1 of 4

Systems Analysis of the CANDU 3 Reactor

Manuscript Completed: June 1993
Date Published: July 1993

Prepared by
J. R. Wolfgang, M. A. Linn, A. L. Wright,
M. Olszewski, M. H. Fontana

Oak Ridge National Laboratory
Operated by Martin Marietta Energy Systems, Inc.

Oak Ridge National Laboratory
Oak Ridge, TN 37831-6285

Prepared for
Division of Systems Research
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC FIN L2015
Under Contract No. DE-AC05-84OR21400

MASTER

phz
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Abstract

This report presents the results of a systems failure analysis study of the CANDU 3 reactor design; the study was performed for the U. S. Nuclear Regulatory Commission. As part of the study a review of the CANDU 3 design documentation was performed, a plant assessment methodology was developed, representative plant initiating

events were identified for detailed analysis, and a plant assessment was performed. The results of the plant assessment included classification of the CANDU 3 event sequences that were analyzed, determination of CANDU 3 systems that are "significant to safety," and identification of key operator actions for the analyzed events.

Contents

	Page
Abstract	iii
List of Figures	ix
List of Tables	xi
Acknowledgments	xiii
Acronyms and Abbreviations	xv
1. Introduction	1
1.1 Background and Purpose	1
1.2 Scope	1
1.3 Methodology	1
1.4 Limitations	2
References	2
2. Summary of CANDU 3 Design	3
2.1 Introduction	3
2.2 Plant Characteristics	3
References	5
3. Description of Assessment Process	7
3.1 Overview of Assessment Process	7
3.2 Identification of Initiating Events	8
3.3 Plant Assessment	9
References	17
4. Selection of Initiating Events	19
4.1 Classification of Initiating Events	19
4.1.1 Master Logic Diagram	19
4.1.2 Initiating Events	19
4.2 Selection of Representative Initiating Events	20
References	21
5. Systems Analysis	27
5.1 Fault Tree Analysis	27
5.2 Systems Description	27
5.2.1 Reactivity Shutdown Systems	27
5.2.1.1 Reactor Regulating System	27
5.2.1.2 Shutdown System 1	37
5.2.1.3 Shutdown System 2	39
5.2.2 Moderator Liquid Poison System	39
5.2.3 Feedwater Systems	43
5.2.3.1 Group 1 Feedwater System	43
5.2.3.2 Group 2 Feedwater System	43
5.2.3.3 Auxiliary Feedwater System	43

Contents (cont.)

5.2.4	Heat Transport System	43
5.2.5	Steam Discharge	51
5.2.5.1	Condenser Steam Discharge Valves	51
5.2.5.2	Atmospheric Steam Discharge Valves	54
5.2.6	Shutdown Cooling System	54
5.2.7	Moderator Cooling System	54
5.2.8	Emergency Core Cooling System	58
5.2.8.1	ECCS High-Pressure Injection	58
5.2.8.2	ECCS Low-Pressure Injection	66
5.2.8.3	ECCS Recirculation	66
5.2.9	Bleed Condenser System	66
5.2.10	Steam Generator Isolation	66
5.2.11	Liquid Relief Valve Closure	67
5.2.12	Crash Cooling	67
5.2.13	Main Steam Safety Valves	67
5.2.14	Emergency Generators	67
References		72
6.	Event Analysis	73
6.1	Large-Break Loss-of-Coolant Event	73
6.1.1	Event Description	73
6.1.2	Event Sequence Diagram and Event Tree	77
6.1.3	LBLOCA Sequence Evaluation Insights	77
6.2	Small-Break Loss-of-Coolant Events	80
6.2.1	Event Descriptions	80
6.2.2	Event Sequence Diagram and Event Tree	82
6.2.3	Sequence Evaluation Insights	82
6.3	Loss of Class IV Power Event	84
6.3.1	Event Description	84
6.3.2	Event Sequence Diagram and Event Tree	87
6.3.3	Sequence Evaluation Insights	87
6.4	Undercooling Events	87
6.4.1	Event Descriptions	90
6.4.2	Event Sequence Diagrams and Event Tree	91
6.4.3	Sequence Evaluation Insights	95
6.5	Reactivity Transient Event	95
6.5.1	Event Description	95
6.5.2	Event Sequence Diagram and Event Tree	95
6.5.3	Sequence Evaluation Insights	96
6.6	Failure to Shutdown Event	96
6.6.1	Event Description	96
6.6.2	Event Sequence Diagram and Event Tree	98
6.6.3	Sequence Evaluation Insights	98
Reference		98

Contents (cont.)

7. Results	101
7.1 Event Sequence Categorization Results	101
7.2 Systems Significant-to-Safety	101
7.3 Identification of Primary and Backup Systems	111
7.4 Significant Operator Actions	112
7.4.1 Reactor Shutdown	112
7.4.2 ECCS Initiation After Small Loss-of-Coolant Events	112
7.4.3 Refill of Group 2 Feedwater Supply Tank	114
7.4.4 Initiation of the Shutdown Cooling System	114
7.4.5 Steam Generator Isolation	114
7.4.6 Poison Addition in Failure-to-Shutdown Sequences	114
7.5 Summary	114
References	114
Appendix A Overview of CANDU 3 Design	115
A.1 Introduction	115
A.2 Plant Configuration	115
A.2.1 Reactor Configuration	115
A.2.1.1 Fuel	120
A.2.1.2 Annulus Gas System	120
A.2.1.3 Moderator System	120
A.2.1.4 Shield Cooling System	120
A.2.2 Heat Transport System	121
A.2.3 Control System	121
A.2.3.1 Reactor Control	121
A.2.3.2 Distributed Control System	121
A.2.4 Fuel Handling and Storage	125
A.2.4.1 Refueling	125
A.2.4.2 Irradiation Fuel Handling and Storage	125
A.2.4.3 Defective Fuel Handling	125
A.2.4.4 Irradiation Fuel Storage Bay	128
A.2.4.5 Fuel Handling Control System	128
A.2.5 Plant Layout (Separation)	128
A.2.6 Electrical Power System	128
A.2.6.1 Classes of Power	128
A.2.6.2 Odd and Even Concepts	131
A.2.6.3 Automatic Transfer System	131
A.2.6.4 Uninterruptible Class II Power Supplies	131
A.2.6.5 Uninterruptible Class I dc Power Supplies	131
A.2.6.6 Group 2 Power Supply System	132
A.2.7 Service Systems	132
A.2.7.1 Group 1 Recirculated Cooling Water System	132
A.2.7.2 Group 1 Raw Service Water System	133
A.2.7.3 Compressed Air System	133
A.2.7.4 Reactor Building Ventilation System	133
A.2.8 Fire Protection	134

Contents (cont.)

A.3 Special Safety Systems	134
A.3.1 Shutdown Systems	135
A.3.1.1 Functional Requirements	135
A.3.1.2 System Description	135
A.3.2 Shutdown System No. 2	141
A.3.2.1 Functional Requirement	141
A.3.2.2 SDS2 System Description	142
A.3.2.3 Equipment Layout	143
A.3.2.4 Reactor and Process Measurements	143
A.3.2.5 Logic Processing	143
A.3.3 Emergency Core Cooling System	144
A.3.3.1 System Functional Requirements	144
A.3.3.2 Summary Description	144
A.3.3.3 System Operation	145
A.3.4 Containment System	148
A.3.4.1 System Functional Requirements	148
A.3.4.2 Design Basis	148
A.3.4.3 System Description	148
A.3.4.4 Operating Modes	149
A.4 Summary of CANDU 3 Design Overview	151
Appendix B System Cut Set Results	153
B.1 Presentation of System Cut Set Results	153
B.2 Discussion of System Cut Set Results	153
Appendix C Event Tree Analysis Results	173
C.1 Introduction	173
C.2 Large-Break Loss-of-Coolant Event Analysis Results	173
C.3 Small-Break Loss-of-Coolant Accident Event Analysis Results	173
C.4 Loss of Class IV Power Event Analysis Results	173
C.5 Undercooling Event Analysis Results	173
C.6 SCRAM Event Analysis Results	173
Appendix D Check of Methodology Integrity	301
Appendix E Comparison to AECL Analyzed Events	311

List of Figures

Figure	Page
2.1 Reactor assembly	4
3.1 Description assessment approach	8
3.2 Sample ESD	10
3.3 Sample event tree	11
3.4 Logic diagram for sequence classification	14
4.1 CANDU 3 MLD	20
5.1 Reactor shutdown systems fault tree	28
5.2 RRS block diagram	38
5.3 SDS1	40
5.4 SDS2 block diagram	41
5.5 SDS2 schematic of poison injection system	42
5.6 MLP system fault tree	43
5.7 MLP flow diagram	44
5.8 Feedwater systems fault tree	45
5.9 FW1	49
5.10 FW2 flow diagram	50
5.11 HTS fault tree	51
5.12 HTS	52
5.13 SD fault tree	53
5.14 Schematic of SD	55
5.15 SDC fault tree	56
5.16 Flow diagram for SDC	57
5.17 MCS fault tree	58
5.18 MCS flow diagram	59
5.19 ECCS fault tree	60
5.20 Schematic for ECCS	65
5.21 BCS isolation fault tree	67
5.22 Pressure and inventory control system	68
5.23 ISO fault tree	69
5.24 LRC fault tree	69
5.25 CC fault tree	70
5.26 MSSV fault tree	72
5.27 GENs fault tree	72

6.1	Feeder tube header break ESD	78
6.2	Feeder tube header break event tree	79
6.3	LRV failure ESD	83
6.4	Feeder tube break ESD	84
6.5	LRV failure event tree	85
6.6	Feeder tube break event tree	86
6.7	LOP ESD	88
6.8	LOP event tree	89
6.9	Feedwater piping break in reactor building ESD	91
6.10	Feedwater piping break in turbine building ESD	92
6.11	Feedwater piping break in reactor building event tree	93
6.12	Feedwater piping break in turbine building event tree	94
6.13	SCRAM ESD	96
6.14	SCRAM event tree	97
6.15	FTSD ESD	99
6.16	F1SD event tree	100
A.1	37-Element fuel bundle	116
A.2	Unit cell for 37-element fuel	117
A.3	Reactor assembly	118
A.4	Reactor structures assembly—front view	119
A.5	HTS simplified composite flow diagram	122
A.6	Reactor building—section	123
A.7	Mechanical zone control unit	124
A.8	Fuel-handling systems	126
A.9	Fueling machine vault, fuel transfer system, and IFSB—plan	127
A.10	Two-group separation philosophy	129
A.11	Station layout—plan	130
A.12	Schematics of logic for actuating mechanical elements of shutdown systems	140
A.13	Schematic diagram of liquid injection system used for SDS2	142
A.14	ECCS	146
A.15	Reactor containment system	150

List of Tables

Table	Page
2.1	CANDU 3 unit data 3
3.1	Criteria for categorization of event sequences 13
4.1	Explanation of PRCs 21
4.2	IE categorization 22
4.3	RIEs chosen for plant analysis 26
4.4	Justification for RIEs 26
5.1	CANDU 3 system fault trees 27
6.1	CANDU 3 dependency matrix 74
7.1	Event Category I results 102
7.2	Event Category II results 104
7.3	Event Category III results 105
7.4	Group 2 Systems used in the mitigation of RIEs for the CANDU-3 conceptual design 110
7.5	Systems and components classified as significant-to-safety 112
7.6	Primary and backup systems from event analyses 113
A.1	CANDU 3 unit data 115
A.2	Coverage of process failures by SDS1 and independently by SDS2 136
A.3	SDS1 trip parameters 138
A.4	SDS2 trip parameters and detectors used 143
B.1	Basic event designator descriptions 156
B.2	System cut set results 159
C.1	Feeder tube header break sequence cut sets 174
C.2	LBLOCA events sequence categorization: representative initiating event—feeder tube header break 206
C.3	Liquid relief valve failure sequence cut sets 207
C.4	Small-break loss-of-coolant events sequence categorization: representative initiating event—liquid relief valve failure 222
C.5	Feeder tube break sequence cut sets 224
C.6	Small-break loss-of-coolant events sequence categorization: representative initiating event—feeder tube break 246
C.7	Loss of Class IV power sequence cut sets 248
C.8	Loss of essential power supply events sequence categorization: representative initiating event—loss of Class IV power 262
C.9	Feedwater piping break in the reactor building sequence cut sets 266
C.10	Undercooling events sequence categorization: representative initiating event—feedwater piping break in the reactor building 284
C.11	Feedwater piping break in the turbine building cut sets 285

C.12	Undercooling events sequence categorization: representative initiating event—feedwater piping break in the turbine building	289
C.13	SCRAM sequence cut sets	291
C.14	Reactivity transient events sequence categorization: representative initiating event—SCRAM	294
D.1	Feeder tube header break sequence comparisons	302
D.2	Liquid relief valve failure sequence comparisons	303
D.3	Feeder tube break sequence comparisons	305
D.4	Loss of Class IV power sequence comparisons	306
D.5	Feedwater piping break in the reactor building sequence comparisons	308
D.6	Feedwater piping break in the turbine building sequence comparisons	309
D.7	SCRAM sequence comparisons	310
E.1	Correspondence of sequences to CSR events	312

Acknowledgments

The authors acknowledge the efforts of Andrew Szukiewicz, Ralph Meyer, and Zoltan Rosztoczy of the U.S. Nuclear Regulatory Commission staff, who were responsible for directing and monitoring the CANDU Systems Research Program efforts and who provided insightful comments that greatly enhanced the technical content of this report. We also wish to thank Louis Rib and Bob Curtis of the AECL Technologies staff, who provided the copies of the CANDU 3 illustrations that are used in this report. In addition, we appreciate the contributions that

S. J. Ball, W. P. Bartnold, J. J. Carbajo, N. Clapp, G. J. Dyer, M. Johnson, S. C. Nelson, W. A. McAfee, D. G. Morris, G. A. Murphy, R. T. Primm, G. C. Robinson, R. P. Wichner, and V. K. Wilkinson made to the overall CANDU Systems project. Finally, we appreciate the assistance provided by members of the Oak Ridge National Laboratory Engineering Technology/Fusion Energy Division Publications Office, who effectively prepared the final version of this report.

Acronyms and Abbreviations

AECL	Atomic Energy of Canada, Limited
AFW	Auxiliary Feedwater System
ANS	Advanced Neutron Source
ASD	Atmospheric Steam Discharge Valve
BCS	Bleed Condenser System
CC	Crash Cooling System
CSD	Condenser Steam Discharge Valve
CSR	Conceptual Safety Report
DOE	Department of Energy
EAB	Exclusion Area Boundary
ECCS, ECC	Emergency Core Cooling System
ECI	Emergency Coolant Injection
ESD	Event Sequence Diagram
FMECA	Failure Modes, Effects and Consequences Analyses
FTSD	Failure To Shutdown
FW	Feedwater System
FW1	Group 1 Feedwater System
FW2	Group 2 Feedwater System
GEN	Emergency Generators
HPI	High-Pressure Injection
HTS	Heat Transport System
IE	Initiating Event
ISO	Steam Generator Isolation
LBLOCA	Large-Break Loss-of-Coolant Accident
LOCA	Loss-of-Coolant Accident
LOCS	Loss-of-Coolant Signal
LOFWRB	Loss of Feedwater in the Reactor Building
LOFWTB	Loss of Feedwater in the Turbine Building
LOP	Loss of Class IV Power
LPI	Low-Pressure Injection
LRC	Liquid Relief Valve Closure
LRFV	Liquid Relief Valve Failure to Reclose
LRV	Liquid Relief Valve
LWR	Light-Water Reactor
MCS	Moderator Cooling System
MLD	Master Logic Diagram
MLP	Moderator Liquid Poison System
MSV, MSSV	Main Steam Safety Valve
NRC	U.S. Nuclear Regulatory Commission
NRR	Nuclear Reactor Regulation
ORNL	Oak Ridge National Laboratory
PRA	Probabilistic Risk Assessment
PRC	Plant Response Category
PSA	Probabilistic Safety Assessment
REC	ECC Recirculation
RIE	Representative Initiating Event
RRS	Reactor Regulating System
SAR	Safety Analysis Report
SBLOCA	Small-Break Loss-of-Coolant
SBLFB	Small-Break LOCA Feeder Tube Break
SD	Steam Discharge

SDC
SDS1, SD1
SDS2, SD2

Shutdown Cooling System
Shutdown System 1
Shutdown System 2

1 Introduction

1.1 Background and Purpose

The U.S. Nuclear Regulatory Commission (NRC) is performing a preapplication review of the Canadian CANDU 3 reactor design in preparation for possible standard design certification at a future date. Because the CANDU 3 design is significantly different from that of any licensed U.S. reactor, certain features of the safety review for CANDU 3 will be new to the NRC. To support that review, Oak Ridge National Laboratory (ORNL) was asked to perform a systems failure analysis of the CANDU 3 systems that are used during normal reactor operation and postulated accidents to provide the NRC with an understanding of the dynamic behavior of the plant.

In performing a safety review, the NRC usually classifies event sequences as Anticipated Operational Occurrences, Design-Basis Accidents, and Severe Accidents. Events in each classification are then held to different requirements. Important safety systems and operator actions also enter into the review. Therefore, the ORNL study includes a classification of important event sequences and an identification of "systems significant to safety" and key operator actions.

1.2 Scope

The expected results from this study included

- a list of categorized CANDU 3 event sequences,
- a list of CANDU 3 systems designated as significant-to-safety, and
- a list of key operator actions.

This report provides the following:

- A brief description of the CANDU 3 design, which focuses on the major characteristics of the plant, particularly those that differ from U.S. light-water reactors (LWRs).
- A description of the assessment methodology, which is an adaptation of Probabilistic Risk Assessment (PRA) analysis techniques using fault trees and event trees.
- Results of the fault tree analysis. These trees identify, for each system, those conditions that could cause failure of the system to perform its mitigation function in response to plant transients.
- A listing of initiating events and results of the event tree analysis for representative initiating events.

- The event tree results that are used to classify event sequences and identify systems that play an important role in the safety of the plant when responding to off-normal events.
- The results of the study as indicated previously.

1.3 Methodology

Because the CANDU 3 design is not fully developed, detailed design information that would be needed for a licensing review or for a PRA analysis is not available. Therefore, the CANDU Systems Research Program adapted assessment methodologies such that a meaningful assessment could be made on the basis of the information available.

The process by which the program arrived at its results is briefly described in the following paragraphs. The plant assessment methodology is described in detail in Chap. 3.

CANDU design characteristics were obtained from Atomic Energy of Canada, Limited (AECL) information sources provided to ORNL by the NRC; these sources are given as Refs. 1–7, or as footnotes.*–**** Information from a CANDU-600 Probabilistic Safety Assessment (PSA) was also made available for on-site inspection at AECL

* Atomic Energy of Canada, Limited, "The CANDU 3 Technical Description," 74-01371-TED-001, Rev. 3/89-09-15.

† Atomic Energy Control Board, Regulatory Document R7, "Requirements for Containment Systems for CANDU Nuclear Power Plants," 1987.

‡ Atomic Energy Control Board, Regulatory Document R8, "Requirements for Shutdown Systems in CANDU Nuclear Plants," 1987.

** Atomic Energy Control Board, Regulatory Document R9, "Requirements for Emergency Core Cooling System in CANDU Nuclear Plants," 1987.

†† Atomic Energy Control Board, Regulatory Document R10, "The Use of Two Shutdown Systems in Reactors," 1977.

‡‡ Atomic Energy Control Board, Regulatory Document R77, "Overpressure Protection Requirements for Primary Heat Transport Systems in CANDU Power Reactors Fitted with Two Shutdown Systems," 1987.

*** Atomic Energy Control Board, Regulatory Document R90, "Policy on Decommissioning of Nuclear Facilities," 1988.

††† H. Tamm et al., Overview of the Technical Basis for the Safety of CANDU Reactors, Paper presented at the International Symposium on Nuclear Safety, Tokyo, Dec. 8-10, 1987.

‡‡‡ D. G. Hurst and F. C. Boyd, Reactor Licensing and Safety Requirements, Paper presented at the 12th Annual Conference of the Canadian Nuclear Association, Ottawa, June 11, 1972.

**** P. J. Allen et al., Atomic Energy of Canada, Limited, "External Analysis Report—Conceptual Probabilistic Safety Assessment," Rev. 0/89-02-28, 1989.

Introduction

Rockville, Maryland, offices. Also, two meetings were held with AECL to clarify questions that arose as the ORNL staff became more knowledgeable about the plant.*†‡**

Initiating events were identified and used in the plant assessment process. The plant assessment process used adaptations of PRA techniques that included the use of fault trees and event trees and was supplemented with a System Dependency Matrix. Fault tree evaluations identified failure modes for the systems assessed.

On the basis of the plant assessment, plant events were classified into groups as EC-Is, EC-IIIs, EC-IIIs, and EC-IVs (Chap. 3 defines these categories). Plant events are comprised of an initiating event (also referred to as an initiator) and the plant response (referred to as the event sequence in the report). Thus, multiple plant events result from each initiating event, depending on the possible combinations of component/system failures. The plant assessment process also identified systems significant-to-safety and key operator actions.

