	CR personnel noted a "foul smell" in the CR. A relay was found to have overheated and created the offgasing.	Not included. Fire precursor only.
380	Three Mile Island 1	8/27/83	Control Building	Cold Shutdown	Relay	Coil failure led to burning of relay due to either end-of-life or undefined mechanical failure.	Not included. Component failure only.
382	San Onofre 3	10/5/83	Control Room		Instrumentation	Operators noted a "smoky odor" being emitted from the Qualified Safety Parameter Display System Train B panel. Problem was traced to a failed circuit card. No open flaming was reported and apparently no fire alarm was initiated.	Not included. Fire Precursor only.
391	Crystal River 3	10/26/85	Control Room	Power Operation	Bus	While operating at 95% power, an undervoltage condition on the radiation monitoring panel caused overheating of relays and the introduction of smoke into the control room. No open flame was reported and the relay smoking was a result rather than the cause of the adverse occurrences.	Not included. Fire precursor. Event occurred outside control room during at-power condition.

Table 9.5 Empirical Data Base Specialization (continued)

Event No.	Plant Unit	Event Date	Location	Operation Mode	Initiated Component	General Description	Comment
400	McGuire 1	7/2/87	Control Room	Hot Shutdown	Breaker	While performing control rod drop timing test, personnel detected smoke in the area of the reactor trip switchgear.	Not included. Switchgear fire.
410	Calvert Cliffs 2	3/1/89	Control Room	Power Operation	Instrumentation	While attempting to trip a solenoid operated auxiliary feedwater pump trip/throttle valve during maintenance, the switch was found to be on fire. The fire was extinguished using a portable Halon extinguisher.	Included in Surry MCR fire data base.
412	Waterford 3	7/14/85	Control Room	Power Operation	Resistor	While at 100% power, an overheated resistor caused a trip. The overheating circuit board cause a fire in the control panel and was quickly extinguished.	Included in Surry MCR fire data base.
416	Hatch 1	3/12/83	Control Room	Power Operation	Relay	Personnel smelled smoke around a panel in the control room as a result of a burning low reactor water level RPS relay.	Included in Surry MCR fire data base.
419	Three Mile Island	9/7/85	Control Building	Hot Shutdown	Instrumentation	A fire resulted from transfer of power supplies without clamping and synchronization. The fire was small and localized to several CRD cabinets in the relay room.	Not included. Not a control room fire. Event not compatible with Surry MCR configuration.
431	Wolf Creek	10/14/87	Control Building	Refueling Outage		A maintenance worker was electrocuted while cleaning potential transformer cabinets. A part of the worker's clothing caught fire.	No included. Event not compatible to Surry MCR.
40	Pilgrim	9/13/83	Control Room	Power Operation	Relay	Failure of a recirculation pump low level water trip relay resulted in smoke emitting from the burned coil coating.	Not included. Fire precursor, component failure.

Table 9.5 Empirical Data Base Specialization (continued)

Event No.	Plant Unit	Event Date	Location	Operation Mode	Initiated Component	General Description	Comment
442	Shoreham	4/7/85	Control Room	Shutdown	Fan	Failure of cooling for a circuit inverter causing the inverter cabinet to overheat. This resulted in the overheating of a resistor and a capacitor in the inverter circuitry.	Included in Surry MCR fire data base. Unit achieved criticality and produced power, but closed down before it could begin commercial operation.
446	Susquehanna 2	7/16/86	Control Room	Power Operation	Instrumentation	Control room personnel observed smoke coming from a "C" Transversing Incore Probe machine.	Not included. Fire precursor only.

Control Room Fire Analysis

Table 9.6 Summary of Control Room Age Assessment

Site-Plant	Number of Control Room	Date Achieved Criticality	Reference Date ¹	Control Room Age
Arkansas Nuclear One Unit 1	1	8/6/74	12/31/89	15.41
Arkansas Nuclear One Unit 2	shared	12/5/78	12/31/89	11.08
Beaver Valley 1	1	5/10/76	12/31/89	13.65
Beaver Valley 2	1	8/1/87	12/31/89	2.42
Big Rock Point 1	1	9/27/62	12/31/89	27.28
Braidwood 1	1	5/15/87	12/31/89	2.63
Braidwood 2	shared	3/15/88	12/31/89	1.8
Brown's Ferry 1	1	8/17/73	3/9/85	11.57
Brown's Ferry 2	shared	7/20/74	3/9/85	10.64
Brown's Ferry 3	1	8/8/76	3/9/85	8.59
Brunswick 1	1	10/8/76	12/31/89	13.24
Brunswick 2	shared	3/20/75	12/31/89	14.79
Byron 1	1	2/2/85	12/31/89	4.91
Byron 2	shared	1/1/87	12/31/89	3.0
Callaway 1	1	10/2/84	12/31/89	5.25
Calvert Cliffs 1	1	10/7/74	12/31/89	15.24
Calvert Cliffs 2	shared	11/30/76	12/31/89	13.09
Catawba 1	1	1/8/85	12/31/89	4.98
Catawba 2	shared	5/15/86	12/31/89	3.63
Clinton 1	1	2/15/87	12/31/89	2.88
Cook 1	1	1/18/75	12/31/89	14.96
Cook 2	1	3/10/78	12/31/89	11.82
Cooper Station	1	2/21/74	12/31/89	15.87
Crystal River 3	1	1/14/77	12/31/89	12.97
Davis Besse 1	1	8/12/77	12/31/89	12.39

Table 9.6 Summary of Control Room Age Assessment

Site-Plant	Number of Control Room	Date Achieved Criticality	Reference Date ¹	Control Room Age
Diablo Canyon 1	1	4/29/84	12/31/89	5.68
Diablo Canyon 2	shared	8/15/85	12/31/89	4.38
Dresden 1	1	10/15/59	10/31/78	19.06
Dresden 2	1	1/7/70	12/31/89	19.99
Dresden 3	shared	1/31/71	12/31/89	18.93
Duane Arnold	1	3/23/74	12/31/89	15.79
Farley 1	1	8/9/77	12/31/89	12.4
Farley 2	shared	5/8/81	12/31/89	8.65
Fermi 2	1	6/15/85	12/31/89	4.55
Fitzpatrick	1	11/17/74	12/31/89	15.13
Fort Calhoun 1	1	8/6/73	12/31/89	16.41
Ft. St. Vrain	1	1/31/74	8/15/89	15.55
Ginna 1	1	11/8/69	12/31/89	20.16
Grand Gulf 1	1	8/18/82	12/31/89	7.38
Haddam Neck	1	7/24/67	12/31/89	22.45
Harris	1	1/15/87	12/31/89	2.96
Hatch 1	1	9/12/74	12/31/89	15.31
Hatch 2	shared	7/4/78	12/31/89	11.5
Hope Creek 1	1	6/16/86	12/31/89	3.55
Humboldt Bay	1	2/16/63	7/2/76	13.38
Indian Point 1	1	4/6/76	12/31/89	13.75
Indian Point 2	1	8/2/62	10/31/74	12.25
Indian Point 3	1	5/22/73	12/31/89	16.62
Kewaunee	1	3/7/74	12/31/89	15.83
La Crosse	1	7/11/67	4/15/87	19.78

Control Room Fire Analysis

Table 9.6 Summary of Control Room Age Assessment (continued)

Site-Plant	Number of Control Room	Date Achieved Criticality	Reference Date ¹	Control Room Age
La Salle 1	1	6/21/82	12/31/89	7.53
La Salle 2	shared	3/10/84	12/31/89	5.81
Limerick 1	1	12/22/84	12/31/89	5.03
Limerick 2	shared	8/15/89	12/31/89	0.38
Maine Yankee	1	10/23/72	12/31/89	17.2
McGuire 1	1	8/8/81	12/31/89	8.4
McGuire 2	shared	5/8/83	12/31/89	6.65
Millstone 1	1	10/26/70	12/31/89	19.19
Millstone 2	1	10/17/75	12/31/89	14.22
Millstone 3	1	1/15/86	12/31/89	3.96
Monticello	1	12/10/70	12/31/89	19.07
Nine Mile Point 1	1	9/5/69	12/31/89	20.33
Nine Mile Point 2	1	5/15/87	12/31/89	2.63
North Anna 1	1	4/5/78	12/31/89	11.75
North Anna 2	1	6/12/80	12/31/89	9.56
Oconee 1	1	4/19/73	12/31/89	16.71
Oconee 2	shared	11/11/73	12/31/89	16.15
Oconee 3	1	9/5/74	12/31/89	15.33
Oyster Creek 1	1	5/3/69	12/31/89	20.68
Palisades	1	5/24/71	12/31/89	18.62
Palo Verde 1	1	5/25/85	12/31/89	4.61
Palo Verde 2	1	4/15/86	12/31/89	3.72
Palo Verde 3	1	10/15/87	12/31/89	2.21
Peach Bottom 1	1	6/15/67	11/1/74	7.39
Peach Bottom 2	1	9/16/73	12/31/89	16.3

Table 9.6 Summary of Control Room Age Assessment

Site-Plant	Number of Control Room	Date Achieved Criticality	Reference Date ¹	Control Room Age
Peach Bottom 3	shared	8/7/74	11/1/74	0.24
Perry	1	6/15/86	12/31/89	3.55
Pilgrim 1	1	6/16/72	12/31/89	17.55
Point Beach 1	1	11/2/70	12/31/89	19.18
Point Beach 2	shared	5/30/72	12/31/89	17.6
Prairie Island 1	1	12/1/73	12/31/89	16.09
Prairie Island 2	shared	12/17/74	12/31/89	15.05
Quad Cities 1	1	10/18/71	12/31/89	18.22
Quad Cities 2	shared	4/26/72	12/31/89	17.69
Rancho Seco	1	9/16/74	6/15/89	14.76
River Bend 1	1	10/15/85	12/31/89	4.21
Robinson 2	1	9/20/70	12/31/89	19.29
Salem 1	1	12/11/76	12/31/89	13.06
Salem 2	shared	8/8/80	12/31/89	9.4
San Onofre 1	1	6/14/67	12/31/89	22.56
San Onofre 2	1	7/26/82	12/31/89	7.44
San Onofre 3	shared	8/29/83	12/31/89	6.35
Seabrook	1	6/15/89	12/31/89	0.55
Sequoyah 1	1	7/5/80	3/9/85	4.68
Sequoyah 2	shared	11/5/81	3/9/85	3.34
Shippingport	1	12/23/57	10/1/82	24.79
Shoreham	1	2/15/85	5/15/89	4.25
South Texas Project 1	1	3/15/88	12/31/89	1.8
South Texas Project 2	shared	3/15/89	12/31/89	0.8
St. Lucie 1	1	4/22/76	12/31/89	13.7

Control Room Fire Analysis

Table 9.6 Summary of Control Room Age Assessment (continued)

Site-Plant	Number of Control Room	Date Achieved Criticality	Reference Date ¹	Control Room Age
St. Lucie 2	1	6/2/83	12/31/89	6.59
Summer 1	1	10/22/82	12/31/89	7.2
Surry 1	1	7/1/72	12/31/89	17.51
Surry 2	shared	3/7/73	12/31/89	16.83
Susquehanna 1	1	9/10/82	12/31/89	7.31
Susquehanna 2	shared	5/8/84	12/31/89	5.65
Three Mile Island 1	1	6/5/74	12/31/89	15.58
Three Mile Island 2	1	3/27/78	3/28/79	1.0
Trojan	1	12/15/75	12/31/89	14.05
Turkey Point 3	1	10/20/72	12/31/89	17.21
Turkey Point 4	shared	6/11/73	12/31/89	16.57
Vermont Yankee 1	1	3/24/72	12/31/89	17.78
Vogtle 1	1	3/15/87	12/31/89	2.8
Vogtle 2	shared	3/15/89	12/31/89	0.8
Waterford 3	1	3/4/85	12/31/89	4.83
WNP 2	1	1/19/84	12/31/89	5.95
Wolf Creek 1	1	5/22/85	12/31/89	4.61
Yankee Rowe	1	8/19/60	12/31/89	29.39
Zion 1	1	6/19/73	12/31/89	16.55
Zion 2	shared	12/24/73	12/31/89	16.03
Total				1,359.35

Industry generic control room experience excluding Surry-1 is 1341.84 year

Note: 1. Reference date is either 12/31/89 or date of decommissioning.

Table 9.7 Main Characteristics of the Noninformative Prior

D A T A M A N

092492

GENERIC DISTRIBUTION UPDATE REPORT

MCRPRI MCR GENERIC NONINFORMATIVE PRIOR FIRE FREQUENCY

PRIOR - Median 5.2200E-03 Range Factor 7.0000E+00

MAIN CHARACTERISTICS OF THE DISTRIBUTION

MEAN	1.0509E-02
VARIANCE	2.9012E-04
5 TH PERCENTILE	7.0270E-04
50TH PERCENTILE	5.0853E-03
95TH PERCENTILE	3.5460E-02

DISCRETE PROBABILITY DISTRIBUTION

VALUE	PROBABILITY	CUMULATIVE
1.7943E-04	5.0000E-03	5.0000E-03
2.9267E-04	5.0000E-03	1.0000E-02
5.0800E-04	3.0000E-02	4.0000E-02
6.8010E-04	5.0000E-03	4.5000E-02

D A T A M A N

092492

GENERIC DISTRIBUTION UPDATE REPORT

9.2873E-04	5.5000E-02	1.0000E-01
1.5336E-03	1.0000E-01	2.0000E-01
2.3562E-03	1.0000E-01	3.0000E-01
3.3186E-03	1.0000E-01	4.0000E-01
4.3754E-03	8.0000E-02	4.8000E-01
4.9931E-03	1.0000E-02	4.9000E-01
5.5468E-03	6.0000E-02	5.5000E-01
6.5361E-03	5.0000E-02	6.0000E-01
8.2815E-03	1.0000E-01	7.0000E-01
1.1700E-02	1.0000E-01	8.0000E-01
1.8165E-02	1.0000E-01	9.0000E-01
2.7776E-02	4.0000E-02	9.4000E-01
3.3688E-02	5.0000E-03	9.4500E-01
4.9640E-02	4.5000E-02	9.9000E-01
9.3766E-02	5.0000E-03	9.9500E-01
1.7200E-01	5.0000E-03	1.0000E+00

Control Room Fire Analysis

Table 9.8 Main Characteristics of the Posterior

D A T A M A N

092492

GENERIC DISTRIBUTION UPDATE REPORT

MCRPOS MCR POSTERIOR FIRE FREQUENCY

POSTERIOR - Number of Events 0

Number of Time Units 1.7510E+01

MAIN CHARACTERISTICS OF THE DISTRIBUTION

MEAN	7.6561E-03
VARIANCE	9.6108E-05
5 TH PERCENTILE	6.1778E-04
50TH PERCENTILE	3.9181E-03
95TH PERCENTILE	1.9964E-02

DISCRETE PROBABILITY DISTRIBUTION

VALUE	PROBABILITY	CUMULATIVE
1.7943E-04	5.8167E-03	5.8167E-03
2.9267E-04	5.8052E-03	1.1622E-02
5.0800E-04	3.4700E-02	4.6322E-02
6.8010E-04	5.7660E-03	5.2088E-02
9.2873E-04	6.3150E-02	1.1524E-01
1.5336E-03	1.1361E-01	2.2885E-01
2.3562E-03	1.1198E-01	3.4083E-01
3.3186E-03	1.1011E-01	4.5094E-01
4.3754E-03	8.6475E-02	5.3742E-01
4.9931E-03	1.0693E-02	5.4811E-01
5.5468E-03	6.3540E-02	6.1165E-01
6.5361E-03	5.2040E-02	6.6369E-01
8.2815E-03	1.0095E-01	7.6464E-01
1.1700E-02	9.5082E-02	8.5972E-01
1.8165E-02	8.4906E-02	9.4463E-01
2.7776E-02	2.8702E-02	9.7333E-01
3.3688E-02	3.2349E-03	9.7656E-01
4.9640E-02	2.2019E-02	9.9858E-01
9.3766E-02	1.1298E-03	9.9971E-01
1.7200E-01	2.8711E-04	1.0000E+00