1.4 Limitations

Several limitations exist that preclude the performance of a complete and comprehensive independent analysis of the safety-related issues regarding the CANDU 3 reactor. Because the CANDU 3 design is currently incomplete, sufficient design detail does not exist to perform in-depth failure analyses. For instance, certain aspects such as operator actions and maintenance effects cannot be examined in detail because the procedures on which these analyses would be based are not yet available.

The focus of this effort was on systems behavior during power operations. Other plant conditions such as low or zero power operations were not examined. In addition, earthquakes, fires, floods, and common-mode failures associated with such events were not considered in this analysis.

The main focus of the report is on events that affect the fuel in the reactor core; it is thought that these have the greatest potential to lead to significant radionuclide releases. Event tree and fault tree analyses were not performed for the containment, refueling, and waste storage systems because available information on these systems in the Canadian documentation was sparse.

The initiating events were obtained from a review of a comprehensive set of sources, including U.S. LWRs and research reactors and Canadian CANDU operating experience. The representative initiating events against which the plant response is gaged are comprehensive, but further analysis and experience could indicate different or additional events that should be analyzed.

References

1. Atomic Energy of Canada, Limited, "CANDU 3 Conceptual Safety Report," Vols. 1 and 2, 1989.*
2. Atomic Energy of Canada, Limited, "The CANDU 3 Technical Outline," Rev. 11, June 1992.†
3. P. H. Wigfull, "Reactor Licensing in Canada," *Nuclear Safety* 24(4) (1983).†
4. R. K. Nakagawa, Atomic Energy of Canada, Limited, "The Technology of CANDU On-Power Refueling," TTR-305, 1991.*
5. D. Pendergast et al., Atomic Energy of Canada, Limited, "The Technology of CANDU Loss of Coolant Analysis," TTR-276, Rev 0, 1991.*
6. A. R. Khan and P. Archer, Atomic Energy of Canada, Limited, "The Technology of CANDU Shutdown Systems," TTR-306, Rev 0, 1991.*
7. E. G. Price et al., The Technology of CANDU Fuel Channels, TTR-291, Rev 0, Atomic Energy of Canada, Limited, 1991.*

*"Point Lepreau Nuclear Generating Station - Unit 1 - Safety Report," Parts 1 and 2, 1990.

†Atomic Energy of Canada, Limited Technologies, Rockville, Maryland, personal communication to Oak Ridge National Laboratory Staff, March 10, 1992.

‡Atomic Energy of Canada, Limited, Presentation of Information at NRC/AECL Review Meeting on the CANDU 3 Systems Research Study, February 10, 1993.

**Letter from AECL Technologies to the U.S. NRC, "Responses to February 10, 1993 NRC/ORNL Request for Information," February 22, 1993.

* Available in NRC PDR for inspection and copying for a fee.

† Available in public technical libraries.

2 Summary of CANDU 3 Design

2.1 Introduction

This section provides a very brief summary of CANDU 3 characteristics that affect safety considerations. Appendix A, which is derived from extensive condensation of the CANDU 3 Conceptual Safety Report (CSR),¹ the CANDU 3 Technical Outline,² and the CANDU 3 Technical Description,^{*} serves as a convenient source of plant design information.

2.2 Plant Characteristics

The CANDU 3 design is a derivation of the CANDU reactors that have been in operation for almost 30 years. Twenty-three CANDU-type reactors have been built and operated to date. The CANDU 3 is a smaller power version of the CANDU concept that builds on an extensive data and information base, but at present it is in a conceptual design stage. Therefore, many details, needed for extensive safety assessment and for PRAs, are not available. The plant unit data are given in Table 2.1. A sketch of the reactor assembly is shown in Fig. 2.1.

The reactor is cooled and moderated by heavy water and is fueled by natural enrichment uranium. The fuel is in the form of uranium dioxide pellets, in zirconium alloy tubes 495 mm long. The fuel assemblies are bundles containing 37 rods and are stacked horizontally in zirconium pressure tubes, 12 to a tube. The 232 pressure tubes are arranged so that each is fed by a coolant feeder tube from 4 inlet headers.² The heated coolant exits from the core to individual tubes that feed to two outlet headers that supply the primary coolant side of two steam generators. The pressure tubes, feeder tubes, headers, pumps, pressurizer, fuel loading machine, and associated supply systems form the main pressure boundary.

The pressure tubes are contained inside zirconium alloy calandria tubes; these penetrate the calandria vessel, which contains a heavy water moderator at low pressure. The moderator system includes a moderator level control system, a pressure relief system employing rupture disks, a moderator cover gas control system that controls moderator pressure as well as recombines radiolytic deuterium to prevent buildup of combustible concentrations in the cover gas, and a moderator neutron poison system. The calandria vessel is contained within a shield tank that contains light water.

^{*}Atomic Energy of Canada, Limited, "The CANDU 3 Technical Description," 74-01371-TED-001, Rev. 3/89-09-15, 1989.

Table 2.1 CANDU 3 unit data

Reactor	
Type	Horizontal pressure tube
Coolant	Pressurized heavy water
Moderator	Heavy water
Number of fuel channels	232
Fuel	
Fuel	Compacted and sintered natural UO ₂ pellets, 12.15-mm diam., clad in 13.08-mm-OD, 0.42-mm-thick Zircaloy—4 sheath
Form	Fuel bundle assembly of 37 elements
Length of bundle	495.3 mm
Outside diameter	102.4 mm
Bundle weight	23.5 kg (includes 19.1 kg U)
Bundles per fuel channel	12
Heat transport system	
Number of steam generators	2
Steam generator type	Vertical U-tube with integral steam drum and preheater
Number of heat transport pumps	4
Heat transport pump type	Vertical, centrifugal, single suction, double discharge
Reactor outlet header pressure (gage)	9.9 MPa
Reactor outlet temperature	310°C
Reactor coolant flow	5.3 Mg/s
Steam temperature (nominal)	260°C
Steam quality (minimum)	99.75%
Steam pressure (gage)	4.6 MPa
Total fission heat	1440.3 MW(th)
Net electrical output (nominal)	450 MW(e) ^a

^aTypical for a cold water site; net electrical output is dependent on cooling water temperature and turbine-generator and condenser design.

Refueling is performed continuously while at power. This is necessary because of the low excess reactivity due to the use of natural enrichment uranium. On-line refueling

CANDU 3

Figure 2.1 Reactor assembly

contributes to the historically very high capacity factors achieved by the CANDU class reactors. Refueling for the CANDU 3 differs from previous CANDUs in that all fueling is performed from one face of the reactor, whereas in prior designs, fuel was inserted from one face and removed from the opposite face. For fuel removal, coolant flow pressure forces are relied upon to propel the fuel string into the refueling machine. The refueling is automatically controlled by computer and can be observed remotely by the operators in the control room.

The reactor is controlled by a distributed digital control system. One reason for this is that the core is sufficiently large in physical size to be potentially subject to spatial variations in neutron flux, which must be locally monitored and controlled; manual control is not feasible.

Normal reactor control is accomplished by mechanical regulating rods, which enter the core from the top. Also, reactivity is controlled by the refueling scheme, which shuffles new and irradiated fuel, and by a boron or gadolinium liquid poison system in the moderator.

The reactor has a positive coolant void reactivity coefficient and could theoretically experience a positive power transient in the event of voids from, for example, large loss-of-coolant accidents (LOCAs). Under this circumstance, the normal regulating system is not capable of shutting down the reactor. Therefore, there are two independent safety shutdown systems, SDS1 and SDS2. SDS1 uses mechanical spring-injected rods that enter the core from the top. SDS2 uses a helium-pressure-driven gadolinium nitrate poison solution injection, with the injectors entering the moderator vessel from the side (at right angles to the fuel and calandria tubes).

An emergency core cooling system (ECCS) employs a gas-driven high-pressure injection (HPI) system and a low-pressure injection (LPI) system, with long-term residual heat removal using pump-driven cooling water.

The containment system utilizes a steel-lined reinforced concrete building that has space coolers, but does not have a spray or deluge system. The system is designed to withstand a large-break LOCA, but a break in the main steam system internal to containment could exceed the design basis although it would not exceed the ultimate capability of the containment. The containment has heavy water vapor recovery systems and a hydrogen igniter system.

The plant is designed to provide physical separation between Group 1 systems and Group 2 systems. Generally, Group 1 systems provide for normal operation of the plant, and Group 2 systems provide safety backup. Group 2 systems are environmentally qualified, including seismic qualification. Electrical power supplies are arranged in four classes, I, II, III, and IV, depending on interruptability and reliability requirements.

The concept of dual failures is different than that of the U.S. systems. For CANDU, failure of the normal process system counts as the first failure, while failure of the backup safety system counts as the second failure.

As mentioned previously, Appendix A is a convenient source of design information. It is recommended that those needing familiarization with the CANDU 3 design read Appendix A before proceeding. More detail is provided in Refs. 1 and 2.

References

1. Atomic Energy of Canada, Limited, "CANDU 3 Conceptual Safety Report," Vols. 1 and 2, 1989.*
2. Atomic Energy of Canada, Limited, "The CANDU 3 Technical Outline," Rev. 11, June 1992.*

* Available in NRC PDR for inspection and copying for a fee.

3 Description of Assessment Process

3.1 Overview of Assessment Process

The project products were developed by performing a systematic assessment of the CANDU 3 plant conceptual design. The major steps in the assessment process are indicated in Fig. 3.1. The design information sources detailed in Chap. 1 were reviewed* by a team of technical experts to become familiar with the plant design. This team consisted of experts in the following technical areas:

1. instrumentation and control;
2. reactor operations and human factors;
3. fuel performance, radiological waste, and fission products;
4. severe accident phenomena;
5. neutronics;
6. materials, structures, and mechanical systems; and
7. reactor safety.

The team of technical experts then provided technical guidance in the application of the assessment methodology and reviewed the fault and event trees for completeness and accuracy.

Several plant assessment methodologies were considered for use including HAZOP, FMECA, and standard fault tree and event tree techniques. Three criteria were used when selecting the assessment methodologies to be used in the study. One was related to the products required from the project. Because they are typical of products from a PRA of a plant, techniques normally used in PRAs (event trees and fault trees) were favored.

The amount of detail required to implement the methodology effectively was the second criterion to be considered when selecting the approach to be used in this study. And finally, there is the need to provide the NRC with the information in a deterministic format to allow a more consistent review with respect to NRC regulatory criteria. As described in Chap. 2 and Appendix A, the CANDU 3 plant is a highly complex design that depends upon multiple layers of active engineered systems to provide for safe operation. From the project's inception it was clear that the project scope would not support utilization of an approach that required formal processing of a high level of detail. In addition, difficulties would

have existed with such an approach because the level of detail available at the present stage of the CANDU 3 design would not support application of such an approach. Fortunately, a substantial data base exists from previous CANDU experience. A large number of individual components and subsystems are of a standard nature (pumps, heat exchangers, etc.), and the vulnerabilities of these systems are understood by experts knowledgeable in such systems in other nuclear plants. Methodologies utilizing such expertise (with additional attention devoted to significant, unique systems to ensure that their designs and potential weaknesses were understood) would, therefore, provide the results required. Thus, the methodology chosen needed to be flexible so that it could be tailored to take advantage of expert judgment and devote additional attention to specific areas of interest when warranted, while providing the logical framework needed to complete the systematic assessment of the plant and provide PRA-type information. An assessment methodology using a combination of event trees and fault trees was chosen because it best fit the requirements of the program.

A comprehensive list of initiating events (IEs) was developed (this is described in Sect. 3.2) utilizing experience with U.S. LWRs, U.S. research reactors, and currently operating CANDU power reactors. The goal of this activity was to develop a short list of representative initiating events (RIEs) for which event trees would be completed. The IEs selected for this short list are to be representative of the spectrum of CANDU 3 plant responses (i.e., systems that respond to mitigate the IE).

The plant assessment used the RIEs and the CANDU plant design information to produce the project products specified in Chap. 1. Systematic assessment began with a description of the event sequence and preparation of an event sequence diagram (ESD) for each RIE. The ESD shows the normal and alternative paths for successful termination of an event and, thus, provides a pictorial representation of the progression of a plant sequence from the IE to the termination of the sequence. It was used to identify those systems called upon to respond to a given IE. An event tree was prepared for the IE using the ESD. Fault trees were prepared for each system identified in the event tree. The fault trees were used to gain insight into the vulnerabilities of each system. A system dependency matrix was developed to determine the relationship between frontline (e.g., the shutdown systems that are directly engaged in mitigating an IE) and support systems (e.g., the electrical power supply system that provides a support function to the frontline systems). The event tree and fault tree models were solved to (1) classify the event

*In the context of this program "review" is interpreted as meaning familiarization rather than assessment of acceptability, which is an NRC formal review function.

Figure 3.1 Description of assessment approach

sequences, (2) identify key operator actions, (3) provide insights concerning potential failure modes, and (4) identify systems significant-to-safety.

3.2 Identification of Initiating Events

The objectives of this effort were to (1) produce a comprehensive list of IEs and their estimated frequency of occurrence, (2) group the initiators into plant response categories, and (3) select RIEs that would be analyzed using the plant assessment methodology. As a starting point, data regarding IEs for various types of reactors were

collected. The following experience was reviewed for applicability:

- operating experience for commercial U. S. LWRs and research reactors,
- the regulatory data base for commercial U. S. LWRs, and
- Canadian operating experience for CANDU designs.

In addition, information concerning potential IEs unique to the CANDU 3 design was obtained from the review performed by the team of technical experts. The listing of all IEs (drawn from the sources described previously) was

reviewed to help identify any overlap in plant response to the various postulated IEs. Because the plant responds to several IEs in the same manner (i.e., there are many more IEs than there are unique plant responses), IEs that invoke similar plant responses were grouped together into a single plant response category (PRC). The PRC could then be evaluated rather than requiring a separate analysis for each individual event.

PRCs for the CANDU 3 were determined using a Master Logic Diagram (MLD). The MLD, a common tool now used in PRAs, presents the logical process of identifying the mechanisms that could lead to an undesired event such as a release of radioactivity from the reactor plant. Essentially, the MLD functioned as a top-level fault tree and served to identify the PRCs.

Each CANDU 3 IE was assigned to a PRC. In addition, a frequency of occurrence was estimated for each IE. This frequency is an order-of-magnitude estimate based on available data and engineering judgment. An IE table was prepared to summarize this information. This table contains a comprehensive listing of initiating events and their estimated frequency of occurrence (see Chap. 4).

The next step was to review the PRCs to determine whether any were similar enough to warrant further combination. The guideline for this review was to reduce the level of effort required while maintaining sufficient analysis detail. This reduction step resulted in the selection of seven RIEs that would be evaluated using the fault tree and event tree methodology. Selection of the RIEs is based on PRA experience and operational information for the CANDU 3 plant. Consequently, an RIE represents or is typical of the type of response that the plant would have to a set of specific initiators. Although it could exist, it is not necessary to have a one-to-one relationship between PRCs and RIEs. For illustration purposes, assume event X is similar to a loss of essential power supplies. This event and all other IEs that invoke a similar plant response would be placed in the PRC "Loss of Essential Power Supplies." Now, assume that event Y is similar to a loss of primary heat transport event. This event and all other IEs that invoke a similar plant response would be placed in the PRC "Loss of Heat Transport." However, the CANDU 3 plant response to both the "Loss of Essential Power Supplies" PRC and the "Loss of Heat Transport" PRC is expected to be generally the same, and that response can be adequately modeled by the IE "Loss of Class IV Power." Thus, "Loss of Class IV Power" is designated an RIE and it is used to represent all initiators under the "Loss of Heat

Transport" PRC and the "Loss of Essential Power Supplies" PRC.

3.3 Plant Assessment

Systematic assessment of the plant was performed by applying the event tree and fault tree methodology to each RIE. Description of each step in the methodology is provided below.

Prepare ESD and Event Trees. For each RIE, narrative text and an ESD were developed. An ESD is a graphical representation of the plant response to a particular IE. It shows, as a minimum, the normal and alternative (given postulated failures) plant system requirements for responding to a particular event. The objective is to produce a complete pictorial representation of the plant's operation. In addition, the ESDs were used to identify primary and backup systems and systems significant-to-safety in the CANDU 3 design. Systems required in the primary success path are designated *primary* systems. These systems are simply those systems and components that would be *expected* to respond to a given IE (i.e., no failures). Any system that is called upon in the ESD to prevent core damage outside the primary success path is designated a *backup* system.

A simplistic example of an ESD is found in Fig. 3.2. This ESD shows the primary path (designated as the farthest left-hand side path of the ESD) after an IE to be the successful operation of system A and system C. If system A fails, then system B must function as a backup to system A. System C must still work in order to mitigate the event. If either system A or system B succeeds and system C succeeds, the IE is successfully mitigated.

Based on the plant response information contained in the ESDs, an event tree was prepared for each RIE. Figure 3.3 contains an example event tree that corresponds to the example ESD contained in Fig. 3.2. The event tree branch points represent success (upward) or failure (downward) of systems designed to mitigate the IE. Each path through the event tree results in some "end state" that defines a specific condition of the plant. This condition would be a function of the particular series of system success or failures defined by that event tree sequence. While there could be any number of end states up to the number of unique sequences in the event tree, the number of end states actually defined is usually much less than this maximum number. This is because many "unique" sequences result in the same plant

Figure 3.2 Sample ESD

condition. For the example event tree in Fig. 3.3, only two end states are defined, success or failure in termination of the event.

Three plant end states have been defined for use in this study. Event tree designations of end states are based largely on engineering judgment, because no significant consequence analyses have been performed. The defined plant end states follow:

- CC-1—No significant fuel cladding damage and no fission product release from the fuel.
- CC-2—Moderate fuel cladding damage with release of some volatile fission products from the fuel (the fuel rod gap inventory), but coolable geometry of fuel bundles is maintained.

- CC-3—Extensive core damage with large release of fission products from the fuel and potential relocation of core debris.

As described in the next section, fault trees were used to model the systems and understand how failure of the systems could occur. Only the frontline systems (including both primary and backup) were incorporated in the event trees. Frontline systems are those systems that act directly to respond to or mitigate an event. Support systems are those systems that provide a support function to the frontline system (electric power is the most common one). Because of the lack of design details at this stage, the impact of support systems and components cannot be evaluated completely through the use of only event and fault trees. Consequently, additional tools were developed (such as a system dependency matrix, discussed later) to separately track and evaluate these support functions.

Figure 3.3 Sample event tree

Development of Failure Information. For each system identified in the event tree, a fault tree was developed to determine the system vulnerabilities. The fault trees were developed to differing levels of detail depending on whether failures were being developed for a frontline or support system. The design information generally allowed fault trees to be developed to the component level for the frontline systems but only to the system (essential cooling water) or subsystem level (train A of the essential cooling water) for support systems. Thus, the fault trees include the following: (1) active component failures of frontline systems; (2) passive component failures of frontline systems; (3) operator error of frontline systems (operations and maintenance); and (4) system level failures of support functions. This level of analysis was acceptable because at this point in the conceptual design, primary interest is in the identification of potential common-mode and dependent failure mechanisms within the support systems. These were identified through the combined use of the fault trees and the system dependency matrix.

The fault trees for each system were solved to determine the 1, 2, and 3 failure combinations (cut sets) associated with that system function. Cut sets are those combinations of failures that result in failure of the system function; for a given system, this means the failure of the system to perform its mitigation function. One-event cut sets identify those instances where a single active component failure or operator action failure can fail the system function. Two- and three-event cut sets, likewise, identify dual and triple independent failures that result in system function failure. This was accomplished using the Integrated Reliability and Risk Analysis System (IRRAS) code.¹ This cut set

information was then used for identification of design issues associated with each system. For example, the CANDU 3 special safety systems SDS1, SDS2, and the ECCS are required to be tolerant of a single operator failure or the failure of a single active component. Thus, any one-event cut sets for these systems identify areas where additional information or further attention is warranted. (If quantitative failure data are available, the cut sets also identify the failures that are most probable, and this also can highlight areas that may merit further attention.)

The event trees were then solved using the fault tree solutions, and sequence level failure combinations were generated. This information identified the system failure combinations that could contribute to a particular failure sequence in the event tree. This information along with the IE frequency was used to classify the event sequences.