Table 9.9 Control Room Cabinet Fire Frequency Apportionment

Control Cabinet	Approx Panel Area (ft ²)	Normalized Ratio	Cabinet Fire Frequency (/yr) ⁴
Benchboard 1-1 and 1-2 (2x12'x4')	96	0.1	7.96E-04
Vertical Board 1-1 and 1-2 (2x2x13.5'x8') ¹	432	0.47	3.58E-03
Vertical Board 1-3 (6.4'x8')	51.2	0.06	4.21E-04
Vertical Board 1-4 (6'x5')	30	0.03	2.53E-04
Vertical Board 1-5 (11.3'x4.5')	50.85	0.06	4.21E-04
Vertical Board 1-6 (11.3'x5.3')	59.89	0.07	4.98E-04
Vertical Board 1-7 (6.7'x5.3')	35.51	0.04	2.91E-04
Semi-Vital bus (2.5'x5') ²	12.5	0.01	1.07E-04
Vital Bus cabinet 1-II (2.5'x5') ²	12.5	0.01	1.07E-04
Vital Bus cabinet 1-IV (2.5'x5') ²	12.5	0.01	1.07E-04
125V DC cabinet 1-1 (2.5'x5') ²	12.5	0.01	1.07E-04
125V DC cabinet 1-2 (2.5'x5') ²	12.5	0.01	1.07E-04
120V AC cabinet (2.5'x5') ²	12.5	0.01	1.07E-04
Other miscellaneous panels and junction boxes (10% of the total panel area of all MCR cabinets) ³	92.27	0.10	7.66E-04
Sum	922.72	1.00	7.67E-03

Note:

- Both of the front and back panels of the Vertical boards were observed to have instrumentations and related cables.
- The height of these cabinets is conservatively assumed to be 5 ft.
- 10% of the total fire frequency is conservatively apportioned to the miscellaneous areas, total surface areas of all control panels is 922.72 sq ft.
- Individual panel fire frequency is equal to the product of the normalized panel surface area ratio and the total MCR fire frequency (7.656E-3 per year).

Control Room Fire Analysis

Table 9.10 Fire Frequency Apportionment of Panel Subsections in Benchboard Boards 1-1 and 1-2

Benchboard Subsection	Approx. Panel Length (ft) ¹	Normalized Ratio ²	Fire Frequency (/yr) ³
3W/3V	2.35	0.606	1.80E-04
3X	1.53	0.394	1.18E-04
3Y	1.27	0.407	1.21E-04
3Z	0.93	0.298	8.88E-05
3AA	0.92	0.295	8.79E-05
3AB	1.19	0.613	1.83E-04
3AC	0.75	0.387	1.15E-04
3AD	0.92	1.000	1.49E-04
3AE	1.57	1.000	1.01E-04
3A/3B	2.23	1.000	1.49E-04
3C	1.00	0.398	5.94E-05
3D	0.88	0.351	5.22E-05
3E	0.63	0.251	3.74E-05
3F/3G/3H	2.53	1.000	1.80E-04
3J	1.47	0.531	7.91E-05
3K	1.30	0.469	6.99E-05
Sum	21.47		1.77E-03

Note:

1. Approximate panel subsection length is measured from Drawings 11448-RE-25A through J.
2. The normalized ratio, in this case, is the geometry factor for the panel subsection.
3. Panel subsection fire frequency is the product of the geometry factor and the grouped panel section fire frequency in each row of Table 9-9.

Table 9.11 Fire Frequency Apportionment of Panel Subsections in Vertical Boards 1-1 and 1-2

Vertical Board Subsection	Approx. Panel Length (ft) ¹	Normalized Ratio ²	Fire Frequency (/yr) ³
3BC/3BD	1.80	0.323	1.93E-04
3BE	1.70	0.305	1.82E-04
3BF	2.07	0.372	2.21E-04
3BG	2.67	0.444	2.65E-04
3BH	1.87	0.311	1.85E-04
3BJ	1.47	0.245	1.46E-04
3AS	1.57	0.261	1.87E-04
3AR	2.37	0.394	2.82E-04
3AQ	2.07	0.344	2.46E-04
3AT	3.58	0.523	3.73E-04
3AU	1.27	0.185	1.32E-04
3AV	2.00	0.292	2.08E-04
Sum			2.62E-03

Note:

1. Approximate panel subsection length is measured from Drawings 11448-RE-25A through J.
2. The normalized ratio, in this case, is the geometry factor for the panel subsection.
3. Panel subsection fire frequency is the product of the geometry factor and the grouped panel section fire frequency in each row of Table 9-9.

Table 9.12 Summary of Scenario Quantification

Scenario	Target Subsection	Relevant Fire Origin	Geometry Factor and Fire Frequency (/yr)	Required Fire Radius (ft)	Severity Factor	Combined Severity and Geometry Factor/Fire Frequency (/yr)	Failure Mode Factor	Scenario Frequency (/yr)
BB-1-1	3Z	3Z	8.88E-05	0.0 < R < 4.4	0.962	8.54E-05	0.10	2.04E-05
		3AB	1.83E-04	2.1 < R < 3.0	0.153	2.80E-05		
		3AA	8.79E-05	0.9 < R < 4.1	0.517	4.54E-05		
		3Y	1.21E-04	1.2 < R < 3.3	0.377	4.56E-05		
		Total:				2.04E-04		
BB-1-2	3W/3V	3W/3V	1.80E-04	0.0 < R < 4.4	0.962	1.73E-04	0.10	2.04E-05
		3X	1.18E-04	2.0 < R < 2.5	0.130	1.53E-05		
		3K	6.99E-05	1.8 < R < 3.3	0.217	1.52E-05		
		Total:				2.04E-04		
BB-1-3	3A/3B	3A/3B	1.49E-04	0.0 < R < 5.6	0.972	1.45E-04	0.10	1.49E-05
		3C	5.94E-05	2.3 < R < 3.3	0.075	4.46E-06		
		Total:				1.49E-04		
BB-1-4	3AE, 3Z	3AE	1.01E-04	5.0 < R < 8.0	0.009	9.09E-07	0.10	2.46E-06
		3AD	1.49E-04	3.8 < R < 8.0	0.035	5.22E-06		
		3AC	1.15E-04	3.0 < R < 7.5	0.058	6.67E-06		
		3AB	1.83E-04	3.0 < R < 6.5	0.054	9.96E-06		
		3AA	8.79E-05	4.1 < R < 5.4	0.021	1.86E-06		
		Total:				2.46E-05		

Table 9.12 Summary of Scenario Quantification (continued)

Scenario	Target Subsection	Relevant Fire Origin	Geometry Factor and Fire Frequency (/yr)	Required Fire Radius (ft)	Severity Factor	Combined Severity and Geometry Factor/Fire Frequency (/yr)	Failure Mode Factor	Scenario Frequency (/yr)
BB-1-5	3AE, 3Z, 3W/3V	3AC	1.15E-04	7.5 < R < 8.0	0.001	1.15E-07	0.10	3.12E-07
		3AB	1.83E-04	6.5 < R < 8.0	0.005	8.42E-07		
		3AA	8.79E-05	5.4 < R < 8.0	0.008	6.86E-07		
		3Z	8.88E-05	5.0 < R < 8.0	0.009	7.99E-07		
		3Y	1.21E-04	6.1 < R < 8.0	0.006	6.79E-07		
		Total:				3.12E-06		
BB-1-8	3Z, 3W/3V	3Z	8.88E-05	4.4 < R < 5.0	0.020	1.78E-06	0.10	1.73E-06
		3Y	1.21E-04	3.3 < R < 6.1	0.043	5.25E-06		
		3X	1.18E-04	2.5 < R < 6.1	0.073	8.66E-06		
		3W/3V	1.80E-04	4.4 < R < 5.2	0.009	1.56E-06		
		Total:				1.73E-05		
BB-1-9	3Z, 3W/3V, 3H/3G/3F	3W/3V	1.80E-04	5.2 < R < 8.0	0.008	1.49E-06	0.10	1.87E-07
		3K	6.99E-05	6.2 < R < 8.0	0.005	3.77E-07		
		Total:				1.87E-06		
BB-1-11	3W/3V, 3H/3G/3F	3K	6.99E-05	3.8 < R < 6.2	0.029	2.00E-06	0.10	6.27E-07
		3J	7.91E-05	3.2 < R < 7.5	0.052	4.07E-06		
		3H/3G/3F	1.80E-04	5.2 < R < 5.6	0.001	1.98E-07		
		Total:				6.27E-06		

Table 9.12 Summary of Scenario Quantification (continued)

Scenario	Target Subsection	Relevant Fire Origin	Geometry Factor and Fire Frequency (/yr)	Required Fire Radius (ft)	Severity Factor	Combined Severity and Geometry Factor/Fire Frequency (/yr)	Failure Mode Factor	Scenario Frequency (/yr)
	3A/3B, 3H/3G/3F	3E	3.74E-05	6.8 < R < 8.0	0.004	1.35E-07	0.10	1.46E-07
		3D	5.22E-05	7.8 < R < 8.0	0.001	3.13E-08		
		Total:				1.46E-06		
BB-1-13	3H/3G/3F, 3A/3B	3E	3.74E-05	4.1 < R < 6.8	0.023	8.75E-07	0.10	7.47E-07
		3D	5.22E-05	3.3 < R < 7.8	0.050	2.63E-06		
		3C	5.94E-05	3.3 < R < 8.0	0.049	2.91E-06		
		3A/3B	1.49E-04	0.0 < R < 8.0	0.007	1.06E-06		
		Total:				7.47E-06		
VB-1-1	3BH	3BG	2.65E-04	2.3 < R < 6.6	0.137	3.62E-05	1.00	2.69E-04
		3BH	1.85E-04	0.0 < R < 8.0	0.979	1.81E-04		
		3BJ	1.46E-04	1.7 < R < 8.0	0.301	4.39E-05		
		Total:				2.69E-04		
VB-1-2	3BC/3BD	3BF	2.21E-04	4.2 < R < 4.6	0.011	2.43E-06	0.10	2.32E-05
		3BE	1.82E-04	2.3 < R < 6.5	0.120	2.17E-05		
		3BC/BD	1.93E-04	0.0 < R < 8.0	0.979	1.89E-04		
		3AT	3.73E-04	3.3 < R < 8.0	0.049	1.83E-05		
		3AU	1.32E-04	5.7 < R < 7.6	0.006	7.39E-07		
		Total:				2.32E-04		

Table 9.12 Summary of Scenario Quantification (continued)

Scenario	Target Subsection	Relevant Fire Origin	Geometry Factor and Fire Frequency (/yr)	Required Fire Radius (ft)	Severity Factor	Combined Severity and Geometry Factor/Fire Frequency (/yr)	Failure Mode Factor	Scenario Frequency (/yr)
		3AR	2.82E-04	2.2 < R < 8.0	0.150	4.23E-05	0.10	5.98E-06
		3AS	1.87E-04	4.2 < R < 8.0	0.024	4.49E-06		
		3AV	2.08E-04	5.9 < R < 7.4	0.004	9.15E-07		
		Total:				5.98E-05		
VB-1-4	3BH, 3BC/3BD	3BG	2.65E-04	6.6 < R < 8.0	0.004	1.14E-06	0.10	4.39E-07
		3BF	2.21E-04	4.6 < R < 8.0	0.011	2.43E-06		
		3BE	1.82E-04	6.5 < R < 8.0	0.005	8.19E-07		
		Total:				4.39E-06		
VB-6-DG1	DG1	RMS-100	8.07E-05	R > 4.4	0.038	3.07E-06	0.10	1.37E-05
		IS	5.38E-05	R > 2.9	0.084	4.52E-06		
		GTG	6.41E-05	R > 1.5	0.358	2.29E-05		
		DG1	7.48E-05	R > 0.0	1.000	7.48E-05		
		SWS	7.48E-05	R > 1.7	0.322	2.41E-05		
		LFHT	7.48E-05	R > 3.3	0.070	5.24E-06		
		VENT	7.48E-05	R > 5.0	0.030	2.25E-06		
		Total:				1.37E-04		
VBC-1-II-1	VBC-1-II	VBC-1-II	1.07E-04	R > 0.0	1.000	1.07E-04	1.00	1.07E-04

10. MODIFICATION OF THE INTERNAL PRA MODEL

The internal PRA IRRAS model¹ was used as a starting point in the analysis of the impact of failures caused by fire events.

The model was then modified by adding fire-induced failures to the existing component failures in the fault trees. For instance, for an LPI pump, fire-caused failures due to damage to the control cables or damage to the power cables were added to the failure due to internal causes wherever this event appeared in the fault trees. For a running pump, or a valve, failure modes due to spurious operation were also added. Such failures are caused by fire-induced hot shorts. There were no modifications of the event trees.

The event trees used are shown in Appendix I, and the modified fault trees are shown in Appendix J.

10.1 References:

1. T-L. Chu, Z. Musicki, P. Kohut, et al., "Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Surry Unit-1: Analysis of Core Damage Frequency from Internal Events During Mid-Loop Operations", NUREG/CR-6144, Volume 2, June 1994.

11. QUANTIFICATION

11.1 Summary of Procedure

For each fire scenario in Section 5.5, the appropriate initiating event was identified, and the corresponding event tree sequences were used in quantification (e.g., loss of 4 kV bus, station blackout, etc. sequences). The initiating event frequency was set equal to the scenario frequency from Table 5.4 or, for items from Table 9.12 multiplied by the mid-loop fraction (0.066), the probability of the particular POS and the particular window.

Appropriate fire-induced failures were flagged (according to descriptions in Section 5.5), and the scenario-dependent, high-level human error probabilities were set to their appropriate values (see Section 11.2 and Appendix G).

The core damage sequences were quantified with a cutset cutoff of 1.E-10. The resulting values were modified for successful systems, where appropriate (because the cutset evaluation algorithm assumes a probability of 1 for success of such systems).

Finally, recovery actions were applied to qualifying cutsets greater than 1.E-8/yr to account for operator actions not credited in the model (e.g., opening of the LPI discharge valves 1890C or 1890B, which are normally closed in mid-loop), or to refine conservatisms.

The recovery actions considered were opening of valves 1890B or C when failure of forced cooling is indicated in the cutset and opening of Unit 2 charging cross-tie, under the same circumstances.

Recovery of forced cooling is not included if the cutset indicates that the failure of forced cooling is caused by operator error. No recovery is applied in cutsets showing more than one human error.

Recovery actions rules are shown in Appendix Q.

11.2 Quantification of HEP for High-Level Human Action Events

11.2.1 High Level HEP Quantification

The approach used for the evaluation of operator actions in response to the fire initiating events is the same as that used for the internal event analysis¹. The dynamic operator actions analyzed in this study are listed in Table G-1 of Appendix G. All of the human actions with unique numerical values are quantified in Table G-2 of Appendix G, following the descriptions of Table G-1. There are other actions defined in Table G-1 that have the same numerical values as those tabulated in Table G-2 and are also used in the event sequence quantification.

11.2.2 Recovery Actions

Recovery actions quantifications are shown in Tables G-3 and G-4. In these tables, only a sample of scenarios is given where these recovery actions apply. In the analysis, these recovery actions were applied to all the applicable scenarios.

11.3 Successful System Correction

Another type of correction (or recovery action) occurs in certain sequences with success of the F event (forced feed and bleed), and failure of the C event (recirculation), see Appendix I. Some such sequences have a high value for the F event (> 0.1), such that a correction is needed (computer code IRRAS used for modeling always quantifies

Quantification

successful systems as having a probability of 1). The complement value (1-F) of the fault tree quantification of F was used to multiply the affected sequence cutsets to arrive at the correct sequence quantification. Likewise, uncertainty analysis of the affected F trees was used to arrive at an uncertainty histogram for this recovery factor.

11.4 Uncertainty Analysis

An in-house VAX resident computer code was used for generation of uncertainty distribution for total CDF.

Fire scenarios are usually composed of several components (e.g., there could be a cable fire and a large and a small transient fire, or a bus panel fire may affect more than one component of the RHR system); each component will have several (on the order of 10) multiplicative terms, most of which will have an uncertainty distribution. This results in complicated algebraic expressions with many shared elements for evaluation of initiating events (see Appendix K). A separate computer program was created on the VAX to generate histograms of uncertainty distributions for the initiating events for each scenario (each scenario has 10 POS-window combinations). This is accomplished by combining LHS samples of uncertainty distributions of constituent events in the algebraic expressions for the initiating events. The initiating event histograms that resulted from this procedure are shown in Appendix L. The samples of initiating event distributions were input into the VAX uncertainty code, along with the cutset Boolean expression and basic event uncertainty data.