Development of Support Data and Evaluation of Common-Mode Effects. To track the dependencies between frontline and support systems and between support systems themselves, a system dependency matrix was developed. The system dependency matrix (see Chap. 6) was developed to identify support systems whose failure could affect the operation of a frontline system and to identify any dependencies among the support systems themselves. Normally, this matrix is developed to the detail necessary to identify very specific information regarding the many dependencies within the plant. However, the design detail available at the conceptual stage is not sufficient to fully develop such a high level of dependency

Description

information. Consequently, the results reflect the available level of detail. Because the design is conceptual and will likely undergo change, data base tools were developed to assist the NRC in tracking these changes and aid in the identification of their impacts on the plant.²

Evaluation of Sequence Information. The sequence information resulting from solution of the event trees was evaluated to (1) classify each sequence, (2) identify the systems significant-to-safety, and (3) identify key operator actions. Each sequence in the event tree was evaluated to determine its event category as a function of its IE (from the IE table) and the type and number of failures in the sequence (from the event tree solution). The four possible event categories are designated as EC-I, EC-II, EC-III, and EC-IV. These event categories were defined by NRC to help identify scenarios to be analyzed by the applicant for design certification:

- The EC-I category was defined to include scenarios that might occur at least once in the lifetime of a given plant. Scenarios similar to those in this category might be selected by NRC as Anticipated Operational Occurrences for analysis by the applicant.
- The EC-II category was defined to include low-frequency initiators and single component or operator failures. These scenarios might occur once in the lifetime of a class of plants. Some of these scenarios might later be selected as Design-Basis Accidents for analysis by the applicant.
- The EC-III category was defined to include very-low-probability scenarios, some with multiple failures, which would be typical of "Severe Accidents." Such scenarios might be analyzed in PRAs to determine licensing source terms and to assess containment capabilities.
- The EC-IV category was defined to include scenarios with such low probabilities that detailed analysis would probably not be worthwhile. These are sometimes referred to as Residual Risk scenarios.

The criteria for categorizing a particular sequence is provided in Table 3.1. A logic diagram for the categorization process is shown in Fig. 3.4(a-c). As indicated in Fig. 3.4, each categorization bin is individually identified. This classification method is used in Appendix C when classifying the event tree sequences.

Although this methodology produces qualitative results, it has a basis in quantitative analysis. This method is discussed further in Appendix D where some limited quantification is done to confirm these qualitative results.

Systems significant-to-safety were identified using the ESDs and the System Dependency Matrix. As used in this report "systems significant-to-safety" identifies those systems that can have a significant impact on the successful response of the plant to an IE. Thus the term is related to, but does not mean, "safety related" as defined in the Canadian design (i.e., a Group 2 system) or "safety-grade" as applied in U. S. designs. Commercial U.S. operating experience demonstrates that nonsafety-related equipment is sometimes required to successfully mitigate an IE. Thus, in the context of this definition of significant-to-safety, safety-related equipment is a subset of systems significant-to-safety.

The CANDU 3 design has two general categorizations of systems with respect to their safety functions. "Group 1" systems are those process systems and components required for the production of electrical power while the plant is in its normal operating mode. "Group 2" systems and components are required in the event of serious process system failures. As such, Group 2 systems must ensure that all safety functions required to mitigate a serious process system failure are accomplished. However, it is recognized that Group 1 systems have been qualified to perform one or more "safety-related" functions, where safety-related has a particular meaning within the Canadian design philosophy.³ These safety-related functions are usually defined for very specific conditions or accidents. This report is not intended to provide an evaluation of the CANDU 3 design vs U.S. criteria for safety-related functions. Consequently, systems and components will be designated as either Group 1 or Group 2.

These are the criteria used in this report for judging whether a system is classified as significant-to-safety:

Candidate Systems Criteria:

1. Only those systems or components that contribute to successful termination (primary and backup paths) of an IE are considered candidates for being designated significant-to-safety. Successful termination is defined as resulting in plant end states CC-1 and CC-2. Systems on pathways leading to plant end state CC-3 are not considered as being significant-to-safety, although such systems could be considered candidates for severe accident management actions.
2. All Group 1 systems or components on paths terminating in plant end states CC-1 and CC-2 are considered candidates for being designated significant-to-safety. This included frontline systems and their support systems.

Table 3.1 Criteria for categorization of event sequences

Event category	Criteria
EC-I	IE frequency $P_{IE} \geq 10^{-2}$ Plus no failures (Bin A) or 1 single active component failure (Bin B) or 1 operator error (Bin B)
EC-II	IE frequency $10^{-2} > P_{IE} \geq 10^{-4}$ Plus no failures (Bin E) or 1 single active component failure (Bin F) or 1 operator error (Bin F)
EC-III	IE frequency $P_{IE} \geq 10^{-4}$ Plus 1 system failure (Bin C,G) ^a or 2 single active component failures (Bin C,G) ^a or 2 operator errors (Bin C,G) ^a or 2 combination failures (Bin C,G) ^a or 1 common-mode failure (Bin C,G) ^a OR IE frequency $10^{-4} > P_{IE} \geq 10^{-7}$ Plus no failures (Bin I) or 1 single active component failure (Bin J) or 1 operator error (Bin J)
EC-IV	All other sequences (Bins D, H, K, L, M)

^aDepending on IE frequency, the event may fall in either Bin C or Bin G.

3. All Group 2 systems on paths terminating in plant end states CC-1 and CC-2 are designated as significant-to-safety.

Criteria for Systems Significant to Safety:

1. Any Group 1 candidate system or component whose function is not backed up will be designated as being significant-to-safety. For the purposes of selecting systems significant-to-safety, the term backup here will be restricted to its use only where the backup system leads to the equivalent plant end state as the original system.
2. If any Group 1 candidate system or component has only Group 1 backup, the candidate system or component will be designated as significant-to-safety. The backup will not.
3. If a Group 2 candidate system is backed up by a Group 1 system, the Group 1 backup will not be designated as significant-to-safety.
4. Any Group 1 candidate system or component with at least one Group 2 backup will not be designated as significant-to-safety.

NOTES:

Single failure denotes 1 single active component failure or 1 operator failure.

Double failure denotes 1 system failure or 2 component failures or 2 operator failures or combination component/operator failures or 1 common mode failure.

(*) Triple failure denotes multiple failures which exceed the criteria for Double Failure.

Figure 3.4 Logic diagram for sequence classification

NOTES:

Single failure is 1 single active component failure or 1 operator failure.

Double failure is 1 system failure or 2 component failures or 2 operator failures or combination component/operator failures or 1 common mode failure.

(b) Triple failure is multiple failures which exceed the criteria for Double Failure.

Figure 3.4 (continued)

NOTES:

Single failure is 1 single active component failure or 1 operator failure.

Double failure is 1 system failure or 2 component failures or 2 operator failures or combination component/operator failures or 1 common mode failure.

(c) Triple failure is multiple failures which exceed the criteria for Double Failure.

Figure 3.4 (continued)

References

Updating the Electrical Dependency Database
Generated for the CANDU 3 Nuclear Reactor,"
ORNL/TM-12178, August 1992.*

1. K. D. Russell et al., Idaho National Engineering Laboratory, "Integrated Reliability and Risk Analysis System," USNRC Report NUREG/CR-5813, ID-83415, January 1992.*
2. M. E. Chandler, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., "Guide to Reading and

3. Atomic Energy of Canada, Limited, "CANDU 3 Conceptual Safety Report," Vol. 1, Appendix D1 1989.†

* Available for purchase from the National Technical Information Service, Springfield, VA 22161.

† Available in NRC PDR for inspection and copying for a fee.

4 Selection of Initiating Events

4.1 Classification of Initiating Events

For this work IEs were developed primarily using existing U.S. LWR PRA and Safety Analysis Report (SAR) experience and CANDU safety analyses along with engineering judgment based on the available conceptual design information for the CANDU 3 design. A rigorous analysis identifying potential initiators for this design had been provided in the CANDU documentation. The CANDU information was used extensively to identify IEs for this project. The approach used here was sufficient to obtain a broad-based understanding of potential IEs applicable to the CANDU 3 plant.

4.1.1 Master Logic Diagram

An MLD was developed to show the conditions necessary for off-site releases to occur. The MLD presented in Fig. 4.1 shows that the undesired event (off-site release) can result either from a release from a subsystem outside containment (e.g., fuel handling operations) or as a result of core damage concurrent with containment failure or excessive leakage. The ten conditions shown in the MLD as having the potential for leading to core damage are the PRCs identified for CANDU 3. Table 4.1 provides an explanation of each PRC.

4.1.2 Initiating Events

Several sources were considered to develop a comprehensive list of IEs for this analysis. These sources include analyses of commercial LWR and research reactor experience,* NRC standards,¹ NRC Safety Review Plans,² and existing CANDU reactor analyses.^{†,‡} In addition, a limited operating history of CANDU plants and other AECL-designed plants was reviewed for initiators that have occurred or events that may be precursors to possible IEs. The list was also supplemented with engineering judgment of ORNL personnel familiar with the CANDU 3 design. This was to help identify initiators not identified from other sources and to give credence to those taken from other sources, particularly those not specifically related to CANDU reactors.

Each potential initiator was evaluated to determine the plant response to that initiator. Events for which the plant response is similar (i.e., the same systems respond to mitigate the event) were grouped into the same PRC. Some of the events reviewed were not applicable to the CANDU 3 design and, therefore, were not included. Grouping of the events into PRCs was done so that events could be evaluated concurrently as a group rather than repeating the evaluation for every IE separately. The initiators within each PRC were assumed to occur with the reactor operating at full power. A frequency for each initiator was assigned based on available data and engineering judgment. If frequency information was available and the sources of that information were judged to be applicable to the CANDU 3, the frequency value was used. If frequency information was not readily available, a frequency was derived using conservative screening values for the initiating failures. The following screening values were used:

• mechanical active failure	10 ⁻²
• mechanical passive failure	10 ⁻³
• system failure (group 2 system)	10 ⁻³
• system failure (nongroup 2 system)	10 ⁻²
• human error (nonroutine)	10 ⁻¹
• human error (routine)	10 ⁻²

The frequencies assigned were order-of-magnitude values because of the preliminary nature of the plant design. This IE is presented in Table 4.2 along with the reference sources for each event and its frequency.

The CANDU 3 plant has many design features that are similar to light-water PWRs (LWPWRs). For this reason, it was prudent to use existing PWR information as a source for identifying IEs for CANDU 3. The categorization of IEs for PWR risk assessments was used as a starting guideline for grouping the CANDU IEs into PRCs. However, some additional categories were also identified because of the design differences between the CANDU 3 and LWPWRs, or events were moved between categories because of differences in the plant response between the PWR design and the CANDU 3. In some cases, there are additional aspects to consider regarding the consequences of some initiators within a category. For example, a steam-line break initiator can cause overcooling of the reactor core; however, in the CANDU 3 design, a break within containment may have greater significance as a challenge to the containment. In such cases, the event was placed into the category that was judged to best represent the event.

*D. H. Johnson et al., Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., "High Flux Isotope Reactor Probabilistic Risk Assessment," ORNL/RRD/INT-36/R1/V1, August 1991.

†P. J. Allen et al., Atomic Energy of Canada Limited, "CANDU 3 External Analysis Report, Conceptual Probabilistic Safety Assessment," 74-03660-AR-001, Rev. 0, February 28, 1989.

‡R. K. Jaitly et al., Atomic Energy of Canada Limited, "CANDU 3 Systematic Review of the Plant Design for Identification of Initiating Events," 74-00580-ASD-001, Rev. 2, April 10, 1992.

*REFER TO INITIATING EVENTS LIST IN TABLE 4.2

Figure 4.1 CANDU 3 MLD

4.2 Selection of Representative Initiating Events

Two of the major goals of this study were the classification of accident sequences and the identification of systems, structures, and components significant to safety. Because there is a limited number of unique plant responses (i.e., components and systems available to respond to an event), not all of the PRCs need be evaluated to achieve these goals. The PRCs chosen are expected to (1) exhibit similar

plant responses as other categories and (2) show the safety significance of the respective systems, structures, and components.

The PRCs chosen for further analysis included: (1) Large-Break Loss-of-Coolant (LBLOCA), (2) Small-Break Loss-of-Coolant (SBLOCA), (3) Loss of Essential Power Supplies, (4) Undercooling Event, and (5) Reactivity Transient. The remaining PRCs represent plant responses

Table 4.1 Explanation of PRCs

PRC	Explanation
Loss of Shutdown Cooling	Shutdown cooling system fails to remove the decay heat following successful shutdown of the reactor
Reactivity Transient	Events associated with the reactor core that adversely affect reactor power
Overcooling Event	Events that result in an increase in heat removal by the secondary system
Undercooling Event	Events that result in a decrease or loss of heat removal by the secondary system
Loss of Heat Transport	Events that result in a decrease or loss of heat removal by the primary system
Small-Break Loss-of-Coolant Accident	Pipe breaks in heat transport system lines of diameter <10 cm or events that result in an equivalent loss of inventory
Large-Break Loss-of-Coolant Accident	Pipe breaks in heat transport system lines of diameter >10 cm or events that result in an equivalent loss of inventory
Loss of Essential Power Supplies	Events that result in loss of power to plant equipment
Interfacing LOCA	Boundary between the primary and secondary systems is breached
Loss of Moderator Event	Events that result in a reactor transient due to a moderator anomaly

that are not expected to be unique from the five selected categories or that impose less demands on the plant systems. Consequently, they were considered to be adequately represented by the five selected categories and not further analyzed.

For each of the five selected categories, one or more RIEs were chosen for further analysis. The initiators were chosen based on an engineering judgement that the events would be the most demanding on the system functions. These representative events were selected based upon PRA experience and operational information of the CANDU plant and were judged to adequately address the remaining initiators. The seven RIEs selected for the chosen categories are presented in Table 4.3. Detailed plant analysis was conducted for these IEs. The representative event for each of the PRCs is given in the RIE column of Table 4.2. Table 4.4 presents the justification for the RIEs selected for each PRC.

References

1. R. A. Bari et al., Brookhaven National Laboratory, "Probabilistic Safety Analysis Procedures Guide," USNRC Report NUREG/CR-2815, Rev. 1, August 1985.*
2. U. S. Nuclear Regulatory Commission, "Standard Review Plan," USNRC Report NUREG-0800, Rev. 2, July 1981.*

* Available for purchase from the National Technical Information Service, Springfield, VA 22161.

Table 4.2 IE categorization

PRC	RIE	IE	References or footnotes	IE frequency	IE frequency source
Large-Break Loss of Coolant (LBLOCA)	Break in feeder tube header	1. Break in feeder tube headers	2, a-d	1×10^{-4}	Frequency obtained from c
		2. Backflow into ECC system	d	1×10^{-6}	Screening value for 3 independent mechanical active failures
Small-Break Loss of Coolant (SBLOCA)	Liquid relief valve (LRV) failure	1. LRV failure, pressurizer relief valve failure	a, c, d	1×10^{-1}	Frequency obtained from c
		2. Pressure and inventory control system failure	d	1×10^{-2}	Screening value for system failure (non-Group 2)
	Feeder tube break	1. Pressure tube leak/rupture	a, c, d	1×10^{-2}	Frequency obtained from c
		2. Inlet and outlet feeder tube leak/break	b, c	1×10^{-2}	Frequency obtained from c
		3. Fuel handling machine breaks end fitting	a, c, d	1×10^{-2}	Frequency obtained from c
		4. Leakage from fuel handling machine/cooling system	a	1×10^{-2}	Screening value for mechanical active failure
Loss of Essential Power Supplies	Loss of Class IV power (LOP)	5. Vent line and sample line leaks/breaks, leakage from primary system	1, 2, a, d	1×10^{-1}	Frequency obtained from Ref. 1 and c
		6. Heat transport pump seals fail	d	1×10^{-2}	Screening value for mechanical active failure
Undercooling Event	Loss of Class IV power (LOP)	1. Loss of station electric load	1, 2, c	1×10^{-1}	Frequency obtained from Ref. 1
		2. Off-site power lost	1, b, d	1×10^{-0}	Frequency obtained from Ref. 1
		3. LOP	d	1×10^{-2}	Frequency obtained from c
	Feedwater piping break	1. Turbine trip	1, 2, d	1×10^{-0}	Frequency obtained from Ref. 1
		2. Loss of condenser vacuum	1, 2, d	1×10^{-1}	Frequency obtained from Ref. 1
		3. Loss of normal feedwater flow	1, 2, a-d	1×10^{-0}	Frequency obtained from Ref. 1
		4. Feedwater piping break in the reactor building	1, 2, a, c, d	1×10^{-5}	Frequency obtained from c
		5. Feedwater piping break in the turbine building	1, 2, a, c, d	1×10^{-3}	Frequency obtained from c

Table 4.2 (continued)

PRC	RIE	IE	References or footnotes	IE frequency	IE frequency source
		6. Failure of steam generator pressure control resulting in closure of turbine throttle valves	c, d	1×10^{-2}	Screening value for mechanical active failure
		7. Loss of condensate pumps	1, d	1×10^{-1}	Frequency obtained from Ref. 1
		8. Failure of steam generator level control	d	1×10^{-2}	Screening value for mechanical active failure
Reactivity Transient	SCRAM	1. Uncontrolled control rod assembly withdrawal	1, 2, d	1×10^{-2}	Frequency obtained from Ref. 1
		2. Control rod maloperation (hardware or human error)—includes part length control rods, rod ejection, or rod drop accidents	1, 2, a, d	1×10^{-0}	Frequency obtained from Ref. 1
		3. SCRAM—manual or inadvertent	1, b, d	1×10^{-0}	Frequency obtained from Ref. 1
		4. Rod reposition error—pressure/temperature/power imbalance	1, a, d	1×10^{-1}	Frequency obtained from Ref. 1
		5. Moderator anomalies	a, d	1×10^{-2}	Screening value for mechanical active failure
Overcooling Event	SCRAM	1. Feedwater system malfunctions that result in an increase in feedwater flow or a decrease in feedwater temperature	1, 2, d	1×10^{-0}	Frequency obtained from Ref. 1
		2. Steam pressure regulator malfunction or failure that results in increasing steam flow (turbine overspeed)	2, d	1×10^{-2}	Screening value for mechanical active failure
		3. Inadvertent opening of a steam generator relief or safety valve	1, 2, a, d	1×10^{-2}	Frequency obtained from Ref. 1
		4. Increased heat transfer flow or inventory	2, b, d	1×10^{-2}	Screening value for mechanical active failure
		5. Steamline piping breaks inside or outside of containment	2, c, d	1×10^{-5}	Frequency obtained from c
		6. Startup of an inactive heat transfer loop or recirculating loop at an incorrect temperature	1, 2, c, d	1×10^{-3}	Frequency obtained from Ref. 1

Table 4.2 (continued)

PRC	RIE	IE	References or footnotes	IE frequency	IE frequency source
Loss of Heat Transport	LOP	1. Loss of flow in one or all heat transfer loops	1, 2, a, d	1×10^{-1}	Frequency obtained from Ref. 1
		2. Decreased heat transport system flow	2, a, b, d	1×10^{-2}	Screening value for system failure (non-Group 2)
		3. Pressurizer anomalies (high pressure, low pressure, spray failure)	1, d	1×10^{-2}	Frequency obtained from Ref. 1
		4. Deformation of fuel channel structure that restricts coolant flow	d	1×10^{-3}	Screening value for mechanical passive failure
Interfacing LOCA	Feedwater piping break	1. Steam generator tube failure	2, d	1×10^{-3}	Screening value for mechanical passive failure
Loss of Moderator Event	SCRAM	1. Degradation or loss of moderator flow	c, d	1×10^{-2}	Screening value for system failure (non-Group 2)
		2. Degradation or loss of moderator cooling	c, d	1×10^{-2}	Screening value for system failure (non-Group 2)
		3. Loss of moderator inventory	c, d	1×10^{-2}	Screening value for system failure (non-Group 2)
		4. Failure of the cover gas system	c, d	1×10^{-2}	Screening value for system failure (non-Group 2)
		5. Moderator deuterium excursion	c, d	1×10^{-4}	Screening value for two independent mechanical active failures
		6. Loss of calandria structural integrity	d	1×10^{-3}	Screening value for mechanical passive failure
Loss of Shutdown Cooling	Not analyzed. Event occurs when reactor is not at power	1. Failure to initiate system	c, d	1×10^{-2}	Screening value for human error (routine)
		2. Shutdown cooling hardware failures	d	1×10^{-2}	Screening value for mechanical active failure

Table 4.2 (continued)

PRC	RIE	IE	References or footnotes	IE frequency	IE frequency source
Radioactive Release from Subsystem	This category does not fall within the selected events	1. Leakage from radioactive gas or liquid waste systems	2	1×10^{-2}	Screening value for system failure (non-Group 2)
		2. Fuel or spent fuel hardware failure or handling accidents	2, c, d	1×10^{-2}	Screening value for mechanical active failure
Events not used		Failures of instrument air service water, plant control data highways, etc., are support system associated and are not included as separate IEs but are considered contributors to other initiators	1, a-d		
		Internal flooding and external events	1, a, c, d		
		Beam tube failure	b		
		Pressurizer pump malfunction	b		
		Reactivity insertion	b		
		Leakage from control rods	1		
		Inadvertent safety injection	1		

^aOperating Experience—IRS Database for CANDU Reactors.

^bThe High Flux Isotope Reactor Probabilistic Risk Assessment," ORNL/RRD/INT/36/R1/V1, Chap. 4, August 1991.

^cP. J. Allen et al., Atomic Energy of Canada Limited, "CANDU 3 External Analysis Report, Conceptual Probabilistic Safety Assessment," 74-03660-AR-001, Rev. 0, February 28, 1989.

^dR. K. Jaitly et al., Atomic Energy of Canada Limited, "CANDU 3 Systematic Review of the Plant Design for Identification of Initiating Events," 74-00380-ASD-001, Rev. 2, April 10, 1992.