It should be noted that a uniform distribution was used for such parameters as the large oil fraction (from 0. to 0.6) and damage fractions for various scenario (the upper bound of 1.0 was used). The latter is subject to many unknown uncertainties, starting with input parameters to the COMPBRN code and including (but not limited to) COMPBRN modeling itself. For most other variables, a lognormal distribution was assumed. For fire frequencies in various equipment, and from cable and transient fires, the distributions presented in Chapter 4 were used.

For the HEPs that appeared in the cutsets (including the recovery actions), a lognormal distribution was assumed with the following error factors: HEPs of $< 1.E-2$ were given an error factor of 10; between $1.E-2$ and 0.1 resulted in an error factor of 5; from 0.1 to 0.3 were given an error factor of 2; HEPs from 0.3 to 0.5 assumed an error factor of 1.5, and above 0.5, an error factor of 1.0 was assumed.

For recovery actions resulting from treatment of successful systems in the event trees, the resulting histograms were generated in accordance with the procedure described in Subsection 11.3.

11.5 References

1. T-L Chu, Z. Musicki, P. Kohut, et al., "Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Surry Unit-1: Analysis of Core Damage Frequency from Internal Events During Mid-Loop Operations", NUREG/CR-6144, Volume 2, June 1994.

12. RESULTS

12.1 Point Estimate Results

The unrecovered total core damage frequency (CDF) at Surry Unit 1 due to fire events is $2.72 \times 10^{-5}/\text{yr}$. The recovered total core damage frequency is $1.68 \times 10^{-5}/\text{yr}$. As can be seen, the recovery actions bring about less than a factor of 2 reduction in the total CDF. This is due to the fact that in windows 1 and 2, the recovery actions considered (e.g., Unit 2 charging cross-tie) will only extend the time to core damage, as recirculation is needed within the 24-hour mission time frame. Damage done by fire is considered irrecoverable in this time frame. Windows 1 and 2 are significant, on the other hand, because the decay heat level is the highest, and the success criteria are the most stringent.

Table 12.1 shows the scenario, window, and POS-dependent core damage frequency from sequences exceeding $1.0 \times 10^{-7}/\text{yr}$ after recovery. Sequences were quantified down to the $1.0 \times 10^{-10}/\text{yr}$ level, but only sequences greater than 1.0×10^{-8} were considered for recovery. (These added up to 96% of the total CDF for the unrecovered sequences and 88% of the total CDF for the recovered sequences). This table shows the interplay between decay heat, success criteria, and unavailabilities of equipment due to shutdown activities and those caused by a fire scenario.

In Table 12.1, the first column denotes the combination of fire scenario, window, and POS of the significant sequences. The POS is the last two or three characters, denoted by D6 (drained maintenance), R6 (first refueling mid-loop) or R10 (second refueling mid-loop). The window designation is in the middle of the string, denoted by WN, where N refers to the window number (1 through 4). Finally, the string is started by the scenario designator. A detailed description of scenarios appears in Chapters 5 and 9.

For the purposes of this chapter, the E designators are the scenarios in the emergency switchgear room, CV1 is the cable vault and tunnel scenario, CT are containment scenarios, N are the normal switchgear room scenarios and, M are the main control room scenarios. MN, where N is a number, refers to the benchboard scenario (designated BB-1-N in Chapter 9) of the same number. MA, where A is an alphabet character, refers to the vertical board scenario (designated VB-X-M in Chapter 9). For the scenarios of interest (others were screened out), MA refers to scenario VB-1-1, MC refers to VB-1-3, MG refers to VB-6-DG1, and MH is scenario VBC-1-II-1.

The second column is the sequence number in the appropriate event tree and the last column is the sequence CDF. The 32 sequences in Table 12.1 add up to about 87% of the total CDF (altogether there were about 600 sequences above the cutoff of $1.0 \times 10^{-10}/\text{yr}$).

As can be seen from Table 12.1, POS R10 (second refueling outage) is not represented among the significant sequences, i.e., it is not very risk significant. This is due to the fact that this POS can only occur in Windows 3 and 4, when the decay heat is lower. Also it can be seen that D6 is more heavily represented (21 out of 32 sequences), i.e., it is more risk significant than R6. D6 tends to occur earlier in the outage, i.e., its distribution is more heavily weighted toward the earlier windows than R6. An option that is available in R6, namely gravity feed, is not available in D6 due to nonremoval of safety valves. Furthermore, in window 1, where D6 occurs much more frequently than R6, another option, reflux cooling is also not available. This is due to the success criteria for this alternative and the fact that one steam generator is assumed to be quickly isolated in this type of outage. Again, Window 1 has the highest decay heat.

It can also be seen in Table 12.1 that earlier windows are more heavily represented than later ones. Window 4, which has the lowest decay heat level, is not represented at all. In this window, gravity feed alone can provide sufficient cooling to last the 24-hour mission time. Window 3 is represented in those scenarios (E4, E5 and CV1) where there is heavy damage from the fire, which causes many options to be lost. In the three scenarios cited, all methods of

Results

forced feed and bleed from Unit 1 are lost, as is Unit 1 AFW and the primary means of relief from the steam generator secondary for reflux cooling (i.e., the steam generator PORVs).

Window 2 is more of a contributor than Window 1, because it lasts much longer and a higher proportion of outages fall into this window.

As far as the representation of scenarios is concerned, the table shows what can be expected: the scenarios with moderate to heavy damage to the plant, due to multiple fire-induced equipment failures. Most of the important scenarios are in the ESGR (emergency switchgear room), and the cable vault and tunnel, where cables for many important emergency equipment converge. Note that there are no scenarios from the main control room (MCR) or the normal switchgear room (NSGR) in Table 12.1, because the fire scenarios in these areas fail to inflict enough damage to enough equipment (or the scenario frequency may be low).

Some insights about possible plant vulnerabilities may be gleaned from this table. Scenarios E4 and E5 occur in locations where many cables from both the H and the J division (the two emergency divisions at Surry) come together. Similarly, scenario CV1 occurs in a tunnel, where many emergency cables from both divisions are located. The H and J sides of the tunnel are about 10 ft apart (wall to wall, only 5 ft between cable trays). A transient or a cable fire will quickly spread to both sides of the tunnel. Another insight comes from consideration of containment scenarios, where it can be seen that the two RHR divisions are not separated.

Tables 12.2 through 12.7 show a more detailed picture of the results after recovery actions. Table 12.2 presents total CDF for each scenario; Table 12.3 shows the same information, but broken down into the three POSs; and Table 12.4 has the CDF for Window 1, when the decay heat level is the highest. Tables 12.5-12.7 show the conditional core damage probability (i.e., given a fire scenario), arranged in the same format as the previous three tables.

These tables bear out the above discussion. In Table 12.2, scenarios with the total CDF greater than 1.-6/yr are E3, E4, E7, E13B, and CV1 (E2 and E3 are close). These are scenarios with moderate to heavy damage and/or relatively high frequency. In Table 12.3, the scenario-POS combinations that are the highest in frequency are E4D6, E5D6, E7D6, and E7R6, i.e., the high damage scenarios in combination with the risk significant POSs.

In Table 12.5, the scenarios with the highest conditional core damage probability (CCDP) are, again, those where multiple equipment damage (preferably from both divisions) is expected. These are the scenarios E4, E5, E6, E7, E8, E10, and CV1 (all of these have a CCDP on the order of 0.5), and, to a lesser extent, M4 and M13. In Table 12.6, one can see that POSs D6 and R6 have a relatively high CCDP compared to POS R10. In Table 12.7, for Window 1, it can be seen that the following scenarios have a conditional core damage probability of 1 or close to 1: E4, E5, E6, E7, CV1, E8, M4, MG, and E10.

Figures 12.1 through 12.5 pictorially represent some of the discussion points above. Sequence quantification report appears in Appendix M; basic event descriptions and the uncertainty report are given in Appendix N; the total CDF cutsets are shown in Appendix O; importance measures are printed out in Appendix P.

12.2 Uncertainty Results

The uncertainty analysis was run, as explained in Chapter 11, in a pretty straightforward manner, once all the uncertainty distributions for basic events and fire scenarios were generated. The results of LHS analysis of the total recovered core damage frequency, from a sample size of 500 observations, are presented in Tables 12.8 and 12.9.

As can be seen, the mean value is 2.19-5/yr (vs. the point estimate of 1.68-5/yr), the median is 9.14-6/yr, while the 5th and the 95th percentile are 1.44-6/yr and 7.55-5/yr, respectively. If a lognormal distribution were fitted through the 5th and the 95th percentile, the resulting error factor would be 7.2.4.

12.3 Conclusions

Risk significant scenarios are found mainly in the emergency switchgear room (ESGR), the cable vault and tunnel (CVT). In the ESGR, several important scenarios (which are also the most risk significant ESGR scenarios) occur in locations where many cables for the H and the J emergency divisions come together in a close proximity. In the CVT, the tunnel part is a constrained space, where damage would quickly propagate to both divisions (serving many different emergency equipment). In the CT, the risk significance stems from the relatively high fire frequency and non-separation of the two RHR divisions.

POSS D6 and R6 are much more risk significant than R10, with POS D6 more significant than R6.

Windows 1, 2, and 3 are much more important than Window 4, and Windows 1 and 2 are more important than Window 3. Window 2 is the most risk significant window.

The most significant scenario-window-POS combination, according to Fussell-Vessely importance measure, is CV1-W2-D6 (importance of over 10%), followed by E7W2D6, E4W2D6, E5W2D6 and followed by the R6 POS in the same scenario and window combinations.

Human error events are not prominent contributors individually in terms of Fussell-Vesely importance range (F-V importance of a few percent). These are the basic events that start with 'A-' (operator errors) and certain events starting with 'R-' (recovery actions, ending with '2CH' or '1869B'). The most important HEPs are recovery via charging cross-tie in window 3 and scenario CV1 and operator failure to establish RHR cooling in window 2 of scenario 2 of scenario E13B.

Part of the reason for lack of prominence of individual HEPs is that there are many HEPS, each applicable in a small fraction of sequences; another reason is in the values assigned to the HEPs; the third reason is that in many important scenarios hardware failures dominate due to heavy damage by fire.

Of hardware failures the most important ones are the fire induced spurious operation of certain valves (RHR isolation valve MOV1700 and pressurizer PORV block valves MOV1535 and 1536), inverter failures, CCW failures and plugging of the sump. Maintenance of the AFW pump 3B is very important.

FIRE AREA CONTRIBUTION TO CDF

Figure 12.1

CONTRIBUTION OF WINDOWS TO FIRE CDF

Figure 12.2
12-5

Sequences > 1.E-7

POS CONTRIBUTION

TO FIRE CDF

Figure 12.3

SIGNIFICANT SCENARIO, POS, WINDOW COMBINATIONS

CONTRIBUTORS TO FIRE CDF

Figure 12.4

SCENARIO CONTRIBUTION TO CDF

Figure 12.5

Table 12.1 Quantification of Sequences Greater than 10^{-7} /yr

Scenario, Window, POS	Sequence No.	Core Damage Frequency (/yr)
E1W2D6	9	1.02-7
E2W2D6	4	2.42-7
E2W2R6	8	1.36-7
E3W2D6	4	2.42-7
E3W2R6	8	1.36-7
E4W1D6	3	3.68-7
E4W2D6	8	1.37-6
E4W2R6	8	7.68-7
E4W3D6	3	2.24-7
E4W3R6	3	1.04-7
E5W1D6	3	3.68-7
E5W2D6	8	1.37-6
E5W2R6	8	7.68-7
E5W3D6	3	2.24-7
E5W3R6	3	1.04-7
E7W1D6	7	2.86-7
E7W1D6	8	1.96-7
E7W2D6	9	8.85-7
E7W2D6	10	3.32-7
E7W2R6	17	7.45-7
E7W2R6	18	3.00-7
E10W2D6	4	1.70-7
E12W1D6	7	1.88-7
E13BW2D6	9	3.63-7
E13BW2D6	10	1.24-7
E13BW2R6	17	2.02-7
CV1W1D6	3	4.98-7
CV1W2D6	4	1.86-6

Results

Table 12.1 Quantification of Sequences Greater than $10^{-7}/\text{yr}$ (continued)

Scenario, Window, POS	Sequence No.	Core Damage Frequency (/yr)
CV1W3D6	3	$3.04 \cdot 10^{-7}$
CV1W3R6	3	$1.40 \cdot 10^{-7}$
CT2W1D6	2	$4.68 \cdot 10^{-7}$
TOTAL		$1.46 \cdot 10^{-5}$

Table 12.2¹ Total Core Damage Frequency (/yr)

Scenario	CDF (/yr)
E1	2.96-07
E2	7.04-07
E3	7.04-07
E4	2.98-06
E5	2.98-06
E6	2.46-07
E7	2.84-06
E8	2.18-07
E9	7.42-10
E10	3.77-07
E11	-
E12	2.27-07
E13A	1.01-07
E13B	1.12-06
CT1	9.95-08
CT2	5.28-07
CV1	4.03-06
N1	3.52-08
N2	1.62-08
N3	-
M1	5.74-09
M3	3.88-08
M4	5.23-08
M5	-
M8	8.77-09
M9	-
M12	-

¹Events, marked '-' have a core damage frequency below the cutset cutoff of 1.E-10.

Table 12.2¹ Total Core Damage Frequency (/yr) (continued)

Scenario	CDF (/yr)
E1	2.96-07
M13	9.45-09
MA	4.18-08
MC	1.35-09
MD	-
MG	4.42-07
MH	1.30-09

Results

Table 12.3² Total CDF for Each POS and Scenario

Scenario	POS	CDF (/yr)
E1	D6	1.96-07
E1	R6	8.67-08
E1	R10	1.29-08
E2	D6	4.79-07
E2	R6	2.09-07
E2	R10	1.30-08
E3	D6	4.79-07
E3	R6	2.09-07
E3	R10	1.30-08
E4	D6	1.97-06
E4	R6	9.52-07
E4	R10	5.31-08
E5	D6	1.97-06
E5	R6	9.52-07
E5	R10	5.31-08
E6	D6	1.63-07
E6	R6	7.55-08
E6	R10	6.85-09
E7	D6	1.71-06
E7	R6	1.11-06
E7	R10	1.32-08
E8	D6	1.36-07
E8	R6	6.56-08
E8	R10	1.58-08
E9	D6	2.64-09
E9	R6	7.42-10
E9	R10	-

² Events, marked '2' have a core damage frequency below the cutset cutoff of 1E-10.

Results

Table 12.3 Total CDF for Each POS and Scenario (continued)

Scenario	POS	CDF (/yr)
E10	D6	4.58-08
E10	R6	2.83-09
E10	R10	9.46-09
E11	D6	-
E11	R6	-
E11	R10	-
E12	D6	2.01-07
E12	R6	2.60-08
E12	R10	-
E13	D6	6.84-08
E13	R6	2.88-08
E13	R10	3.88-09
E13	D6	7.40-07
E13	R6	3.67-07
E13	R10	1.08-08
CT	D6	7.27-08
CT	R6	2.23-08
CT	R10	4.53-09
CT	D6	4.80-07
CT	R6	4.78-08
CT	R10	4.64-10
CV	D6	2.67-06
CV	R6	1.28-06
CV	R10	7.40-08
N1	D6	2.38-08
N1	R6	1.04-08
N1	R10	9.29-10
N2	D6	1.12-08
N2	R6	4.45-09

Table 12.3 Total CDF for Each POS and Scenario (continued)

Scenario	POS	CDF (/yr)
N2	R10	4.56-10
N3	D6	-
N3	R6	-
N3	R10	-
M1	D6	4.24-09
M1	R6	1.50-09
M1	R10	-
M3	D6	2.99-08
M3	R6	8.44-09
M3	R10	3.46-10
M4	D6	2.91-08
M4	R6	2.19-08
M4	R10	1.33-09
M5	D6	-
M5	R6	-
M5	R10	-
M8	D6	3.91-09
M8	R6	4.98-09
M8	R10	7.56-10
M9	D6	-
M9	R6	-
M9	R10	-
M12	D6	-
M12	R6	-
M12	R10	-
M13	D6	6.65-09
M13	R6	2.80-09
M13	R10	-