Table 4.3 RIEs chosen for plant analysis

PRC	RIEs
LBLOCA	Break in feeder tube header
SBLOCA	Liquid relief valve failure Pressure and inventory control system failure
Loss of Essential Power Supplies	Loss of Class IV Power (LOP)
Undercooling Event	Feedwater piping break in reactor building Feedwater piping break in turbine building
Reactivity Transient	SCRAM

Table 4.4 Justification for RIEs

PRC	RIE	Justification
LBLOCA	Break in feeder tube header	Large volume of coolant inventory loss Requires immediate ECCS response
SBLOCA	Liquid relief valve failure	Requires elements of other SBLOCAs such as crash cooling Requires isolation of the bleed condenser Reactor regulating system not credited for reactor shutdown
	Feeder tube break	Demonstrates plant response to a small loss of coolant that cannot be isolated
Loss of Essential Power Supplies	LOP	Designed plant to feed power to itself upon loss of off-site power or station load Requires operation of diesel generators
Undercooling Event	Feedwater piping break in reactor building	Loss of coolant supply to the steam generators Poses potential challenge to the containment Poses a direct challenge to the Group 2 feedwater system
	Feedwater piping break in turbine building	Does not require the operator to isolate a draining boiler Initiating frequency is estimated to be 2 orders of magnitude greater than feedwater piping breaks in the reactor building
Reactivity Transient	SCRAM	Requires the reactor to be shut down Other reactivity initiators result in a SCRAM-type event
Overcooling Event	SCRAM	Overcooling of the core not a direct concern except that it forces the reactor to be shut down, which then closely follows a SCRAM sequence
Loss of Heat Transport	LOP	The heat transport pumps trip on a LOP, resulting in loss of forced flow through the core, which looks like a LOP event except that loss of power implies that other equipment also is unavailable. Simply stated, classifying this event as a LOP makes the analysis of the event more conservative.
Interfacing LOCA	Feedwater piping break	Shutdown cooling system would initiate to bypass the steam generators such as in a feedwater piping break
Loss of Moderator Event	SCRAM	Moderator anomaly would result in a reactivity transient, which will result in reactor shutdown

5 Systems Analysis

5.1 Fault Tree Analysis

The RIEs selected for analysis (Table 4.3) were analyzed using event trees as discussed in Chap. 3. The event tree branch points represent success or failure of systems designed to mitigate the initiator. Fault trees were used to model these systems to demonstrate how failure of the systems could occur. Many of the same systems would be used to mitigate different IEs and, therefore, are present in more than one event tree. For this reason, the fault trees are treated separately in this chapter. In addition, fault trees allow system evaluations to help identify potential system vulnerabilities (see Appendix B). The plant analyses that utilize the fault trees will be presented in Chap. 6.

Fourteen fault trees are presented and described in this chapter. (Information contained in the system descriptions was obtained from Ref. 1 unless indicated otherwise.) The fault trees will reflect failure of general mitigating functions intended to be performed by the systems. In some cases, the fault trees contain more than one system that could satisfy that function. For example, the feedwater system (FW) fault tree contains fault trees for the Group 1 feedwater system (FW1), Group 2 feedwater system (FW2), and the auxiliary feedwater system (AFW). In some accident scenarios any one of these three systems

could satisfy the requirements for the FW needs, and therefore the FW fault tree would be employed at the event tree branch point calling for the FW function. In those cases where a specific system is needed, only the appropriate portion(s) of the fault tree would be called upon in the event. Table 5.1 summarizes the fault trees developed for each mitigating function. Multiple systems contained by a single fault tree are shown in this table.

5.2 Systems Descriptions

5.2.1 Reactivity Shutdown Systems

The three methods of reactor shutdown are the reactor regulating system (RRS), SDS1, and SDS2. Figure 5.1(a)–(q) presents the fault tree for failure to shut down the reactor.

5.2.1.1 Reactor Regulating System

The RRS is an integrated system comprising reactor flux and thermal power measurements, reactivity control devices, and a set of distributed control system programs; all are coordinated to perform three main functions: (1) monitor and control total reactor flux and power to satisfy the station load demands, (2) monitor and control

Table 5.1 CANDU 3 system fault trees

Mitigating function	Fault tree	Systems within fault tree
Reactivity Shutdown	Reactor Regulating System	Reactor Regulating System Shutdown System 1 Shutdown System 2
Heat Removal	Moderator Liquid Poison Feedwater	Group 1 Feedwater Group 2 Feedwater Auxiliary Feedwater
	Heat Transport System Steam Discharge	Condenser Steam Discharge Valves Atmospheric Steam Discharge Valves
Inventory Control	Shutdown Cooling System Moderator Cooling System Emergency Core Cooling System	High-Pressure Injection Low-Pressure Injection
Pressure Control	Bleed Condenser System Isolate Steam Generator Liquid Relief Valve Closure Crash Cooling Main Steam Safety Valves	
On-site Power	Emergency Generators

Figure 5.1 Reactor shutdown systems fault tree

ORNL-DWG 93M-3219 ETD

(b)

Figure 5.1 (continued)

Figure 5.1 (continued)

Figure 5.1 (continued)

(g)

(h)

Figure 5.1 (continued)

(i)

(j)

Figure 5.1 (continued)

Figure 5.1 (continued)

Figure 5.1 (continued)

Figure 5.1 (continued)

Figure 5.1 (continued)

reactor flux shape, and (3) monitor important plant parameters and reduce reactor power at an appropriate rate if any parameter is out of limits.

Two control absorbers, similar to shutoff rods, are controlled by the RRS. The control absorbers can also be inserted by operator action. Mechanical control absorbers are normally parked out of the core and are driven in to supplement the negative reactivity of the zone control elements or dropped to cause a fast reactor power reduction. Mechanical zone control units are moved into the core or withdrawn out of the core to maintain the appropriate power level in each zone of the core. Mechanical zone control units can act in unison for bulk reactivity control or differentially for spatial (flux tilt) control. The control absorbers can be used for reactor shutdown in cases where a quick shutdown is not required. Both absorbers must be inserted to shut down the reactor. Figure 5.2 is a block diagram representing the RRS.

5.2.1.2 Shutdown System 1

SDS1 is the primary method of quickly terminating reactor operation when certain parameters enter an unacceptable range. SDS1 releases 24 spring-assisted gravity-drop

absorber elements or shutoff rods to terminate the fission process. SDS1 is required to have sufficient speed and negative reactivity to immediately reduce the reactor power to decay heat level with the two most effective shutoff rods assumed immobile.

Two banks of shutdown rods (12 rods each) are tripped by an associated logic circuit. Each logic circuit is designed to trip upon receiving signals from any two of the three trip computers, designated as channels "D," "E," and "F." Tripping a logic circuit will cause the shutdown rod clutch coils in that bank to be deenergized, allowing the rods to be inserted. SDS1 uses "general coincidence logic," which means that if any two of the nine signals feeding a trip computer exceed their trip limits, that channel will trip. This is somewhat less restrictive than the "local coincidence logic" used in SDS2 (see Sect. 5.2.1.3). To not satisfy the two-of-three logic and fail to activate SDS1, two of the three channels must fail to detect the need for a reactor trip or fail to respond to the trip signal.

SDS1 receives power from Group 2, Class I and II power supplies. The logic is arranged so that a channel trips upon loss of power to that channel. Loss of power to the neutron

CANDU 3

Figure 5.2 RRS block diagram

instrumentation or the process transmitters results in a channel trip. A power loss that results in an irrational signal to the trip computer results in a channel trip. A second channel must be then tripped to activate SDS1. Loss of power to the clutch coils results in the shutoff rods being dropped. Figure 5.3 is a block diagram for SDS1.

5.2.1.3 Shutdown System 2

SDS2 provides an independent, alternate method of quickly terminating the fission process. SDS2 opens quick-acting valves to release high-pressure helium that forces concentrated gadolinium nitrate solution (i.e., poison) from six poison tanks into the moderator. SDS2 has sufficient speed and negative reactivity to reduce the reactor power to levels consistent with available cooling for all SDS2 trip parameters with the most effective nozzle assumed out of service. SDS2 incorporates design features to prevent unnecessary injections when SDS1 has shut down the reactor.

Eight of the nine trip variables used in SDS1 are used in SDS2 (moderator level is eliminated from the SDS2 trip parameters); sensor channels for the SDS2 system variables are kept independent of those for SDS1. Three solenoid valves are used to actuate the quick-opening helium supply valves that are signaled by three independent trip computer channels designated "G," "H," and "J." Each solenoid valve is used to control one pair of quick-opening valves. Unlike the "general coincidence logic" used in SDS1, the "local coincidence logic" used for SDS2 requires at least two shutdown signals from two trip computers be actuated by a common variable. Some communication between trip computers is needed to determine coincident trips on a common variable. To have SDS1 trip preferentially (an SDS2 trip would require extensive cleanup of the moderator D₂O to remove the poisons), the SDS2 flux signals are delayed (low-pass filtered) with respect to the SDS1 signals.

Group 2, Class I and Class II power supplies are connected to each channel. The logic and instrumentation are designed so that a channel trips on loss of power. Loss of power to individual transmitters is annunciated and causes a parameter trip due to the faulted signal. The outputs from each sensor after amplification are fed to a trip computer, and the trip computer sends a trip signal to the trip logic circuits. SDS2 has three trip logic circuits, one for each pair of the quick-opening helium supply valves. The quick-opening valves are arranged in three parallel pairs. Two of the three channels must fail to detect the need for a reactor trip or fail to respond to the trip signal to prevent poison injection.

A vessel containing high-pressure helium supplies the source of energy for rapid injection. Measurements of the helium makeup supply pressure are performed by two different methods. The tank is connected to a helium header (i.e., three parallel paths with two quick-opening valves in each path) that supplies the injection force for the six poison tanks. The level in each poison tank is also monitored, and the operator is warned by alarm if more than one poison tank is valved off.

The quick-opening valves are air-to-close, spring-to-open, so they fail open on loss of air supply or loss of electrical power. Air is supplied to the quick-opening valves by the plant compressed air system. Special logic prevents the testing of two different valve pairs within 10 min of each other. This ensures that the interspace between the quick-opening valves is depressurized and, thus, prevents spurious partial injections. Vent lines are provided to vent the helium from the interspace to the reactor building atmosphere. The vent valves are normally closed and fail open on loss of air or power.

A pressure balance line exists between the SDS2 piping and the upper region of the calandria tank. The purpose of this line is assumed to keep pressure on both ends of the poison tanks at the same pressure to avoid partial poison injections because there is no isolation between the poison tanks and the moderator. This line was assumed to be small in comparison to the helium supply lines and was, therefore, not considered as a potential failure in the analysis of this system. Figure 5.4 is a block diagram for SDS2, and Fig. 5.5 is a schematic of the SDS2 poison injection system.

5.2.2 Moderator Liquid Poison System

The moderator liquid poison system (MLP) is used during normal operations as part of the reactor power control scheme. The system may also provide an alternate means to poison the reactor when other means of reactor shutdown have failed. Note that the system is not designed for this purpose; however, it is assumed for this analysis that the system contains sufficient negative reactivity to effectively shut down the reactor for some sequences. This method of reactor shutdown is slower than the normal shutdown systems and, therefore, would be less effective in mitigating some accidents. The poison is delivered from the boron poison tank by way of gravity through a flow control valve and an isolation valve. The MLP is used during normal operation, and a tank level alarm is provided to notify the operator when more poison must be added and mixed in the tank. Figure 5.6 presents the fault tree for this system. A system diagram is presented in Fig. 5.7.

CANDU 3

Figure 5.3 SDS1

ORNL-DWG 93-3230 ETD

Figure 5.4 SDS2 block diagram

CANDU 3

Figure 5.5 SDS2 schematic of poison injection system

Figure 5.6 MLP system fault tree

5.2.3 Feedwater Systems

The purpose of the FW in mitigating accidents is to remove heat from the reactor via the steam generators. Three systems can satisfy the feedwater requirements, and these are modeled together as FW; these three systems are designated FW1, FW2, and AFW. Figure 5.8(a)–(i) shows the FW fault tree model.

5.2.3.1 Group 1 Feedwater System

The FW1 supplies controlled feedwater flow to maintain required steam generator levels. FW1 includes three 50% main feedwater pumps that operate on Class IV power. The feedwater is stored in a deaerator storage tank, and flow is regulated by three 50% capacity regulating valves (boiler level control valves). In addition, two trim valves are installed at each steam generator. The main FW pump motors and lube oil coolers are cooled by the recirculated cooling water system, and backup cooling is provided by the firewater system. If plant air is lost and not restored within 1.5 h, the three main level control valves will fail closed. It was assumed that the valves receive power from the Class II Group 1 buses. Figure 5.9 shows the FW1 configuration.

5.2.3.2 Group 2 Feedwater System

The FW2 provides an independent supply of high-pressure feedwater to the steam generators following a total loss of FW1 supply. The FW2 system is housed in the Group 2 pumphouse and includes two (100% capacity) pumps and a supply tank separate from FW1. The tank contains a 10-h

supply and requires operator action to refill the tank when empty. Following a loss of normal feedwater, the FW2 pumps start automatically on low steam generator level or low feedwater supply pressure. The major fault categories are loss-of-coolant fault, coolant flow path fault, and loss of pumping function. Each steam generator has two valves (in parallel) that isolate the FW2 from the steam generator. It is assumed that there is sufficient flow to the steam generator if one of the two isolation valves are open. It was also assumed that the isolation valves receive power from Class II Group 2 buses. A flow diagram for FW2 is presented in Fig. 5.10.

5.2.3.3 Auxiliary Feedwater System

The AFW pump can discharge 4% of normal feedwater flow into the two steam generators. The pump is diesel driven and is started within 30 s of loss of feedwater flow. AFW supply is taken from the FW1 supply, and flow is pumped through the FW1 piping. The discharge valve for the AFW pump must also open. Figure 5.9 shows how the AFW pump is connected to the FW1 piping.

5.2.4 Heat Transport System

The heat transport system (HTS) circulates pressurized heavy water through the reactor fuel channels to remove heat produced by fission of natural uranium fuel. The heat is carried by the reactor coolant to the steam generators where it is transferred to light water to produce steam,

CANDU 3

Figure 5.7 MLP flow diagram

Figure 5.8 Feedwater systems fault tree

Figure 5.8 (continued)

Figure 5.8 (continued)

Figure 5.8 (continued)

CANDU 3

Figure 5.9 FW1

Figure 5.10 FW2 flow diagram

which subsequently drives the turbine-generator. The major components of the HTS are the 232 reactor fuel channels, two vertical steam generators, four motor-driven heat transport pumps, four reactor inlet headers, two reactor outlet headers, and interconnecting pipes.² The failure mode addressed by the fault tree in Fig. 5.11 is loss of flow in the HTS due to pump failure. The pumps require Class IV electrical power. The HTS is shown in Fig. 5.12.

5.2.5 Steam Discharge

The systems included in the steam discharge (SD) function are the condenser steam discharge valves (CSD) and the atmospheric steam discharge valves (ASD). The purpose of the SD function is to remove the heat transferred to the main steam system in the steam generators. Each of these is described in further detail in the following paragraphs.

Figure 5.13(a)–(c) presents the fault tree for the SD heat removal function. Figure 5.14 shows the schematic for these systems.

5.2.5.1 Condenser Steam Discharge Valves

The primary function of CSDs is to discharge live steam to the condenser and maintain temperature in the HTS so that the reactor power remains at the designated level. The CSDs are also used to discharge steam on a loss of load or turbine trip, so the main steam safety valves (MSSVs) do not lift. There are four CSDs for each steam generator. These valves have pneumatic actuators and fail closed on loss of air.² The CSD fault tree uses an earlier CANDU 3 design¹ of two CSDs per steam line because the success criteria for the new configuration were not specified. This results in a conservative model for CSD unless all four valves are required for success in the new configuration.

ORNL-DWG 93M-3243 ETD

Figure 5.11 HTS fault tree

CANDU 3

Figure 5.12 HTS

(a)

(b)

Figure 5.13 SD fault tree

Figure 5.13 (continued)

5.2.5.2 Atmospheric Steam Discharge Valves

The ASDs are used to control steam generator pressure. The ASDs are opened in proportion to steam generator pressure error, normally with an offset in the steam pressure set point. These valves may also be used to provide a heat sink during shutdown for decay heat removal when the main condenser is unavailable. There is one ASD per steam generator.

5.2.6 Shutdown Cooling System

The shutdown cooling system (SDC) removes decay heat following reactor shutdown and cools the HTS to a temperature suitable for maintenance of the heat transport components. It is capable of cooling the HTS from full system pressure and temperature and of maintaining it at a low temperature for an indefinite period of time. The SDC consists of two pumps (50% capacity), two heat exchangers (50% capacity), and associated valves and piping. The pumps take coolant from the reactor outlet headers and return it via the heat exchanger to the reactor inlet headers. The SDC is normally cold and depressurized and isolated

from the HTS. The SDC must be started manually. The fault tree for loss of shutdown cooling is shown in Fig. 5.15(a) and (b). The failure modes modeled in the fault tree are failure to initiate system operation, loss of flow, and loss of heat removal from the heat exchangers. Figure 5.16 shows the flow diagram for the SDC.

5.2.7 Moderator Cooling System

The moderator cooling system (MCS) is independent from the HTS. It includes two pumps (50% capacity) and two 50% heat exchangers. The calandria extension maintains the moderator level in the calandria within the required range by accommodating moderator swell and shrinkage resulting from temperature fluctuations. The moderator functions as a heat sink when other heat removal systems have failed. For the MCS to remove heat from the HTS, the pressure tubes must deform and come in contact with the calandria tube because very limited heat transfer will occur across the CO₂-filled space. Figure 5.17 shows the fault tree for loss of moderator cooling, and Fig. 5.18 is a flow diagram for the moderator system.

Figure 5.14 Schematic of SD

(a)

(b)

Figure 5.15 SDC fault tree

CANDU 3

Figure 5.16 Flow diagram for SDC

Figure 5.17 MCS fault tree

5.2.8 Emergency Core Cooling System

The ECCS supplies emergency coolant to the reactor headers in the event of a loss-of-coolant type accident. The system operation is divided into two parts, short-term injection and long-term recirculation. The short-term injection consists of two stages: HPI and LPI. The fault tree in Fig. 5.19(a)–(i) demonstrates how the ECCS can fail to replenish lost HTS inventory. Figure 5.20 shows a schematic for the ECCS. The ECCS design analyzed in this report is that documented in the CSR.¹

5.2.8.1 ECCS High-Pressure Injection

The HPI mode of the ECCS is initiated by the loss-of-coolant signal (LOCS) when there is a loss-of-coolant event and subsequently the need to refill the core. The ECCS (i.e., HPI, LPI, and recirculation) is controlled by dedicated computers that perform the initiation, monitor-

ing, display, and testing function. Each signal essential for the system operation is triplicated so that a single component or power supply failure does not incapacitate or spuriously invoke system operation.

A LOCS is generated when the HTS pressure falls to a predetermined value and one of the emergency core cooling conditioning signals (high reactor building pressure or low pressurizer level) is activated. The logic used with the three channels is such that any two channels alarming due to low heat transport pressure in conjunction with any two of the three conditioning signals will generate the LOCS.

The system logic performs the following functions:

1. opens gas isolation valves, the HPI valves, and the D₂O isolation valves,

CANDU 3

Figure 5.18 MCS flow diagram

Figure 5.19 ECCS fault tree

Figure 5.19 (continued)

Figure 5.19 (continued)

Figure 5.19 (continued)

Figure 5.19 (continued)

2. starts one of the emergency core cooling pumps,
3. opens the grade-level tank isolation valves,
4. starts the Group 2 Class III diesel generators,
5. opens the MSSVs, and
6. trips the heat transport pumps.

Note that only the first three of these functions are required for successful ECCS operation. These other functions are to help alleviate complications that may accompany a LOCA.

The rupture disks in the ECCS burst when the gas isolation and HPI valves open. Opening these valves along with the D₂O isolation valves allows the pressurized gas (stored in the accumulator gas tank) to inject the water from the coolant tank into the HTS when the HTS pressure falls

below the HPI (accumulator gas) pressure. A low-level signal in the water accumulator tank results in the HPI valves being closed to prevent air from being forced into the HTS.

An air compressor backed up by a compressed nitrogen supply maintains the gas tank pressure. The electrical valves for HPI are supplied from Group 2, Class II power. The controls and power supplies for parallel valves are separated and independent. Parallel valves are on "odd" and "even" feeds. The valves fail "as is" on loss of power. The pressure in the gas accumulator tank and the level in the water tank are monitored.

The conditions that can result in failure of HPI can be categorized as follows: (1) conditions that cause LOCS faults, (2) conditions that prevent gas injection (i.e., loss of

CANDU 3

Figure 5.20 Schematic for ECCS

Systems

pressure and flow path faults), and (3) conditions that prevent coolant injection (i.e., loss of coolant and coolant flow path faults).

5.2.8.2 ECCS Low-Pressure Injection

During the HPI mode, the grade-level isolation valves are opened, and one of the two pumps is started by the LOCS, which initiated HPI. The operating pump recirculates water via a bypass loop during HPI.

Following the HPI mode of ECCS, the LPI mode of the ECCS is initiated automatically. The HPI valves are closed, and the LPI valves are opened. Water from the grade-level tank is injected into the HTS via the pumps. A low-level signal in the grade-level tank closes the valves in the pump suction line from the tank and terminates the LPI mode of ECCS. These operations are required for successful system operation.

The pumps are energized from Group 2, Class III buses and are 100% capacity. The valves used during LPI are powered by Group 2, Class III power and fail "as is." The controls and power supplies to each valve of a pair are separated and independent. The pair of valves are fed from "odd" and "even" circuits. The water level in the grade-level tank is monitored.

The three main failure categories for LPI are loss of coolant, coolant flow path fault, and loss of pumping function. Flow path faults include isolation valves for the water tank and LPI injection valves.

5.2.8.3 ECCS Recirculation

Recirculation of the ECCS (REC) is the long-term mode of cooling the reactor core following a loss-of-coolant event. Recirculation is initiated following LPI mode of operation of ECCS, which terminates when the low-level signal in the grade-level tank closes the valves in the pump suction line from the tank.

The REC mode starts when cooling water flow is initiated to the recirculation heat exchangers and the recovery line isolation valves are opened to the reactor building sump. The mixture of the heat transport coolant and water from the HPI and LPI tanks that collected on the floor and sump of the reactor building is then returned to the HTS by the pumps. For large breaks, decay heat is removed from the core via the coolant discharged from the break, and this heat is transferred to the recirculated cooling water (or the Group 2 service water as a backup) via the ECCS heat exchangers. There are two 100% capacity heat exchangers in this system. The valves used during REC mode are

powered by Group 2, Class III power and fail "as is." The controls and power supplies to each valve of a pair are separated and independent. The valve pairs are powered from "odd" and "even" circuits.

The major failure categories are loss of the heat exchangers and coolant flow path faults. The pumps are modeled as part of the LPI stage of ECCS.

For small breaks, decay heat is transferred to the steam generators and rejected via the MSSVs. These valves have a total capacity of over 100% steam flow at normal steam generator pressure.

5.2.9 Bleed Condenser System

The bleed flow from the HTS is discharged into the bleed condenser system (BCS) as two-phase steam and liquid. The steam is condensed by cooling spray supplied by the heavy water feed pumps. The bleed flow is further cooled by the shutdown/bleed cooler. The shutdown/bleed cooler also operates as shutdown cooler for decay heat removal during reactor shutdown. The BCS is equipped with spring-loaded safety relief valves that are designed in conjunction with the heat transport relief valves to ensure that HTS overpressure protection requirements are met.

The liquid relief valves (LRVs) are designed to open to avoid overpressurization of the HTS. These valves are designed to fail open on loss of power or air. Failure of these valves to reclose will result in loss of HTS inventory through the BCS to the D₂O storage tank and into the reactor building. Failure to isolate the BCS in this situation would result in an event like a SBLOCA. The BCS and makeup system level control valves can isolate the BCS. The fault tree for the failure to isolate the BCS is shown in Fig. 5.21. It was assumed that the valves receive power from the Class II Group 1 buses and the BCS level control valves require plant air. Figure 5.22 shows the HTS pressure and inventory control system.

5.2.10 Steam Generator Isolation

The feedwater piping breaks between a steam generator and its check valve require the operator to isolate flow away from that steam generator to minimize water loss.* The valve used to accomplish this is air-operated and fails open on loss of air or power. It was assumed that the valve

* Atomic Energy of Canada, Limited, Presentation of Information at NRC/AECL Review Meeting on the CANDU 3 Systems Research Study, February 10, 1993.

Figure 5.21 BCS isolation fault tree

receives its control power from Group 1 Class II power. Figure 5.9 shows the valves that would be used to accomplish ISO. The fault tree for ISO failure is shown in Fig. 5.23.

5.2.11 Liquid Relief Valve Closure

It is necessary for the LRVs to open and relieve HTS inventory into the BCS to control HTS pressure during normal plant operation and during mitigation of some IEs. It is important for the LRVs to reclose so that sufficient HTS inventory is maintained. The fault tree in Fig. 5.24 shows the failure mechanisms for the LRVs failing to close. The LRVs are part of the pressure and inventory control system and are shown in Fig. 5.22.

5.2.12 Crash Cooling

The crash cooling (CC) of the steam generators is performed to quickly remove heat from the reactor core, allowing the pressure in the HTS to drop so that ECCS injection can be achieved. CC is accomplished by opening the MSSVs to release steam. The MSSVs are signaled by the ECCS control system to open upon receipt of a LOCS. In addition, half of the MSSVs are signaled to open when SDS2 is initiated.* The MSSVs require instrument air to

open and are assumed to receive control power from the Group 2 Class II buses. The CC fault tree is presented in Fig. 5.25(a)–(c).

5.2.13 Main Steam Safety Valves

Four MSSVs are provided for each of the two steam mains (i.e., steam generators). The MSSVs protect the steam system and steam generators from overpressure. The failure mode of concern in Fig. 5.26 is failure of the MSSVs to open to discharge the steam. The MSSVs for both steam generators are required to open to discharge steam. It is assumed that if three MSSVs open, then flow is sufficient to discharge the steam from that steam generator. It is also assumed that the MSSVs self-actuate for the steam removal function. Figure 5.14 shows the MSSVs.

5.2.14 Emergency Generators

The emergency generators (GENs) are required to supply power to equipment necessary to safely shut down the plant on LOP. Little information was provided regarding the GEN system; therefore, a single event fault tree was drawn for restoration of Class III power. The restoration of Class III power includes either off-site power being recovered or operation of the diesel generators. The fault tree for the GEN system is presented in Fig. 5.27. Partial restorations of power were not analyzed due to the amount of available resources.

*Letter from AECL Technologies to the U.S. NRC, "Responses to February 10, 1993 NRC/ORNL Request for Information," February 22, 1993.

Figure 5.22 Pressure and inventory control system

Figure 5.23 ISO fault tree

Figure 5.24 LRC fault tree

Figure 5.25 (continued)

Figure 5.26 MSSV fault tree

ORNL-DWG 93M-3261 ETD

Figure 5.27 GENs fault tree

References

1. Atomic Energy of Canada, Limited, *CANDU 3 Conceptual Safety Report*, Vols. 1 and 2, 1989.[†]
2. Atomic Energy of Canada, Limited, *CANDU 3 Technical Outline*, Rev. 11, June 1992.[†]

[†]Available in NRC PDR for inspecting and copying for a fee.

6 Event Analysis

The IEs identified in Chap. 4 were classified according to the general plant response to each one. It was then judged that the plant responses (event sequences) for all identified initiators could be evaluated based on the analysis of five plant response categories:

- 1 LBLOCA,
- 2 SBLOCA,
- 3 Loss of Essential Power Supplies,
- 4 Undercooling Event, and
- 5 Reactivity Transient.

Seven specific IEs were judged to adequately address the plant response for these categories and to be representative of the remaining initiators. The seven events analyzed are

1. Feeder Tube Header Break,
2. LRV Failure,
3. Feeder Tube Break,
4. LOP,
5. Feedwater Piping Break in the Reactor Building,
6. Feedwater Piping Break in the Turbine Building, and
7. SCRAM.

In analyzing plant response to each of these IEs, failure to shutdown (FTSD) was included, notwithstanding the fact that CANDU 3 has two independent shutdown systems. For most of these cases, FTSD led to additional event sequences that could be described by a separate event tree referred to as the FTSD transfer sequence (see Sect. 6.6). It can be noted that LBLOCA with failure to scram leads directly to major core damage and does not involve the FTSD transfer sequence.

Sections 6.1 through 6.6 contain event descriptions, ESDs, and event trees for the seven RIEs and the FTSD sequences.

To track dependencies between systems, a system dependency matrix was developed. Plant systems are listed in the first column, and supporting systems are placed across the top of the matrix. The numbers represent the intersection of a system and its support system. This information is used during various stages of the analysis to help identify system supports and common dependencies between systems

and components. The dependency matrix is presented in Table 6.1.

6.1 Large-Break Loss-of-Coolant Event

6.1.1 Event Description

An LBLOCA is defined in this study as a break in large-diameter (>10-cm) piping of the primary HTS (primary loop). Such failures can occur in the reactor inlet header or reactor outlet header. Consequently, the LBLOCA event analyzed is a break in a feeder tube header. These failures are expected to occur with probabilities in the range of 10^{-4} ; a value of 5.9×10^{-5} for an inlet header break has been cited in Canadian safety studies.*

During the period of low flow, the fuel temperature rises, and fuel cladding failures may occur. These challenges must be met:

1. timely shutdown of the fission process (reactivity control),
2. rapid injection of emergency coolant (primary heat removal), and
3. maintenance of a coolable geometry.

The LBLOCA scenario will be followed through the following four time intervals:

1. before reactor trip	0–2 s
2. after trip but before ECCS signal	2–10 s
3. after ECCS signal	10 s–15 min
4. long term	>15 min

Before Reactor Trip

An LBLOCA leads to a discharge of coolant in the 1000-kg/s range (for Point Lepreau Unit 1, a CANDU-6 type, the SAR† cites a value of 10,000 kg/s). This leads to a rapid depressurization of the primary system and a rapid increase in containment pressure. Conditioning of the ECCS logic is provided by either high containment pressure or sustained low pressurizer level; also containment isolation would be initiated. The loss of coolant would also

* P. J. Allen et al., Atomic Energy of Canada, Limited, *External Analysis Report—Conceptual Probabilistic Safety Assessment*, Rev. 0/89-02-28, 1989.

† "Point Lepreau Nuclear Generating Station Unit 1 Safety Analysis Report," Parts 1 and 2, 1990.

Table 6.1 CANDU 3 dependency matrix

	Class IV Power	Class III		Class II		Class I		Recirc. Cooling Water	Fire Water	Raw Service Water		Group 1 Service Water		Group 2 Service Water		Plant Air
		Group 1 Power	Group 2 Power	Group 1 Power	Group 2 Power	Group 1 Power	Group 2 Power			Water	Water	Water	Water	Water	Water	
HTS	15															
MCS		8						9								
ECCS LPI			5													
ECCS HPI					1											
REC			5					6						7		
Group 2 Service Water System			13													
FW1	16			16				22	22							24
FW2			17		17											
AFW																
SDC					18			23						23		
Raw Service Water System		12														
Plant Air System		14														
SDS1					2		2									3
SDS2					4		4									25
MSSVs					19		19									26
CSDs					19		19									26
ASDs					19		19									27
LRVs																28
BCS				20												
Recirc. Cooling Water System (RCW)		10		21												
											11					

Key:

1. All electrical valves required for HPI are supplied from Class II Group 2 power. This type of valve fails "as is."
2. Separately channelled Group 2a Class I and Class II power supplies are provided for each channel of SDS1. The logic is arranged so that any loss of power to a channel results in a channel trip. The direct current clutches operated from rectified redundant Class II power release on loss of power.
3. The quick-opening valves in SDS2 are air-to-close, spring-to-open on loss of air or electric power.
4. Separately channelled Group 2b Class I and Class II power supplies are connected to each SDS2 channel. The logic and instrumentation have been designed so that a channel trips on loss of power.
5. The ECCS pumps are energized by Group 2 Class III power. This power is also supplied to electrical valves required for operation. This type of valve fails "as is."
6. RCW supplies normal cooling water for the ECCS heat exchangers.
7. Group 2 service water system supplies backup cooling water for the ECCS heat exchangers.
8. Moderator cooling pumps are supplied with Group 1 Class III power.
9. Moderator cooling pumps and heat exchangers are cooled by the RCW.
10. RCW pumps are supplied from Group 1 Class III power.
11. The RCW heat exchangers have the heat removed by the raw service water system.
12. The raw service water pumps are supplied from Group 1 Class III power.

Table 6.1 (continued)

13. The Group 2 service water pumps are supplied from Group 2 Class III power.
14. The plant air compressors are supplied from Group 1 Class III power.
15. HTS pumps are supplied by Class IV power.
16. FW1 pumps are supplied by Class IV power, and the valves are assumed to be supplied by Group 1 Class II power.
17. FW2 pumps are supplied by Group 2 Class III power, and the valves are assumed to be supplied by Group 2 Class II power.
18. SDC pumps and valves are supplied by Group 2 Class II power.
19. MSSVs, CSDs, and ASDs are assumed to be supplied by Group 2 Class II power.
20. LRVs fail open on loss of Group 2 Class II power.
21. Isolation valves are assumed to be supplied by Group 1 Class II power.
22. FW1 backup cooling are supplied by RCW and fire water systems.
23. Shutdown cooling heat exchangers (heat removal side) are fed by RCW and FW2.
24. Level control valves fail closed 1.5 h after loss of air.
25. Air required for CC.
26. Air required to open ASDs and SDVs.
27. LRVs fail open on loss of air.
28. BCS LCVs require air to close.

Event

lead to void formation with the power to flow mismatch causing additional voiding. Because of the positive coolant void reactivity, the reactor power rises quickly. Within 1 to 2 s after the break, the reactor is shut down following detection of high flux, high rate of flux increase, or high containment pressure. Reactivity control is established by inserting shutoff rods (SDS1) or injecting liquid poison into the moderator (SDS2). Failure to trip the reactor will lead to a core damage state.

After Trip but Before ECCS Signal

Following the reactor trip, the reactor fission process is stopped, and reactor power decreases to 10% of full power within 2 s. The decay power level continues to decrease rapidly, but, in the absence of cooling, primary system temperatures continue to rise, and the potential exists for zirconium-steam reactions that produce hydrogen.

After ECCS Signal

When the primary system pressure drops below the initiation set point (5.5 MPa for Point Lepreau*), the LOCS is given. This causes the following actions:

- initiation of emergency coolant injection (ECI) beginning with the high-pressure system, followed by the LPI system, and
- closure of valves to the pressurizer, feed system, and purification circuit.

Thus, the coolant inventory of the primary heat transport loop is no longer replenished from the pressurizer and inventory control system.

The ECI sequence is then initiated. The high-pressure isolation valves open to allow flow of gas from the high-pressure gas tank to pressurize the water tanks containing the emergency coolant. The high-pressure gas vent valves close to prevent the loss of high-pressure gas through the relief valves. The HPI valves open, blowing the two ECCS rupture disks, and allow cool water to flow from the emergency coolant water tanks toward the D₂O isolation valves, which are signaled to open. The injection of emergency coolant into the HTS via the shutdown coolant connections to each header occurs when the pressure drops sufficiently (4.14 MPa for Point Lepreau†).

The two standby Class III diesel generators are also started and provide power for the LPI and recirculation modes in the event that Class IV power is not available.

The MSSVs open 30 s after the LOCS is received and cause the steam generators (and, hence, the entire steam and FW systems) to be crash-cooled. In addition to the LOCA signal, which opens all the MSSVs, a signal generated by the SDS2 instrumentation opens half of the MSSVs.† The steam generators are crash-cooled to reduce the transfer of heat from the steam generator secondary side to the primary coolant. Crash cooldown is not considered in this analysis of an LBLOCA because it is not initiated until at least 30 s into the transient and therefore acts too late to effectively change the sequence in an LBLOCA.

Long Term

The ECCS pumps are started on the LOCS. As the accumulator pressure decreases, more of the injection flow comes from the pumps. Upon receipt of a low accumulator tank level, the running ECCS pump and grade-level tank are aligned for LPI to the primary system. At this time the HPI path is valved closed. Injection occurs when the primary system pressure is low enough. The REC mode is automatically initiated by the receipt of a low-grade level tank level or high building sump level signal.

If additional failures occur during the sequence, alternative paths are possible for the LBLOCA. Potential complicating factors include the following:

1. LOP
2. ECCS impairment
 - failure of crash cooldown
 - failure of injection and steam generator crash cooldown
 - failure of injection
3. ECCS and moderator heat sink impairment
4. degraded ECCS.

Loss of Class IV Power

This accident is used in the design of the ECCS to ensure that no fuel channel damage occurs.¹ LOP is assumed to occur due to turbine unloading when the pressure in the main steam interconnect drops below 95% of normal. The most important effect is the rundown of the heat transport pumps. Although the ECCS control logic includes trip of the heat transport pumps, the early LOP is more limiting because the pump trip occurs sooner.

*"Point Lepreau Nuclear Generating Station Unit 1 Safety Analysis Report," Parts 1 and 2, 1990.

†Letter from AECL Technologies to the U.S. NRC, "Responses to February 10, 1993, NRC/ORNL Request for Information," February 22, 1993.

A difference in temperature-pressure history during the event is expected only during the short period when the pumps begin to coast down until the emergency coolant is injected. Because the HPI requires only Class II or I power, it is not affected by the LOP. The LPI and recirculation modes require Class III power that, in case of a LOP, would be supplied by the diesel generators.

Failure of Crash Cooldown

In an LBLOCA, crash cooldown of the boiler does not have a major effect on system behavior. Thus, failure of crash cooldown has no significant effect on the progression of the sequence.

Failure of Injection and Boiler Crash Cooldown

This sequence follows that described previously until the time period following ECCS signal receipt. In this sequence the MCS becomes the heat sink for the fuel. The process allowing this to occur involves plastic deformation of the pressure tube due to continued heating. If the pressure is high enough, the pressure tube expands into the calandria tube. If the pressure is low, the pressure tube will sag into contact with the calandria tube. This direct contact between the pressure tube and the calandria tube provides a conduction path for heat to be transferred from the fuel to the moderator.

The system temperature continues to rise with about half (under certain conditions) of the heat generation within the fuel channel coming from the reaction of steam with the Zircaloy cladding. Eventually, the steam flow is very low, and the temperature transient is controlled by (1) the rate of steam flow and (2) the oxidation reaction of the Zircaloy. Significant amounts of hydrogen are produced, and significant fuel damage is expected to occur.

As the power generation within the fuel continues to decay and the unreacted hot Zircaloy is depleted, the temperature begins to decrease. A quasi-steady state would be reached when the decay heat can be removed by radial heat transfer through the pressure tube/calandria interface tube into the moderator.

Failure of Injection

Crash cooldown is assumed to function, and this cools the primary system during the short term of the event. However, the pressure tube behavior would not be modified because the radial strain to contact the calandria tube would occur before crash cooldown becomes effective.

ECCS and Moderator Sink Impairment

The MCS provides the only means for removing decay and reaction heat in the event the ECCS fails to function. An early loss of the MCS would lead to extensive core damage.

6.1.2 Event Sequence Diagram and Event Tree

The ESD for an LBLOCA is shown in Fig. 6.1. The ESD is a pictorial representation of the logical sequence of operations necessary to mitigate an LBLOCA. The ESD was used as an aid in the development of the event tree (Fig. 6.2). The event tree resulted in 29 sequences designated as LB-A through LB-AC. The event tree displays the end state and the classification category for the RIE sequences.

The events listed along the top of the event tree page refer to the system fault trees from Chap. 5 that are called by the LBLOCA event tree. The fault trees are

1. SD1—shutdown system one,
2. SD2—shutdown system two,
3. HTS—heat transport system,
4. HPI—high-pressure injection mode of ECCS,
5. LPI—low-pressure injection mode of ECCS,
6. REC—recirculation mode of ECCS, and
7. MCS—moderator cooling system.

6.1.3 LBLOCA Sequence Evaluation Insights

The two important aspects of the LBLOCA sequences are quick and immediate shutdown of the reactor and prompt refill of the primary coolant system. This demonstrates the necessity for reliability of SDS1, SDS2, and ECCS although the MCS does provide a backup to the ECCS.

The HTS reduces the extent of fuel damage by maintaining forced flow through the reactor core. Failure of the HTS will result in localized fuel damage but not to the extent of an uncoolable geometry as long as the ECCS or MCS is operable.

Crash cooling of the steam generators during an LBLOCA seems to have little effect in the progression of the

Figure 6.1 Feeder tube header break ESD

ORNL-DWG 93-3188 ETD

Figure 6.2 Feeder tube header break event tree

Event

sequences. It appears to have greater significance with regard to SBLOCAs.

6.2 Small-Break Loss-of-Coolant Events

An SBLOCA is defined in this study as a break in small-diameter (<10-cm) piping and spurious openings of primary system relief valves. Such failure can occur in small-diameter pipes and liquid relief or pressurizer relief valves. Two events were selected for analysis to represent these types of SBLOCA events: failure of an LRV to reclose and a feeder tube break.

When compared to LBLOCAs, there are significant differences in system responses to mitigate the consequences of such accidents:

1. The steam generator is the major heat sink for the SBLOCA and is often the only heat sink required to cool down the primary system until the SDC is established. (The steam generator is far less important as a heat sink for LBLOCA events.)
2. A LOCS is not generated for some SBLOCAs and emergency core cooling must be operator-initiated.
3. Steam generator crash cooling is more important to some SBLOCAs, so that rapid cooldown of the primary system may be accomplished.
4. Manual shutdown of the reactor is sufficient to mitigate some SBLOCA events.
5. In an SBLOCA, heat transport to the steam generator is facilitated by natural convection flow.
6. Rewetting is not a concern for the SBLOCA before the introduction of emergency core cooling.