Results

Table 12.3 Total CDF for Each POS and Scenario (continued)

Scenario	POS	CDF (/yr)
MA	D6	1.27-08
MA	R6	2.71-08
MA	R10	2.00-09
MC	D6	1.07-09
MC	R6	2.87-10
MC	R10	-
MD	D6	-
MD	R6	-
MD	R10	-
MG	D6	4.40-07
MG	R6	2.92-09
MG	R10	-
MH	D6	9.04-10
MH	R6	3.98-10
MH	R10	-

Results

Table 12.4 CDF for Window 1

Scenario	CDF (/YR)
E1	4.84-08
E2	1.22-07
E3	1.22-07
E4	3.93-07
E5	3.93-07
E6	3.58-08
E7	5.20-07
E8	2.25-08
E9	2.06-09
E10	4.86-08
E11	-
E12	2.05-07
E13	2.65-08
E13	2.01-07
CT1	3.60-08
CT2	4.70-07
CV1	5.32-07
N1	7.26-09
N2	3.30-09
N3	-
M1	3.30-09
M3	2.87-08
M4	1.03-08
M5	-
M8	1.59-09
M9	-
M12	-
M13	1.29-09
MA	4.15-09

Table 12.4 CDF for Window 1 (continued)

Scenario	CDF (/YR)
MC	7.94-10
MD	-
MG	4.40-07
MH	5.96-10

Results

Table 12.5³ Conditional Core Damage Probability vs. Scenario

Scenario	Conditional Core Damage Probability
E1	1.06-01
E2	9.02-02
E3	9.02-02
E4	4.94-01
E5	4.94-01
E6	4.61-01
E7	3.61-01
E8	6.34-01
E9	2.18-03
E10	5.28-01
E11	-
E12	1.93-03
E13A	1.84-03
E13B	6.51-02
CT1	8.46-03
CT2	1.81-03
CV1	4.95-01
N1	2.05-03
N2	2.13-03
N3	-
N1	4.24-03
M3	3.92-02
M4	3.20-01
M5	-
M8	7.63-02
M9	-

³ Events, marked '-' have a core damage frequency below the cutset cutoff of 1.E-10.

Table 12.5 Conditional Core Damage Probability vs. Scenario (continued)

Scenario	Conditional Core Damage Probability
M12	-
M13	1.91-01
Ma	2.34-03
MC	3.41-03
MD	-
MG	6.20-02
MH	1.42-03

Results

**Table 12.6⁴ Conditional Core Damage Probability
Vs. Scenario and POS**

Scenario	POS	Conditional Core Damage Probability
E1	D6	1.34-01
E1	R6	1.26-01
E1	R10	2.03-02
E2	D6	1.17-01
E2	R6	1.09-01
E2	R10	7.28-03
E3	D6	1.17-01
E3	R6	1.09-01
E3	R10	7.28-03
E4	D6	6.27-01
E4	R6	6.36-01
E4	R10	3.85-02
E5	D6	6.27-01
E5	R6	6.39-01
E5	R10	3.95-02
E6	D6	5.84-01
E6	R6	5.75-01
E6	R10	5.63-02
E7	D6	4.15-01
E7	R6	5.74-01
E7	R10	7.37-03
E9	D6	1.82-02
E9	R6	1.08-02
E9	R10	-
E8	D6	7.56-01

⁴ Events, marked '---' have a core damage frequency below the cutset cutoff of 1.E-10.

Results

**Table 12.6 Conditional Core Damage Probability
Vs. Scenario and POS (continued)**

Scenario	POS	Conditional Core Damage Probability
E8	R6	7.74-01
E8	R10	2.01-01
E10	D6	5.67-01
E10	R6	6.35-01
E10	R10	5.54-02
E11	D6	-
E11	R6	-
E11	R10	-
E12	D6	3.26-03
E12	R6	8.96-04
E12	R10	-
E13	D6	2.37-03
E13	R6	2.12-03
E13	R10	3.08-04
E13	D6	8.22-02
E13	R6	8.65-02
E13	R10	2.75-03
CT1	D6	1.18-02
CT1	R6	7.67-03
CT1	R10	1.68-03
CT2	D6	3.13-03
CT2	R6	6.59-04
CT2	R10	6.93-06
CV1	D6	6.27-01
CV1	R6	6.37-01
CV1	R10	3.98-02
N1	D6	2.65-03

**Table 12.6 Conditional Core Damage Probability
Vs. Scenario and POS (continued)**

Scenario	POS	Conditional Core Damage Probability
N1	R6	2.46-03
N1	R10	2.36-04
N2	D6	2.86-03
N2	R6	2.69-02
N2	R10	5.82-03
N3	D6	-
N3	R6	-
N3	R10	-
M1	D6	5.97-03
M1	R6	4.49-03
M1	R10	-
M3	D6	5.78-02
M3	R6	3.48-02
M3	R10	1.53-03
M4	D6	3.40-01
M4	R6	5.42-01
M4	R10	3.55-02
M5	D6	-
M5	R6	-
M5	R10	-
M8	D6	6.49-02
M8	R6	1.75-01
M8	R10	2.87-02
M9	R10	-
M9	R6	-
M9	R10	-
M12	D6	-

Results

**Table 12.6 Conditional Core Damage Probability
Vs. Scenario and POS (continued)**

Scenario	POS	Conditional Core Damage Probability
M12	R6	-
M12	R10	-
M13	D6	2.56-01
M13	R6	2.29-01
M13	R10	-
MA	D6	1.36-03
MA	R6	6.12-03
MA	R10	4.89-04
MC	D6	5.13-03
MC	R6	2.92-03
MC	R10	-
MD	D6	-
MD	R6	-
MD	R10	-
MG	D6	1.18-01
MG	R6	1.66-03
MG	R10	-
MH	D6	1.89-03
MH	R6	1.76-03
MH	R10	-

Results

Table 12.7⁵ Conditional Core Damage Probability for Window 1

Scenario	WINDOW 1 Conditional Core Damage Probability
E1	2.65-01
E2	2.38-01
E3	2.38-01
E4	1.0
E5	1.0
E6	1.00
E7	1.00
E8	9.97-01
E9	1.14-01
E10	7.10-01
E11	-
E12	2.66-02
E13A	7.36-03
E13	1.79-01
CT1	4.67-02
CT2	2.46-02
CV1	1.00
N1	6.47-03
N2	7.32-03
M8	-
M1	3.72-02
M3	4.43-01
M4	9.64-01
M5	-
M8	2.12-01
M9	-

⁵ Events, marked '-' have a core damage frequency below the cutset cutoff of 1.E-10.

Results

Table 12.7 Conditional Core Damage Probability for Window 1

Scenario	WINDOW 1 Conditional Core Damage Probability
M12	-
M13	3.9-01
MA	3.54-03
MC	3.06-02
MD	-
MG	9.40-01
MH	9.94-03

**Table 12.8 Parameters of Uncertainty Distribution
For Total Core Damage Frequency (1/yr)
500 Trials**

Parameter	Value (/yr)
Point Estimate	1.68-5
Mean	2.19-5
σ	3.75-5
Sample minimum	2.47-7
Sample maximum	3.63-4

Table 12.9 Quantiles of Uncertainty Distribution for Total Core Damage Frequency (/yr)

Quantile (%)	Value (/yr)	Quantile (%)	Value (/yr)
5	1.44-6	60	1.28-5
10	2.22-6	70	1.85-5
20	3.34-6	75	2.25-5
25	4.01-6	80	2.73-5
30	5.03-6	90	4.77-5
40	6.99-6	95	7.55-5
50	9.14-6		

13. PLANT DAMAGE STATE ANALYSIS

In this section a brief summary is presented on the development and identification of plant damage states for Level 2 analysis. This process gathers the dominant core damage sequences and cutsets into plant damage states (PDSs). The plant damage state analysis involved the identification of detailed PDS categories using a seven state indicator. The PRA model discussed in the previous sections assessed the severity of accident consequences in terms of core damage frequency. In order to assess the severity of accident consequences, the degree to which containment systems remain operable must also be determined.