Note that the ECCS signal automatically triggers the ECI and the sequence leading to steam generator crash cooling. In addition, the SDS2 instrumentation signals half of the MSSVs to open should the ECCS fail to initiate crash cooling. In the case of an SBLOCA, there is sufficient time to manually initiate the ECCS should automatic initiation fail to occur.

The SBLOCA events are also analyzed for failure of the reactor shutdown systems. Failure to shut down the reactor sequences are discussed in Sect. 6.6.

6.2.1 Event Descriptions

6.2.1.1 Liquid Relief Valve Failure to Reclose

The LRVs serve as overpressure protection for the HTS. As the HTS pressure increases, liquid may be relieved and sent to a BCS. Failure to reclose after opening results in loss of coolant inventory through the BCS. The estimated frequency of occurrence of this event is $1 \times 10^{-1}/\text{year}$.*

The following scenarios will be discussed for LRV failure:

1. BCS isolation and ECCS available,
2. no BCS isolation,
3. no crash cooldown, and
4. ECCS impaired.

Bleed Condenser Isolation and ECCS Available

Following an opening of an LRV, coolant leaves the primary cooling system and enters the BCS. Pressurizer and heavy-water feed pumps provide make-up water. Local boiling should be expected but could be handled by the reactivity regulating system. The pressurizer level decreases, and reactor shutdown will come from either SDS1 or SDS2.

The steam generator is the main heat sink. When the BCS is isolated, no more leakage occurs from the primary system, and the lost coolant can be fed back via feed pumps. Fuel cooling is ensured by either feedwater to the steam generator or shutdown cooling. When Class IV power is available, the main heat transport pumps ensure forced flow; the ECCS is not called upon. No fuel damage is expected in this event.

No Bleed Condenser Isolation

If the BCS cannot be isolated, coolant will leave the primary system through the D₂O storage tank into the containment building. The LOCS will be given, and emergency core cooling and steam generator crash cooling will start. The operator must isolate the leak, ensure feedwater flow through the steam generators, and later start the SDC.

In SBLOCAs, the piping fills in the forward direction with flow assisted by the main heat transport pumps. The pump head keeps the inlet header pressure higher than the outlet

* P. J. Allen et al., Atomic Energy of Canada, Limited, *External Analysis Report—Conceptual Probabilistic Safety Assessment*, Rev. 0/89-02-28, 1989.

header pressure; because of this, most if not all of the emergency coolant enters the primary system via the outlet headers. Instead of entering the fuel channels through the outlet headers, this coolant must then flow through the steam generator and heat transport pumps before reaching the fuel channels.

To enhance the effectiveness of the emergency coolant, steam generator crash cooling is relied upon. Steam generator crash cooling has a mission time of 30 min, after which it is no longer needed. It cools down the steam generator to avoid a coolant heatup in the steam generator and, at the same time, helps to reduce the primary system pressure to ensure early ECI.

Because the loss of coolant through the D₂O storage tank leads to a significant reduction in primary system pressure and a low pressurizer level, some boiling should be expected. However, because the reactor is already in the shutdown state, the associated reactivity increase has no effect on the power level. Because the core is filled with coolant, the fuel is continually cooled, and at worst case, only minimal cladding damage could be expected. With the injection of emergency coolant, the reduction in fuel and cladding temperatures should stop any further cladding damage if it had occurred.

No Crash Cooldown

Without steam generator crash cooldown, temperatures and pressures remain high, and ECI is delayed. Because of the higher primary system temperatures resulting from the large net input from the steam generator, some fuel damage is expected before emergency coolant is injected. Heat removal would be accomplished with the MCS due to the deformation of the pressure tubes, coming in contact with the calandria tubes, allowing the transfer of heat from the primary coolant into the moderator.

ECCS Impaired

In the case of coolant injection failure but with steam generator crash cooling working, an increase in early fuel failures can be expected. The lowering of the primary system pressure increases the strain rate for the cladding due to the large pressure difference between the fuel rod and the coolant. Failure of the ECCS will result in heat being removed by the MCS as discussed previously.

6.2.1.2 Feeder Tube Break

This event is defined as a break in any of the feeder tube piping. This event results in discharge of the primary coolant directly from the HTS into the reactor building but

at a rate much less than that of an LBLOCA. The frequency of this event is estimated to be 1×10^{-2} .*

The following scenarios will be discussed for a feeder tube break:

1. crash cooldown and ECCS available,
2. no crash cooldown, and
3. ECCS impaired.

Crash Cooldown and ECCS Available

Following a feeder tube break, coolant is discharged from the HTS. Pressurizer and heavy water feed pumps provide make-up water. The pressurizer level decreases and reactor shutdown will come from either SDS1 or SDS2. Because coolant leaves the primary system through the break into the containment building, the LOCS will be given and emergency core cooling and steam generator crash cooling will start.

In SBLOCAs, the piping fills in the forward direction with flow assisted by the main heat transport pumps. The pump head keeps the inlet header pressure higher than the outlet header pressure; because of this, most if not all of the emergency coolant enters the primary system via the outlet headers. Instead of entering the fuel channels through the outlet headers, this coolant must then flow through the steam generator and heat transport pumps before reaching the fuel channels.

To enhance the effectiveness of the emergency coolant, steam generator crash cooling is relied upon. Steam generator crash cooling has a mission time of 30 min, after which it is no longer needed. It cools down the steam generator to avoid a coolant heatup in the steam generator and at the same time helps to reduce the primary system pressure to ensure early ECI.

Because the loss of coolant leads to a significant reduction in primary system pressure and a low pressurizer level, some boiling should be expected. However, because the reactor is already in the shutdown state, the associated reactivity increase has no effect on the power level. Because the core is filled with coolant, the fuel is continually cooled, and at worst case, only minimal cladding damage could be expected. With the injection of emergency

*P. J. Allen et al., Atomic Energy of Canada, Limited, *External Analysis Report—Conceptual Probabilistic Safety Assessment*, Rev. 0/89-02-28, 1989.

Event

coolant, the reduction in fuel and cladding temperatures should stop any further cladding damage if it had occurred.

No Crash Cooldown

Without steam generator crash cooldown, temperatures and pressures remain high and ECI is delayed. Because of the higher primary system temperatures resulting from the large net input from the steam generator, some fuel damage is expected before emergency coolant is injected. Heat removal would be accomplished with the MCS due to the deformation of the pressure tubes coming in contact with the calandria tubes, allowing the transfer of heat from the primary coolant into the moderator.

ECCS Impaired

In the case of coolant injection failure but with steam generator crash cooling working, an increase in early fuel failures can be expected. The lowering of the primary system pressure increases the strain rate for the cladding due to the large pressure difference between the fuel rod and the coolant. Failure of the ECCS will result in heat being removed by the MCS, as previously discussed.

6.2.2 Event Sequence Diagrams and Event Trees

The ESDs for LRV failure and feeder tube break are shown in Figs. 6.3 and 6.4. The ESDs are pictorial representations of the logical sequences of operations necessary to mitigate these SBLOCA events. The ESDs were used in the development of the event trees presented in Figs. 6.5 and 6.6.

The LRV failure event tree resulted in 34 sequences designated as LRVF-A through LRVF-AH plus 14 failure to shutdown (FTSD) sequences designated as LRVF-FTSD-A through LRVF-FTSD-N (the FTSD transfer event tree is presented in Sect. 6.6). The events listed along the top of the event tree refer to the system fault trees from Chap. 5 that are called by the LRV failure event tree. The fault trees are

1. SD1—shutdown system 1
2. SD2—shutdown system 2
3. BCS—isolate BCS
4. CC—crash cooling
5. FW—Group 1 and 2 feedwater systems and auxiliary feedwater
6. HPI—high-pressure injection mode of ECCS
7. LPI—low-pressure injection mode of ECCS

8. SD—steam removal systems—CSDs, ASDs
9. MSV—main steam safety valve
10. SDC—shutdown cooling system
11. MCS—moderator cooling system.

The feeder tube break event tree resulted in 18 sequences designated as SBLFB-A through SBLFB-Q plus 14 FTSD sequences designated as SBLFB-FTSD-A through SBLFB-FTSD-N (the FTSD transfer event tree is presented in Sect. 6.6). The events listed along the top of the event tree refer to the system fault trees from Chap. 5 that are called by the feeder tube break event tree. The fault trees are

1. SD1—shutdown system 1
2. SD2—shutdown system 2
3. CC—crash cooling
4. FW—Group 1 and 2 feedwater systems and auxiliary feedwater
5. HPI—high-pressure injection mode of ECCS
6. LPI—low-pressure injection mode of ECCS
7. MCS—moderator cooling system.

6.2.3 Sequence Evaluation Insights

The SBLOCA events are analyzed assuming Class IV power is available. The unavailability of Class IV power means that forced flow through the HTS would not occur. Decay heat is then transferred via thermal convection to the steam generators where it is removed by the feedwater. Primary system and fuel temperatures are expected to be higher than when Class IV power is available, and some damage to the fuel sheath could be expected. The FW1 would also be unavailable due to LOP, placing greater emphasis on the FW2 and AFW. The CSDs would also not be an option for steam removal because the condensate pumps would trip and result in loss of condenser vacuum. This leaves the ASDs and the MSSVs as the two options for steam removal.

In the event of loss of the plant air systems, the steam removal function relies on the spring actuation of the MSSVs when their air reservoirs are depleted. This is because the CSDs, ASDs, and the MSSVs all require air to open, although the MSSVs are also spring-actuated.*

* Atomic Energy of Canada, Limited, Presentation of Information at NRC/AECL Review Meeting on the CANDU 3 Systems Research Study, February 10, 1993.

ORNL-DWG 93-3189 ETD

Figure 6.3 LRV failure ESD

Figure 6.4 Feeder tube break ESD

6.3 Loss of Class IV Power Event

6.3.1 Event Description

An LOP is defined in this study as the simultaneous loss of power to two 13.8-kV buses. Such failures can occur because of total station disconnection coincident with a turbine trip or a loss of station-generated power, because of a turbine or reactor trip, causing perturbations to the grid. They are expected to occur with probabilities in the range of 10^{-2} .*

*P. J. Allen et al., Atomic Energy of Canada, Limited, *External Analysis Report—Conceptual Probabilistic Safety Assessment*, Rev. 0/89-02-28, 1989.

For this assessment no distinction is made between a short-term loss of power and a long-term loss of power. Short-term losses are typically the result of fluctuations in the grid frequency and/or voltage. Long-term losses usually result from external events such as tornadoes and earthquakes. The former are more frequent and are usually recovered from within a few hours. The latter are less frequent, with recovery sometimes taking days.

The sudden LOP would cause the turbine to trip immediately. This causes an increase in steam generator pressure because of the reduction in steam flow to the turbine. The LOP would also cause the main steam generator feedwater pumps to stop. A diesel-driven auxiliary feedwater pump can supply feedwater at a reduced rate. After a turbine trip,

2 of 4

Figure 6.5 LRV failure event tree

ORNL-DWG 93-3192 ETD

Figure 6.6 Feeder tube break event tree

a signal would normally be applied immediately to fully open the CSDs, which would discharge steam from the main steam header to the condenser. With the LOP the condenser circulating water pumps become unavailable, disabling the steam condenser and preventing the CSDs from opening. The result would be that the boiler pressure rises and the ASDs open. However, the pressure in the steam generators may be too large to be handled by the ASDs alone which, for the Point Lepreau plant, have a total capacity of 10% of rated steam flow.* As a result, the main steam valves would open to limit the pressure rise.

Coolant inventory is normally provided by the feed pumps and the feed and bleed valves that are connected to the primary circuit via the purification lines. The feed pumps are temporarily lost, but the bleed valves would remain available.

The pressure, flow, and power signals are powered by uninterruptible Class I/II power supplies.

The LOP will initiate an automatic startup of the diesel generators to energize Class III buses within 60 s. In the analysis it was assumed that Class III power is restored to all or none of the Class III buses. In other words, partial restorations of power were not analyzed.

Following restoration of Class III power, the LRVs must reclose to prevent continued loss of primary coolant inventory. Failure of either of these valves to reclose results in sequences similar to an SBLOCA. Closure of the LRVs allows the SDC to be activated because it uses Class III power.

FTSD sequences are analyzed for LOP when Class III power has been restored. These sequences are discussed in Sect. 6.6.

6.3.2 Event Sequence Diagram and Event Tree

The ESD for LOP is shown in Fig. 6.7. The ESD is a pictorial representation of the logical sequence of operations necessary to mitigate the LOP condition. The ESD was used in the development of the event tree presented in Fig. 6.8. The LOP event tree resulted in 45 sequences designated as LOP-A through LOP-AS and 14

FTSD sequences designated as LOP-FTSD-A through LOP-FTSD-N (the FTSD transfer event tree is presented in Sect. 6.6).

The events listed along the top of the event tree page refer to the system fault trees from Chap. 5 that are called by the LOP event tree. The fault trees are

1. RSS—reactivity shutdown system
2. GEN—Class III diesel generator
3. LRC—liquid relief valve closure
4. BCS—isolate bleed condenser
5. CC—crash cooling
6. FW2—Group 2 feedwater system
7. AFW—auxiliary feedwater system
8. HPI—high-pressure injection mode of ECCS
9. LPI—low-pressure injection mode of ECCS
10. ASD—atmospheric steam discharge valve
11. MSV—main steam safety valve
12. SDC—shutdown cooling system
13. MCS—moderator cooling system.

6.3.3 Sequence Evaluation Insights

Failure to restore Class III power requires that the power supplies needed for isolation of the BCS be battery backed; otherwise, continued loss of primary coolant inventory will result because the LRVs fail open on loss of power.

Failure of the LRVs to reclose following restoration of Class III power results in sequences very much like the LRVF SBLOCA sequences except that FW1 and the CSDs are not available due to the unavailability of Class IV power.

The FTSD sequences show the FW1 and the CSDs, which would not be available when LOP occurs. These sequences would all result in the EC-IV category because at least three failures are required before a FTSD sequence is reached.

6.4 Undercooling Events

The undercooling PRC is represented by two IEs. One of these involves a feedwater line break inside the reactor

*"Point Lepreau Nuclear Generating Station Unit 1 Safety Analysis Report," Parts 1 and 2, 1990.

Figure 6.7 LOP ESD

Figure 6.8 LOP event tree

Event

building upstream of one of the steam generators, and the other is a feedwater line break that occurs inside the turbine building. These were analyzed separately because the plant responses are different. These initiators are designated as LOFWRB and LOFWTB, respectively. ESDs and event trees were constructed for each of these initiators.

6.4.1 Event Descriptions

6.4.1.1 Feedwater Piping Break in the Reactor Building

The LOFWRB initiator involves a break in the FW1 piping between a steam generator check valve and the steam generator. A frequency of 1×10^{-5} /year was used for this initiator.* The rationale supporting this frequency was judged to be appropriate for this analysis based on the current level of information.

The two basic functions that must be met to mitigate this initiator are reactor shutdown and heat removal from the reactor core. SDS1 and SDS2 can shut down the reactor on high heat transport pressure, low steam generator level, or low feedwater line pressure. RRS shutdown is assumed to be unavailable for this initiator because the steam generator level measurements are not qualified for the steam environment that would be created by the released feedwater. If SDS1 and SDS2 should fail to shut down the reactor, the event is analyzed for FTSD sequences. These sequences are discussed later in Sect. 6.6.

Short-term heat removal is accomplished by thermosyphoning through the steam generators. The heat transport pumps are designed to trip on "sustained low HTS pressure" and therefore would not provide forced flow. The Group 2 feedwater is available for automatic initiation on loss of Group 1 feedwater. The Group 2 feedwater sprays on the top of each tube bundle but will not accumulate in the steam generator where the break occurred. For this reason, the operator must isolate flow away from the draining steam generator to avoid excessive loss of feedwater inventory. The SDC has enough capacity to cool the reactor from 100% heat and pressure. The analysis assumes the steam generator contains sufficient inventory to allow time for the SDC to be initiated even if the FW2 does not start automatically. This would, however, require quick response from the operator because the SDC requires manual initiation.

* P. J. Allen et al., Atomic Energy of Canada, Limited, *External Analysis Report—Conceptual Probabilistic Safety Assessment*, Rev. 0/89-02-28, 1989.

Heat removal via the steam generator using the FW2 may cause some damage to the fuel cladding because the heat removal capability of one of the steam generators would be lost since it is isolated from the system. Operation of either the ASD or the MSSVs will be required for steam removal in conjunction with the Group 2 feedwater. The CSDs are not demanded for these sequences due to unavailability of the condenser. Condenser vacuum is assumed to be lost subsequent to any turbine trip. The condenser would therefore be unavailable for these sequences because the turbine is designed to trip on loss of feedwater.

The MCS is the last line of defense against severe core damage when the other heat removal methods have failed. The pressure tube deformation required for heat transfer to the moderator is the extent of the expected core damage for this sequence. Using the MCS to remove the decay heat implies that other heat removal methods have failed. Failure of the MCS would then result in extensive core damage.

6.4.1.2 Feedwater Piping Break in the Turbine Building

The LOFWTB event includes piping failures occurring inside the turbine building that would result in a total loss of FW1 and auxiliary feedwater. These piping failures could occur in the FW piping, in the deaerator storage tank piping, or in the condensate system. The frequency assigned for this initiator was 1×10^{-3} /year because piping is a passive component. This is also the same frequency used in the "CANDU 3 Conceptual Probabilistic Safety Assessment."*

Again, the required functions for mitigating this initiator are reactor shutdown and reactor core heat removal. The reactor can be shut down by RRS on high HTS pressure or low steam generator level. SDS1 and SDS2 can also shut down the reactor on high HTS pressure, low steam generator level, or low feedwater line pressure. Failure to shut down the reactor using any one of these systems will result in a FTSD sequence. These sequences are discussed in Sect. 6.6.

The FW2 will be initiated automatically on low feedwater line pressure. The Group 2 feedwater is sufficient to remove the heat transferred to the steam generators. The heat will be transferred via thermosyphoning because the heat transport pumps are assumed to be unavailable. The Class IV power supply to the heat transport pumps is not qualified for the steam environment in the turbine building resulting from the feedwater line break. For this reason, the heat transport pumps are not credited for these sequences. The steam from the steam generators would be released

either from the ASDs or the MSSVs. Again, as for the LOFWRB, the CSDs are not available for use because condenser vacuum is lost following a turbine trip.

An alternate means for heat removal is the SDC. The steam generators contain sufficient volume to give the operator time to initiate SDC. Successful initiation and operation of the SDC will terminate the sequence with no core damage.

The MCS is the last means of heat removal. The core damage expected would be that required for pressure tube deformation to allow heat transfer to the moderator. Failure to remove the decay heat by some means will result in extensive core damage.

6.4.2 Event Sequence Diagrams and Event Trees

The ESDs for a LOFWRB and LOFWTB are shown in Figs. 6.9. and 6.10. The ESDs are pictorial representations of the logical sequences of operations necessary to mitigate feedwater piping breaks. The ESDs are used in the development of the event trees, which are presented in Figs. 6.11 and 6.12.

The LOFWRB event tree resulted in 22 sequences designated as LOFWRB-A through LOFWRB-U and 14 FTSD sequences designated as LOFWRB-FTSD-A through LOFWRB-FTSD-N (the FTSD transfer event tree is presented in Sect. 6.6). The LOFWTB event tree resulted

ORNL-DWG 93-3195 ETD

Figure 6.9 Feedwater piping break in reactor building ESD

Figure 6.10 Feedwater piping break in turbine building ESD

in 8 sequences designated as LOFWTB-A through LOFWTB-H plus 14 FTSD sequences designated as LOFWTB-FTSD-A through LOFWTB-FTSD-N (the FTSD transfer event tree is presented in Sect. 6.6).

The events listed along the top of the event tree page refer to the system fault trees from Chap. 5 that are called by the feedwater piping break event trees. The fault trees for LOFWRB are

1. SD1—shutdown system 1
2. SD2—shutdown system 2
3. ISO—isolate steam generator
4. FW2—Group 2 feedwater system
5. ASD—atmospheric steam discharge valve
6. MSV—main steam safety valve
7. SDC—shutdown cooling system
8. MCS—moderator cooling system.

The fault trees for LOFWTB are

1. RSS—reactor shutdown systems
2. FW2—Group 2 feedwater system
3. ASD—atmospheric steam discharge valve
4. MSV—main steam safety valve
5. SDC—shutdown cooling system
6. MCS—moderator cooling system.