13.1 Definition of Plant Damage State Indicators

A total of seven PDS indicators were used to identify the unique plant damage states. The seven indicators address the following issues:

- Time of accident initiation
- Status of AC power
- Human error
- Status of RCS at onset of core damage
- Status of ECCS
- Status of recirculation spray system
- Status of RWST

The above PDS indicators question the status of various safety systems and their actual state is indicated by various letters indicating the possible status of these variables. Table 13.1 lists a more detailed description of the indicators and their possible status with the appropriate letter designations.

13.2 PDS Analysis, Rules

The PDS analysis was based on the previous event tree analysis. There were 151 cutsets above the cutoff of 10^{-8} (1734 cutsets above the 10^{-10} cutoff). The 151 cutsets comprise about 90% of the CDF, and they were used to build the rules for cutset-PDS relationships. These rules were then applied to all the cutsets. The rules were developed and applied in the IRRAS code. The code automatically assigned the fire cutsets into the appropriate PDS according to the specified rules. The final cutset assignment was manually verified to insure full consistency of the results. A total of 59 different PDSs were obtained.

The most dominant PDSs are designated as 2FNLRRR, 2YNLUUN and 1YNGUNN. These PDSS comprise about 50% of the total CDF.

13.3 PDS Uncertainty Analysis

Uncertainty analysis were performed for each of the PDSs utilizing a Monte-Carlo sampling routine in the IRRAS code. The calculations for each PDS were done independently not accounting for effects represented by the sharing of many basic events through the PDSs. The point estimate results and the uncertainty results are listed in Table 13.2.

Table 13-1 Plant Damage State Definitions

PDS Indicator	Status Designator
Time of Accident Initiation	1 - Window 1 2 - Window 2 3 - Window 3 4 - Window 4
Status of AC Power	Y - Available U - Nonrecoverable blackout B - Recoverable blackout (using off-site power) F - Loss of 4 kV Bus
Human Error	N - No human error or nonrecoverable human error D - Diagnosis error A - Action error
Status of RCS at Onset of Core Damage	L - Low pressure G - 5% probability that pressure is high
Status of ECCS	U - Hardware Failure R - Recoverable if human error, LOSP, or 4 kV recovered C - Failure of recirculation
Status of Recirculation Spray System	R - Recoverable U - Nonrecoverable
Status of RWST	Y - Injected R - Recoverable, not injected N - Nonrecoverable, not injected

Table 13-2

Plant Damage States
Results of Uncertainty Analysis

	PDS	POINT	MEAN	5%	MEDIA N	95%
1	1UNGUU N	8.88E- 08	6.97E- 08	2.20E- 09	2.12E-08	2.60E-07
2	1UNGUU Y	3.88E- 10	2.70E- 10	6.96E- 13	2.84E-11	1.05E-09
3	1YAGRRR	9.06E- 09	9.03E- 09	1.09E- 10	2.09E-09	3.23E-08
4	1YAGRRY	1.96E- 09	1.68E- 09	1.14E- 11	2.56E-10	5.97E-09
5	1YAGRU R	5.37E- 08	5.98E- 08	1.29E- 09	1.35E-08	2.30E-07
6	1YAGRU Y	1.85E- 10	1.34E- 10	4.24E- 13	1.33E-11	4.27E-10
7	1YDGRR R	5.95E- 10	5.41E- 10	3.37E- 12	1.08E-10	2.02E-09
8	1YNGRRR	1.11E- 10	8.23E- 11	1.06E- 13	5.40E-12	3.33E-10
9	1YNGRRY	3.05E- 10	2.01E- 10	5.17E- 13	2.11E-11	7.87E-10
10	1YNGRU R	7.35E- 09	7.34E- 09	4.73E- 11	1.28E-09	2.97E-08
11	1YNGRU Y	2.77E- 08	2.88E- 08	2.02E- 10	4.37E-09	9.75E-08

Table 13-2 (continued)

Plant Damage State Analysis

Plant Damage States
Results of Uncertainty Analysis

	PDS	POINT	MEAN	5%	MEDIA N	95%
12	2UNLUUN	1.05E-06	1.21E-06	2.65E-08	2.98E-07	4.47E-06
13	2UNLUUY	7.67E-08	6.05E-08	5.70E-10	1.48E-08	2.15E-07
14	2YALRRR	2.31E-08	2.09E-08	2.03E-10	4.88E-09	7.880E-08
15	2YALRRY	3.09E-09	2.92E-09	3.59E-11	6.55E-10	8.53E-09
16	2YALRUR	1.98E-07	1.89E-07	6.15E-09	6.19E-08	7.79E-07
17	2YALRUY	1.14E-08	1.03E-08	7.91E-11	2.01E-09	5.03E-08
18	2YDLRRR	1.33E-09	1.16E-09	2.64E-11	3.53E-10	4.57E-09
19	2YDLRUR	3.49E-10	3.22E-10	3.92E-12	7.46E-11	1.14E-09
20	2YNLRRR	3.18E-09	3.11E-09	1.99E-11	4.52E-10	1.13E-08
21	2YNLRRY	8.01E-10	7.97E-10	5.17E-12	1.05E-10	2.84E-09
22	2YNLRUR	1.02E-08	1.27E-08	9.58E-11	1.86E-09	4.22E-08

Table 13-2 (continued)
Plant Damage States
Results of Uncertainty Analysis

	PDS	POINT	MEAN	5%	MEDIA N	95%
23	2YNLRUY	1.85E-08	1.59E-08	1.97E-10	3.50E-09	6.73E-08
24	3UNLUUN	1.51E-07	1.84E-07	3.59E-09	4.82E-08	5.79E-07
25	3UNLUUY	1.08E-06	9.83E-07	2.19E-08	2.81E-07	3.92E-06
26	3YALRRR	1.35E-08	1.99E-08	1.96E-10	2.60E-09	3.70E-08
27	3YALRUR	1.94E-07	1.90E-07	6.47E-09	7.01E-08	6.79E-07
28	3YDLRRR	1.07E-09	9.42E-10	2.14E-11	2.85E-10	3.68E-09
29	3YNLRRR	1.82E-10	1.89E-10	1.72E-13	8.87E-12	4.39E-10
30	4UNLUUN	1.89E-06	1.99E-06	1.02E-08	2.34E-07	7.30E-06
31	4UNLUUR	4.88E-09	5.21E-09	1.94E-11	5.09E-10	1.23E-08
32	4YALRRR	1.10E-08	6.98E-09	4.47E-11	9.37E-10	2.86E-08
33	4YALRUR	1.65E-07	1.59E-07	1.93E-09	2.56E-08	5.76E-07

Table 13-2 (continued)**Plant Damage State Analysis****Plant Damage States****Results of Uncertainty Analysis**

	PDS	POINT	MEAN	5%	MEDIA N	95%
34	4YDLRRR	1.33E- 10	1.06E- 10	1.17E- 13	7.41E-12	3.97E-10
35	4YNLRRR	1.62E- 09	1.25E- 09	2.14E- 12	7.56E-11	4.38E-09

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11. ABSTRACT (200 words or less)

During 1989, the Nuclear Regulatory Commission (NRC) initiated an extensive program to carefully examine the potential risks during low power and shutdown operations. The program includes two parallel projects being performed by Brookhaven National Laboratory (BNL) and Sandia National Laboratories (SNL). Two plants, Surry (pressurized water reactor) and Grand Gulf (boiling water reactor), were selected as the plants to be studied. The objectives of the program are to assess the risks of severe accidents initiated during plant operational states other than full power operation and to compare the estimated core damage frequencies, important accident sequences and other qualitative and quantitative results with those accidents initiated during full power operation as assessed in NUREG-1150. The objective of this report is to document the approach utilized in the Surry plant and discuss the results obtained. A parallel report for the Grand Gulf plant is prepared by SNL. This study shows that the core-damage frequency during mid-loop operation at the Surry plant is comparable to that of power operation. We recognize that there is very large uncertainty in the human error probabilities in this study. This study identified that only a few procedures are available for mitigating accidents that may occur during shutdown. Procedures written specifically for shutdown accidents would be useful.

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