ORNL-DWG 93-3197 ETD

LOFWR	SD1	SD2	ISO	FW2	ASD	MSV	SDC	MCS	SEQ #	SEQUENCE	END-STATE	CATEGORY
									1	LOFWRB-A	CC-1	EC-III
									2	LOFWRB-B	CC-1	EC-IV
									3	LOFWRB-C	CC-1	EC-IV
									4	LOFWRB-D	CC-2	EC-IV
									5	LOFWRB-E	CC-3	EC-IV
									6	LOFWRB-F	CC-1	EC-IV
									7	LOFWRB-G	CC-2	EC-IV
									8	LOFWRB-H	CC-3	EC-IV
									9	LOFWRB-I	CC-1	EC-III
									10	LOFWRB-J	CC-2	EC-IV
									11	LOFWRB-K	CC-3	EC-IV
									12	LOFWRB-L	CC-1	EC-IV
									13	LOFWRB-M	CC-1	EC-IV
									14	LOFWRB-N	CC-2	EC-IV
									15	LOFWRB-O	CC-3	EC-IV
									16	LOFWRB-P	CC-1	EC-IV
									17	LOFWRB-Q	CC-2	EC-IV
									18	LOFWRB-R	CC-3	EC-IV
									19	LOFWRB-S	CC-1	EC-IV
									20	LOFWRB-T	CC-2	EC-IV
									21	LOFWRB-U	CC-3	EC-IV
									22	LOFWRB-V	CC-3	EC-IV
									23	LOFWRB-FTSD	FTSD	TRANSFER

Figure 6.11 Feedwater piping break in reactor building event tree

Figure 6.12 Feedwater piping break in turbine building event tree

6.4.3 Sequence Evaluation Insights

Operator action is required to isolate the draining steam generator for LOFWRB. Initiation of shutdown cooling also requires operator action. Therefore, any sequence resulting in end state CC-1 requires some type of operator action for feedwater piping breaks in the reactor building. Special attention should be given to the ASDs for feedwater piping breaks in the turbine building. The ASDs require plant air to open, but the plant air compressors are not qualified for the steam environment that would be present in the turbine building.*

6.5 Reactivity Transient Event

6.5.1 Event Description

The SCRAM initiator was analyzed to represent events when reactor shutdown is initiated by operator action. This initiator is intended to show how the plant will respond to transients that are anticipated to be more likely than some other initiators included in the analysis. SCRAM scenarios may include failure of the reactor to shut down automatically on designated trip parameters, anticipated transients, or response to alarms by the operators.

The functions needed to SCRAM the reactor and bring it to safe shutdown are reactivity shutdown and heat removal. Reactivity shutdown is the insertion of absorber or shutoff rods and/or liquid poison to stop the fission reaction in the reactor core. Heat removal is necessary to take the decay heat away from the reactor core. Inventory control is maintained by the pressurizer volume.

Reactivity shutdown is initiated manually and can be accomplished using the RRS. SDS1 and SDS2 provide backup to the RRS if it were to fail to shut down the reactor. RRS and SDS1 are the preferred shutdown means because activation of SDS2 would require significant poison cleanup from the moderator before the reactor could be restarted. Failure to shut down the reactor with one of these systems would result in a FTSD sequence, which is described in Sect. 6.6.

Removal of the decay heat from the reactor is accomplished by transferring the heat to the feedwater in the steam generators. This is the preferred method of heat removal following a SCRAM so that the plant can be ready to return to power after eliminating the problem that required the SCRAM. The heat transport pumps may continue to operate, but this is not essential because thermosiphoning would provide adequate flow through the reactor core. Any one of the three feedwater systems has sufficient capacity to remove the decay heat. The steam produced in the steam generators would be discharged to the condenser through the CSDs. It is assumed that condenser vacuum is maintained so long as the condensate pumps are running. Failure of the steam discharge valves or condenser vacuum would result in the ASD's opening to release the steam pressure. The steam generator MSSVs are provided as a means to relieve pressure in the steam generators if the steam discharge valves or ASDs do not function adequately. (Although initiation of the SDC would probably be performed before allowing the MSSVs to lift repeatedly, they are included as a redundant portion of the steam removal function for the SCRAM sequences.)

The SDC is designed to cool the reactor from 100% heat and pressure and therefore can be used as an alternate means to cool the reactor following a SCRAM. While the SDC would be required for all long-term reactor shutdowns, this analysis considers only short-term cooling of the reactor while awaiting return to power. The SDC requires manual initiation from the operators.

The MCS can be used to maintain reactor temperature below levels where fuel will melt when other cooling methods have failed. This requires pressure tube deformation to come in contact with the calandria tubes for heat transfer, as discussed earlier with other initiators. This again dictates a certain level of fuel damage but to a lesser degree than that occurring from no core cooling. Failure to remove the decay heat will result in extensive core damage.

6.5.2 Event Sequence Diagram and Event Tree

The ESD for a SCRAM, shown in Figure 6.13, is a pictorial representation of the logical sequence of operations necessary to mitigate the SCRAM condition. The ESD was used in the development of the event tree, which is presented in Figure 6.14. The event tree resulted in 8 sequences designated as SCRAM-A through SCRAM-H and 14 FTSD sequences designated as SCRAM-FTSD-A through SCRAM-FTSD-N (the FTSD transfer event tree is presented in Sect. 6.6).

* P. J. Allen et al., Atomic Energy of Canada, Limited, *External Analysis Report—Conceptual Probabilistic Safety Assessment*, Rev. 0/89-02-28, 1989.

Figure 6.13 SCRAM ESD

The events listed along the top of the event tree page refer to the system fault trees from Chap. 5 that are called by the SCRAM event tree. The fault trees are

1. RRS—reactivity regulating system and shutdown systems 1 and 2
2. FW—Group 1 and 2 feedwater systems and auxiliary feedwater
3. SD—steam discharge (CSD and ASD)
4. MSV—main steam safety valve
5. SDC—shutdown cooling system
6. MCS—moderator cooling system.

6.5.3 Sequence Evaluation Insights

The CSDs and the ASDs require air to open. Therefore, failure of the plant air system to supply instrument air to these valves will require the operator to initiate the SDC, or the repeated lifting of the MSSVs will occur.

6.6 Failure to Shutdown Event

6.6.1 Event Description

The FTSD event is defined in this study as the condition whereby the systems designed for reactor shutdown are not available. In all of the previously analyzed events, SDS1 and SDS2 were designated for reactor shutdown. The RRS was sanctioned for reactivity control in some, but not all, of the events.

FTSD is referred to as a transfer event, as opposed to an IE, because the other events, except for the LBLOCA, “transfer” to it. As such, FTSD is assigned a frequency of occurrence of 1.0. However, this is a conditional event with failures of SDS1 and SDS2 (and in some cases the RRS) having occurred before transferring to the FTSD tree.

ORNL-DWG 93-3200 ETD

SCRAM	RSS	FW	SD	MSV	SDC	MCS	SEQ #	SEQUENCE	END-STATE	CATEGORY
							1	SCRAM-A	CC-1	EC-I
							2	SCRAM-B	CC-1	EC-III
							3	SCRAM-C	CC-1	EC-IV
							4	SCRAM-D	CC-2	EC-V
							5	SCRAM-E	CC-3	EC-V
							6	SCRAM-F	CC-1	EC-V
							7	SCRAM-G	CC-2	EC-V
							8	SCRAM-H	CC-3	EC-V
							9	SCRAM-FTSD	FTSD	TRANSFER

Figure 6.14 SCRAM event tree

Event

After a failure of the reactivity control systems, the following functions are required to mitigate the FTSD transfer event:

- reactivity control,
- heat removal, and
- inventory control.

The MLP system provides boron poison for reactivity control during normal operation of the reactor and during shutdown. However, in the absence of other means of reactor shutdown, the MLP system is proposed as an alternate means for reactor shutdown. Failure of the MLP system is expected to result in extensive core damage.

Heat removal is accomplished by removing steam and supplying cooling water to the secondary side of the steam generator. Steam removal may be accomplished by actuation of the CSDs or the ASDs. Should failure of both the CSDs and ASDs occur, the MSSVs will lift to relieve steam pressure. Assuming the steam generator is available as a heat sink, FW1 or FW2 may be used to remove heat on the secondary side. Unavailability of both these systems will require the AFW. Failure to remove heat is expected to result in core melt.

Finally, water inventory must be made up so that the core is not uncovered. This is accomplished by closing the LRVs. Should this fail, the BCS must be isolated to halt further loss of primary coolant inventory. If this is not possible, the HPI and LPI modes of the ECCS can provide inventory makeup. Failure to control inventory is expected to result in core melt.

6.6.2 Event Sequence Diagram and Event Tree

The ESD for the FTSD is shown in Fig. 6.15. The ESD is a pictorial representation of the sequence of operation necessary to mitigate the FTSD condition. The ESD was used in

the development of the event tree, which is presented in Figure 6.16. The event tree resulted in 14 sequences designated as FTSD-A through FTSD-N.

The events listed along the top of the event tree page refer to the system fault trees from Chap. 5 that are called by the FTSD event tree. The fault trees are

1. MLP—moderator liquid poison system
2. SD—steam discharge systems (CSDs and ASDs)
3. MSV—main steam safety valve
4. FW—Group 1 and 2 feedwater systems and auxiliary feedwater
5. LRC—liquid relief valve closed
6. BCS—isolate bleed condenser
7. HPI—high-pressure injection mode of ECCS
8. LPI—low-pressure injection mode of ECCS

6.6.3 Sequence Evaluation Insights

The FTSD sequences presented in the analysis are based exclusively on engineering judgement. Because transfer to a FTSD sequence requires failure of both SDS1 and SDS2 and in some cases RRS, at least three failures must occur before this transfer occurs. Therefore, all resultant FTSD sequences are automatically classified as EC-IV events. Although the FTSD analysis may provide useful information about the systems that might be employed in this type of situation, few insights are to be drawn from analysis of these sequences.

Reference

1. Atomic Energy of Canada, Limited, "CANDU 3 Conceptual Safety Report," Vols. 1 and 2, 1989.*

* Available in NRC PDR for inspection and copying for a fee.

Figure 6.15 FTSD ESD

Figure 6.16 FTSD event tree

7 Results

This chapter provides a discussion of the insights from the results of the event tree evaluations and the review of the ESDs. Of primary interest are the event sequence categorization results, the identification of systems significant to safety, and identification of key operator actions.

The ESDs and the event trees are presented in Chap. 6. An ESD was prepared for each of the seven RIEs: LBLOCA initiator, two SBLOCA initiators (LRV failure and feeder tube break), LOP initiator, two loss of feedwater initiators (pipe break inside and outside the reactor building), and a general scram initiator. FTSD was not treated as a separate IE in this analysis, but as an extension of possible sequences resulting from other initiators. This is because FTSD sequences potentially serve as the next line of defense should the reactor shutdown systems fail. Consequently, the sequences for mitigation of an FTSD are treated as transfers from the other ESDs. Significant insights from the FTSD transfer event are subject to these conditions.

7.1 Event Sequence Categorization Results

Tables 7.1–7.3 present the event categorization results for the EC-I, EC-II, and EC-III classifications, respectively. These categories identify sequences that might later be chosen as Anticipated Operational Occurrences, Design-Basis Accidents, and Severe Accidents, respectively, for analysis at the time of CANDU 3 design certification. These results were determined by combining the systems and event analyses discussed in Chaps. 5 and 6 with the event sequence categorization criteria discussed in Chap. 3 (Table 3.1). The full event sequence cut sets (presented in Appendix C of this report) were analyzed to develop the data presented in Tables 7.1–7.3 as follows:

1. Each of the seven RIEs had a number of event sequences (e.g., LB-A, LB-B, etc.) associated with it. For each event sequence a determinant failure(s) was identified; this was the sequence cut set(s) that results in the sequence being placed in the most limiting category (EC-I being most limiting, and EC-IV being least limiting). A particular sequence can have more than one determinant failure, because there may be multiple cut sets that would result in the sequence being classified in its most limiting category. Sequences where all cut sets had three or more failures had no determinant cut set (because all would be classified as EC-IV).
2. Based on the determinant failures, each sequence for the analyzed RIEs could then be categorized by the criteria discussed in Chap. 3 (Table 3.1).

3. Finally, the event sequences represented by the RIEs (as noted in Table 4.2) were categorized based on the RIE determinant failures, the initiating frequencies for these events, and the categorization criteria.

The meaning of the EC-I, EC-II, EC-III, and EC-IV classifications (from Chap. 3) are presented again here:

- The EC-I category was defined to include scenarios that might occur at least once in the lifetime of a given plant. Scenarios similar to those in this category might be selected by NRC as Anticipated Operational Occurrences for analysis by the applicant.
- The EC-II category was defined to include low-frequency initiators and single component or operator failures. These scenarios might occur once in the lifetime of a class of plants. Some of these scenarios might later be selected as Design-Basis Accidents for analysis by the applicant.
- The EC-III category was defined to include very low probability scenarios, some with multiple failures, which would be typical of so-called Severe Accidents. Such scenarios might be analyzed in PRAs to determine licensing source terms and to assess containment capabilities.
- The EC-IV category was defined to include scenarios with such low probabilities that detailed analysis would probably not be worthwhile. These are sometimes referred to as Residual Risk scenarios.

Finally, note that Tables 7.1–7.3 also present, for each of the categorized event sequences, the plant end state associated with that sequence. The plant end states defined in Chap. 3 are presented again here:

- CC-1—No significant fuel cladding damage and no fission product release from the fuel.
- CC-2—Moderate fuel cladding damage with release of some volatile fission products from the fuel (the fuel rod gap inventory), but coolable geometry of fuel bundles is maintained.
- CC-3—Extensive core damage with large release of fission products from the fuel and potential relocation of core debris.

7.2 Systems Significant-to-Safety

CANDU-3 systems are separated in terms of a “two-group separation philosophy.” This concept generally divides systems into two groups, each capable of performing the

Results

Table 7.1 Event Category I results

Specific initiators	Sequences	End state	Determinant failures	Failure descriptions
RIE—Feeder Tube Header Break				
None	None	NA	NA	NA
RIE—LRV				
1. LRV failure	LRVF-A	CC-1	NA	Success path
2. Pressure and inventory control system failure				
RIE—Feeder Tube Break				
1. Feeder tube break	SBLFB-A	CC-1	NA	Success path
2. Pressure tube leak/rupture				
3. Fuel handling machine breaks end fitting				
4. Leakage from fuel handling machine/cooling system				
5. Vent line and sample line leaks/breaks or leakage from primary system				
6. Heat transport pump seals fail				
RIE—LOP				
1. LOP	LOP-A	CC-1	NA	Success path
2. Loss of station electric load				
3. Off-site power lost				
4. Loss of flow in one or all heat transport loops				
5. Decreased HTS flow	LOP-N	CC-1	1 valve	LRV fails to reclose
6. Pressurizer anomalies (high pressure, low pressure, spray failure)				
RIE—Feedwater Piping Break in the Reactor Building				
None	None	NA	NA	NA
RIE—Feedwater Piping Break in the Turbine Building				
1. Turbine trip	LOFWTB-A	CC-1	NA	Success path
2. Loss of condenser vacuum				
3. Loss of normal feedwater flow				
4. Failure of the steam generator pressure control resulting in closure of the turbine throttle valves				
5. Loss of condensate pumps				
6. Failure of steam generator level control				

Table 7.1 (continued)

Specific initiators	Sequences	End state	Determinant failures	Failure descriptions
RIE—SCRAM				
1. SCRAM	SCRAM-A	CC-1	NA	Success path
2. Uncontrolled control rod assembly withdrawal				
3. Control rod maloperation (part length control rods, rod ejection, or rod drop)				
4. Rod position error (pressure, temperature, power imbalance)				
5. Moderator anomalies				
6. Feedwater system malfunctions that result in an increase in feedwater flow or a decrease in feedwater temperature				
7. Steam pressure regulator malfunction or failure that results in increasing steam flow (turbine overspeed)				
8. Inadvertent opening of a steam generator relief or safety valve				
9. Increased heat transfer flow or inventory				
10. Degradation or loss of moderator flow				
11. Degradation or loss of moderator cooling				
12. Loss of moderator inventory				
13. Failure of the cover gas system				

Results

Table 7.2 Event Category II results

Specific initiators	Sequences	End state	Determinant failures	Failure descriptions
RIE—Feeder Tube Header Break				
1. Feeder tube header break	LB-A	CC-2	NA	Success path
	LB-H	CC-2	Pump failure	Failure of any one of the four HTS pumps
RIE—LRV Failure				
None	None	NA	NA	NA
RIE—Feeder Tube Break				
None	None	NA	NA	NA
RIE—LOP				
1. Deformation of fuel channel structure that restricts coolant flow	LOP-A	CC-1	NA	Success path
	LOP-N	CC-1	1 valve	LRV fails to reclose
RIE—Feedwater Piping Break in the Reactor Building				
1. Steam generator tube failure	LOFWRB-A	CC-1	NA	Success path
	LOFWRB-Z	CC-1	Signal failure, valve failure, human error	The draining steam generator cannot be isolated due to valve failure, signal failure, or failure of the operator to close the valve
RIE—Feedwater Piping Break in the Turbine Building				
1. Feedwater piping break in the turbine building	LOFWTB-A	CC-1	NA	Success path
RIE—SCRAM				
1. Steamline piping breaks inside or outside containment	SCRAM-A	CC-1	NA	Success path
2. Startup of an inactive heat transfer loop or recirculating loop at an incorrect temperature				
3. Moderator deuterium excursion				
4. Loss of calandria structural integrity				

Table 7.3 Event Category III results

Specific initiators	Sequences	End state	Determinant failures	Failure descriptions
RIE—Feeder Tube Header Break				
1. Feeder tube header break	LB-B	CC-2	2 Valves, 2 heat exchangers	ECCS recirculation sump isolation valves fail to open or the heat exchangers foul
	LB-D	CC-2	2 Valves, 2 pumps, undetected low coolant tank level	ECCS LPI valves fail to open, grade-level tank isolation valves fail to open, or insufficient volume in the grade-level tank goes undetected
	LB-F	CC-2	Support system, 2 signals, 2 valves, undetected low gas tank pressure, undetected low coolant tank volume	ECCS control signals fail, ECCS initiation signals fail, HPI valves fail to open, undetected low pressure in helium accumulator tank, or undetected low volume in coolant tank
	LB-O	CC-2	Common mode, 2 relays, 2 trip computers	Failure of multiple shutdown rods to insert, failure of relays in the SDS1 trip logic, or failure of two SDS1 trip computers
2. Backflow into ECCS	LB-A	CC-2	NA	Success path
	LB-H	CC-2	Pump failure	Failure of any one of the four HTS pumps
RIE—LRV Failure				
1. LRV failure	LRVF-B	CC-1	Support system	Failure of the instrument air system causes the ASDs and CSDs to fail to open
2. Pressure and inventory control system failure	LRVF-I	CC-1	Support systems, 2 valves	Failure of the Group 1 Class II odd power bus, plant control system, or failure of 2 isolation valves may result in failure to isolate the bleed condenser
	LRVF-R	CC-1	Common mode, 2 relays, 2 trip computers	Failure of multiple SDS1 shutdown rods to insert either due to binding or multiple coil failures or failure of 2 trip logic relays or 2 trip computers results in failure of SDS1

Table 7.3 (continued)

Specific initiators	Sequences	End state	Determinant failures	Failure descriptions
RIE—Feeder Tube Break				
1. Feeder tube break	SBLFB-B	CC-2	2 Valves, 2 pumps, undetected low grade-level tank level	ECCS LPI isolation valves, injection valves, or pumps fail; or insufficient volume in the grade-level tank is undetected
2. Pressure tube leak/rupture	SBLFB-D	CC-2	2 Signals, 2 valves, undetected low gas tank pressure, undetected low coolant tank volume	ECCS initiation signals, isolation valves, or injection valves fail; or undetected low pressure in the helium gas tank; or insufficient volume in the high-pressure coolant tank goes undetected
3. Fuel handling machine breaks end fitting				
4. Leakage from fuel handling machine/cooling system	SBLFB-H	CC-2	Support systems, 2 MSSVs	Failure of the instrument air system causing the MSSVs to not open; ECCS control system fails to open the MSSVs; either the even or odd Group 2 Class II power bus or failure of 2 MSSVs on the same steam generator
5. Vent line and sample line leaks/breaks or leakage from primary system				
6. Heat transport pump seals fail	SBLFB-J	CC-1	Common-mode failure, 2 relays, 2 trip computers	Failure of multiple SDS1 shutdown rods to insert either due to binding or multiple coil failures, failure of 2 trip logic relays, or failure of 2 trip computers
RIE—LOP				
1. LOP	LOP-B	CC-1	2 Valves	Failure of ASDs
2. Loss of station electric load	LOP-F	CC-1	2 Valves and/or pumps, human error, and level indication failure	FW2 pump or valve failures that disable the system; failure to replenish the FW2 supply tank after 10 h either due to human error or tank level indication failure
3. Off-site power lost	LOP-AA	CC-1	Support system	Failure of the Group 1 Class II power board may result in failure to isolate the BCS
4. Loss of flow in one or all heat transport loops				
5. Decreased HTS flow	LOP-AK	CC-1	Support system	Failure of the plant control system may cause failure to isolate the BCS and failure to initiate FW2
6. Pressurizer anomalies (high pressure, low pressure, spray failure)				
7. Deformation of fuel channel that restricts coolant flow	LOP-AO	CC-1	Support system	Failure to restore Class III power either with the diesel generators or by restoring Class IV power

Table 7.3 (continued)

Specific initiators	Sequences	End state	Determinant failures	Failure descriptions
RIE—Feedwater Piping Break in the Reactor Building				
1. Feedwater piping break in the reactor building	LOFWRB-A	CC-1	NA	Success path
	LOFWRB-I	CC-1	Signal failure, valve failure, human error	The draining steam generator cannot be isolated either due to valve failure, signal failure, or the operator failing to close the valve
2. Steam generator tube failure	LOFWRB-B	CC-1	2 Valves	Both ASDs fail to open
	LOFWRB-F	CC-1	Tank level indicator and human error, 2 pumps and/or valves	Operator fails to refill the Group 2 feedwater tank after 10 h, and the level indicator fails to alarm on low level, or a combination of pumps and valves in the FW2 fails
	LOFWRB-G	CC-2	Support system	Plant control system failure to operate valves in the FW2 and the SDC
	LOFWRB-J	CC-2	Signal or valve and human error or two human errors	The draining steam generator cannot be isolated either due to valve failure, signal failure, or the operator failing to close the valve; and the operator fails to initiate the SDC
	LOFWRB-L	CC-1	Common mode, 2 trip logic relays, 2 trip computers	Failure of SDS1 due to failure of 2 trip logic relays, or failure of 2 trip computers, or common-mode failure of at least 3 shutoff rods binding or clutch coils failing
RIE—Feedwater Piping Break in the Turbine Building				
1. Feedwater piping break in the turbine building	LOFWTB-B	CC-1	2 Valves, support system	ASDs fail to open due to failure of the valves or failure of the instrument air system
2. Turbine trip	LOFWTB-F	CC-1	Tank level indicator and human error, 2 pumps and/or valves	Operator fails to refill the Group 2 feedwater tank after 10 h, and the level indicator fails to alarm on low level, or a combination of pumps and valves in the FW2 fails
3. Loss of condenser vacuum				
4. Loss of normal feedwater flow	LOFWTB-G	CC-2	Support system	Failure of the plant control system may result in failure to initiate the FW2 and to open valves in the SDC
5. Failure of the steam generator pressure control resulting in closure of the turbine throttle valves				
6. Loss of condensate pumps				
7. Failure of steam generator level control				

Table 7.3 (continued)

Specific initiators	Sequences	End state	Determinant failures	Failure descriptions
RIE—SCRAM				
1. SCRAM	SCRAM-B	CC-1	Support system	Failure of the plant control system may cause the ASDs and the CSDs to not open. Failure of the instrument air system will result in failure of these valves to open.
2. Uncontrolled control rod assembly withdrawal				
3. Control rod maloperation (part length control rods, rod ejection or rod drop)				
4. Rod position error (pressure, temperature, power imbalance)				
5. Moderator anomalies				
6. Feedwater system malfunctions that result in an increase in feedwater flow or a decrease in feedwater temperature				
7. Steam pressure regulator malfunction or failure that results in increasing steam flow (turbine overspeed)				
8. Inadvertent opening of a steam generator relief or safety valve				
9. Increased heat transfer flow or inventory				
10. Degradation or loss of moderator flow				
11. Degradation or loss of moderator cooling				
12. Loss of moderator inventory				
13. Failure of the cover gas system				
14. Steamline piping breaks inside or outside containment				
15. Startup of an inactive heat transfer loop or recirculating loop at an incorrect temperature				
16. Moderator deuterium excursion				
17. Loss of calandria structural integrity				

essential functions of reactor shutdown, decay heat removal, and monitoring of the plant parameters. In general, "Group 1" systems contribute to normal power production, while "Group 2" systems have a safety-related function or safety-related support function. Group 1 systems alone can perform an orderly shutdown and cooldown of the reactor. However, Group 2 systems can perform all required safety-related functions in the event of an accident, even one that disables Group 1. It is recognized, however, that many Group 1 systems have been qualified to perform a safety-related function under specific conditions.¹ This report is not intended to provide an evaluation of the CANDU 3 design vs U.S. criteria for safety-related functions, and systems will be designated as either Group 1 or Group 2.

The phrase "systems significant-to-safety," as used in this report, identifies those systems and components that could have a significant impact on the successful response of the plant to a given IE. The term does not mean "safety-related" as defined previously. U.S. commercial nuclear operating experience has shown that nonsafety-related equipment can exercise significant influence on the path taken to mitigate an event or on the consequences of an event. In the context of this definition of significant-to-safety, safety-related equipment would be considered a subset of equipment significant-to-safety.

The ESDs and the event tree evaluations are used to assist in the identification of such significant impacts on successful plant response. For this analysis, "significant" is defined as any system, component, or operator action that is important for the successful mitigation of an IE. Because the terms "significant" and "important" are judgmental and subject to interpretation, a set of rules was established to permit a rational and consistent means to identify significant-to-safety systems and components and to provide a clear basis for their differentiation from non-significant-to-safety systems and components. These criteria are used in selecting systems and components significant to safety:

Candidate Systems Criteria:

1. Only those systems or components that contribute to successful termination (primary and backup paths) of an IE are considered candidates for being designated significant-to-safety. Successful termination is defined as resulting in plant end states CC-1 and CC-2. Systems on pathways leading to plant end state CC-3 are not considered as being significant-to-safety, although such systems could be considered candidates for severe accident management actions.

2. All Group 1 systems or components on paths terminating in plant end states CC-1 and CC-2 are considered candidates for being designated significant-to-safety. This included frontline systems and their support systems.
3. All Group 2 systems on paths terminating in plant end states CC-1 and CC-2 are designated as significant-to-safety.

Criteria for Systems Significant-to-Safety:

1. Any Group 1 candidate system or component whose function is not backed up will be designated as being significant-to-safety. For the purposes of selecting systems significant-to-safety, the term "backup" here will be restricted to its use only where the "backup" leads to the equivalent plant end state as the original system.
2. If any Group 1 candidate system or component has only Group 1 backup, the candidate system or component will be designated as significant-to-safety. The backup will not.
3. If a Group 2 candidate system is backed up by a Group 1 system, the Group 1 backup will not be designated as significant-to-safety.
4. Any Group 1 candidate system or component with at least one Group 2 backup will not be designated as significant-to-safety.

Group 2 Systems Designated as Significant-to-Safety

A review of the ESDs shows several Group 2 frontline systems that lie on paths leading to safe shutdown of the reactor. A summary of this information is shown in Table 7.4. As a result of the definitions of significant-to-safety presented, these Group 2 systems are defined as significant-to-safety.

Reference to the CANDU-3 dependency matrix in Table 6.1 shows the following Group 2 support systems as providing a support function in the mitigation of transients and accidents:

1. Class I/Group 2 electric power—supports SDS1 and SDS2
2. Class II/Group 2 electric power—supports SDS1, SDS2, FW2, and HPI
3. Class III/Group 2 electric power—supports LPI, REC, and Group 2 service water
4. Group 2 service water—supports REC

These Group 2 support systems are also defined as being significant-to-safety.

Table 7.4 Group 2 Systems used in the mitigation^a of RIEs for the CANDU-3 conceptual design

RIE	SDS1	SDS2	ECCS (HPI)	ECCS (LPI)	ECCS (REC)	CC	FW2	MSV	LRV
Large loss of coolant	✓	✓	✓	✓	✓				
Small loss of coolant (LRV failure)	✓	✓	✓ ^b	✓ ^b	✓ ^b	✓	✓		
Small loss of coolant (feeder tube break)	✓	✓	✓	✓	✓	✓	✓		
Loss of Class IV electric power	✓	✓	✓ ^b	✓ ^b	✓		✓	✓	✓
Loss of feedwater (reactor building)	✓	✓					✓	✓	
Loss of feedwater (Turbine Building)	✓	✓					✓	✓	
Required SCRAM	✓	✓					✓	✓	

^aMitigation is defined as ending in plant end states CC-1 or CC-2.

^bFor these events, the applicable ECCS modes will be dependent on the specific course and timing of the sequence of events.

Group 1 Systems Designated as Significant-to-Safety

Review of the ESDs shows several Group 1 systems in a path for successful termination of the events. The designation of the individual systems as significant-to-safety will depend on the actual function of the Group 1 system, its role as a primary or a backup, and redundancy of the function with respect to available Group 1 and Group 2 systems. A discussion of the Group 1 systems designated as significant-to-safety follows.

Bleed Condenser System (BCS)—This system performs an overpressure protection function for the HTS. The HTS LRVs are designed to open on loss of power or loss of air. Failure of these valves to reclose will result in loss of the primary inventory through the bleed condenser to the D₂O storage tank and then into the reactor building. Failure of this function will result in an event similar to a small loss of coolant. Also, if the primary LRVs open and fail to reclose, isolation of the BCS will effectively isolate this failure and stop the primary inventory loss. This isolation function is backed up by a Group 2 system except for the case of long-term failure to restore Class III power during a LOP event. In this set of circumstances, the function of isolation of the LRVs that failed open on loss of power is not backed up. Consequently, the BCS is designated as significant-to-safety.

Shutdown Cooling System (SDC)—The SDC provides long-term decay heat removal from the core. It is a Group 1 system that has its primary support provided by Group 1 support systems. However, SDC is provided with backup support from Group 2 support systems. Long-term decay

heat removal is a significant function that is necessary to maintain the long-term safety of the reactor. Also, the SDC is sized to remove 100% of maximum core decay heat, thus allowing its use as a possible shutdown path immediately after reactor trip. The SDC is designated as significant-to-safety.

Auxiliary Feedwater System (AFW)—This diesel-powered system provides a small amount of flow to the steam generators. Supply is taken from the FW1 and is pumped through the FW1 piping. Similar to FW1, the AFW function is backed up by the Group 2 system FW2 with the exception of the loss of Class IV electric power event, when there is long-term failure to recover Class III power. If Class III power is not available to provide power to the FW2 pumps and isolation valves, the diesel-driven AFW can be used to provide water to the steam generators with removal of decay heat through the MSSVs. The AFW is designated as significant-to-safety.

Condenser Steam Discharge Valves (CSDs) and Atmospheric Steam Discharge Valves (ASDs)—These valves are used to release steam from the secondary system to control pressure in the steam generators. The ASDs can also be used as a heat sink for decay heat removal when used in conjunction with a source of water to the steam generators. Although the function of opening for steam relief is redundant between the three sets of valves, the function of reclosing afterward is not. If any of the valves do not reclose, then a situation is created that is similar to a loss of feedwater event. These two systems will be designated as significant-to-safety.

Moderator Cooling System (MCS)—The MCS is the last line of defense for heat removal from the core. For analyzed events other than the LBLOCA, actuation of the MCS would most likely result in a more severe plant end state than would be expected using the normal and emergency heat removal systems. For the LBLOCA, however, actuation of the MCS as a backup system is expected to lead to an end state similar to that which would occur if it was not employed. Thus, the MCS will be considered to perform a backup function as defined in the significant-to-safety criteria, and it is designated as significant-to-safety.

Isolation of Steam Generator (ISO)—Isolation of a steam generator is required when a feedwater piping break occurs between the steam generator and its check valve to avoid excessive loss of feedwater inventory. This function is backed up by a Group 1 system. Therefore, ISO will be designated as significant-to-safety.

Group 1 Systems Designated as Not Significant-to-Safety

Based on the criteria defined earlier in this section, the following Group 1 systems were not designated as significant-to-safety.

Reactor Regulating System (RRS)—The RRS is used as the initial means to shut down the reactor after an IE that does not result in large primary or secondary inventory losses. It is backed up by SDS1 and SDS2, both of which are Group 2. Consequently, the RRS will not be designated as significant-to-safety.

Group 1 Feedwater System (FW1)—This system supplies controlled feedwater to maintain required steam generator levels. For all transients, the FW1 function is backed up by the FW2. Consequently, the FW1 will not be designated as significant-to-safety.

Heat Transport System (HTS)—This system circulates pressurized heavy water through the core and to the steam generator to remove core heat. It also serves a function of maintaining flow during a large loss-of-coolant event; it is expected, for this situation, that the ECCS will refill the core more quickly if the HTS is available.* However, the HTS is backed up by the Group 2 ECCS in the large loss-of-coolant event. Consequently, the HTS is not designated as significant-to-safety.

* Atomic Energy of Canada, Limited, Presentation of Information at NRC/AECL Review Meeting on the CANDU 3 Systems Research Study, February 10, 1993.

Moderator Liquid Poison System (MLP)—The MLP is used during normal operations as part of the reactor power control scheme. The system can also be used to poison the reactor when other means of reactor shutdown have failed. This system only appears in the FTSD ESD. However, for this system to be called upon, the RRS, SDS1, and SDS2 systems must have failed; SDS1 and SDS2 are also Group 2 systems. As such the MLP is performing a backup function to a safety-related system. Consequently, the MLP is not designated as significant-to-safety.

Table 7.5 summarizes all of the Group 1 and 2 frontline and support systems and their designations as significant or not significant-to-safety.

7.3 Identification of Primary and Backup Systems

Table 7.6 summarizes how the various CANDU 3 systems were determined to be either primary or backup systems (depending on whether they were on primary or backup success paths in the ESDs) for the events analyzed in this study. The table also notes those systems that were identified as "significant-to-safety" in Sect. 7.2 and also those that are Group 2 systems.

A review of the ESDs shows at what points in the analyzed sequences that Group 1 and Group 2 systems play an important role in the mitigation of transients or accidents at the CANDU 3 reactor. The ESD evaluation for the seven RIEs shows the following:

1. For each of the analyzed RIEs, there are several successful shutdown paths (CC-1 or CC-2 end states) that utilize both Group 1 and Group 2 systems.
2. With the exception of extended loss of Class III power in the LOP event and failure to isolate the draining boiler in the Feedwater Piping Break in the Reactor Building event, all of the RIEs have at least one success path to an acceptable end state (CC-1 or CC-2) that includes only Group 2 systems.
3. The LOP, Feedwater Piping Break in the Turbine Building, and SCRAM events each have at least one success path to an acceptable end state (CC-1 or CC-2) that utilizes only Group 1 systems. The other RIEs do not contain any success paths that only utilize Group 1 systems.

A review of the dependency matrix (see Table 6.1) in combination with the event sequence information shows support functions being provided to Group 2 systems from

Table 7.5 Systems and components classified as significant-to-safety

CANDU 3 designation	Frontline systems	Support systems
Group 2 systems designated as significant-to-safety	Shutdown System 1 Shutdown System 2 ECCS—High Pressure Injection ECCS—Low Pressure Injection ECCS—Recirculation Crash Cooling System Group 2 Feedwater Main Steam Safety Valves Liquid Relief Valves	Group 2 Class I Power Group 2 Class II Power Group 2 Class III Power Group 2 Service Water Group 2 Portion of Plant Air
Group 1 systems designated as significant-to-safety	Bleed Condenser System Shutdown Cooling System Auxiliary Feedwater System Condenser Steam Discharge Valves Atmospheric Steam Discharge Valves Moderator Cooling System Isolation of Steam Generator	Recirculating Cooling Water Group 1 Portion of Plant Air
Group 1 systems designated as not significant-to-safety	Moderator Liquid Poison System Reactor Regulating System Group 1 Feedwater Heat Transport System	

two Group 1 systems. This presents the potential for failure of a Group 1 system to fail the function of a Group 2 system which, in turn, could compromise the Group 2 mitigation path. The dependency matrix shows that plant air provides support to SDS2 (the SDS2 plant air support is, however, for fail-safe valves and, therefore, is not a true dependency), and Group 2 service water and the recirculated cooling water provide support to the REC mode.

The Group 2 service water provides backup cooling water to the ECCS heat exchangers. The recirculated cooling water, a Group 1 system, is the normal cooling water supply to these heat exchangers.

The plant air system support of SDS2 is to provide the means to hold closed the quick-opening valves on the high-pressure helium used to force reactivity poison into the reactor. On loss of air the valves fail open, which is a safe configuration. However, such a design could also result in unanticipated shutdowns if loss of plant air occurred during operations.

The plant air system is also required to open the MSSVs and reclose the LRVs. However, these portions of the air system are classified as Group 2.

7.4 Significant Operator Actions

This section summarizes significant operator actions identified through the systems and event analyses discussed in Chaps. 5 and 6.

7.4.1 Reactor Shutdown

Manual action is required to shut down the reactor for the SCRAM initiator. The SCRAM initiator is defined as an event in which the operator is required to initiate reactor shutdown for some reason. This could be any abnormal occurrence requiring operator intervention. This requires the operators to be alert to abnormal situations and ready to respond to them properly.

7.4.2 ECCS Initiation After Small Loss-of-Coolant Events

A LOCS may not be generated for some of the smaller loss-of-coolant events. Manual activation of the ECCS is therefore required for inventory makeup in these events. The Point Lepreau Safety Report* pointed out that for

*"Point Lepreau Unit 1 Safety Report, Part 2 Accident Analysis," Vol. 1, May 1991.

Table 7.6 Primary and backup systems from event analyses^a

Event	RRS	SD1 ^{b,c}	SD2 ^{b,c}	HTS	HP ^{b,c}	LP ^{b,c}	REC ^{b,c}	MCS ^b	CC ^{b,c}	FW1	FW2 ^{b,c}	AFW ^b	BCS ^b	CSD ^b	ASD ^b	MSV ^{b,c}	SDC ^b	LRV ^{b,c}	ISO ^b
LBLOCA		P	B	P	P	P	P	B											
LRFV		P	B		B	P		B		P	B	B	P		B	B	B		
SBLFB		P	B		P	P		B	P	P	B	B							
LOP	P	B	B		B	B		B			P	B	B		P	B	B	P	
LOFWRB		P	B					B			P				P	B	B		P
LOFWTB	P	B	B					B			P				P	B	B		
SCRAM	P	B	B					B		P	B	B		P	B	B	B		

^aP = system on primary success path; B = system on backup success path.^bA system designated as "Significant to Safety" in this report.^cA CANDU-3 Group 2 system.

Results

some Point Lepreau SBLOCAs, the operator would initiate system ECCS actions; however, the specific actions that the operator would take were not called out in the report. As discussed previously for reactor shutdown, the operators must be able to recognize these events to respond properly.

7.4.3 Refill of the Group 2 Feedwater Supply Tank

The Group 2 feedwater supply tank has a 10-h capacity. The operator must act to refill this tank when the supply has been depleted. Alarms are provided to notify the operator when the tank is in need of refilling. Failure of the SDC could require extended use of the steam generators to remove the decay heat via the FW2. Removal of the sensible heat from the secondary side after other means of decay heat removal have been established may be required to prevent damage to secondary side equipment. This too may require extended use of the FW2.

7.4.4 Initiation of the Shutdown Cooling System

The SDC is used primarily for long-term cooling of the reactor after shutdown. The system is designed for 100% heat and pressure and therefore can be used as an alternative method to cool the reactor during mitigation of events. The system has no automatic start signals and therefore requires operator action any time it is needed. The SDC is the backup means for heat removal following loss of feedwater events, particularly those downstream of the steam generator check valves. The SDC would also be initiated following a steam generator tube break to limit the release of radioactivity to the secondary side.*

*Atomic Energy of Canada, Limited, Presentation of Information at NRC/AECL Review Meeting on the CANDU 3 Systems Research Study, February 10, 1993.

7.4.5 Steam Generator Isolation

Breaks in the feedwater piping between the steam generator and the steam generator check valve require the operator to isolate that steam generator and direct feedwater flow away from it to avoid excessive release of feedwater inventory into the reactor building. Isolation of the steam generator is also needed following a steam generator tube rupture.*

7.4.6 Poison Addition in Failure-to-Shutdown Sequences

In this analysis, the MLP is assumed to be used for reactor shutdown in FTSD sequences. This system would require the operator to open the flow control valve from the poison tank to allow the poison to be introduced to the moderator. This action would be important because it would become the means of reactor shutdown after the shutdown systems have failed. It is likely that this action would have to be performed in a high-stress situation, considering the events that may have occurred for the event to have progressed to this point.

7.5 Summary

In summary, this study has provided an independent examination of event sequences, safety systems, and operator actions that might play a role in any future NRC review of the CANDU 3 for design certification. The results and observations recorded here will provide the NRC with documented information that can be used in reaching regulatory decisions for the CANDU 3.

Reference

1. Atomic Energy of Canada, Limited, "CANDU 3 Conceptual Safety Report," Vol. 1, Appendix D1, 1989.†

†Available in NRC PDR for inspection and copying for a fee.

Appendix A

Overview of CANDU 3 Design

A.1 Introduction

The purpose of this appendix is to identify succinctly the characteristics of the CANDU 3 design that affect the plant safety characteristics. The material in this chapter is a condensation of descriptions given in the Conceptual Safety Report (CSR)¹ and the CANDU 3 Technical Outline.² The CANDU 3 plant is in the conceptual design stage, but it is based on considerable experience with plants of this type. The design is described in depth, consistent with its conceptual status, in Refs. 1 and 2.

The functional requirements and capabilities of the plant to accommodate accidents are as described by Atomic Energy of Canada, Limited (AECL).^{1,2*} No implication is made that the U.S. Nuclear Regulatory Commission (NRC) or its contractors agree with these claims at this time.

A.2 Plant Configuration

General plant parameters are given in Table A.1 (from Ref. 2).

A.2.1 Reactor Configuration

The reactor is a D₂O-cooled, D₂O-moderated, natural enrichment design in which the UO₂ fuel is clad in Zircaloy and arranged in 37-rod clusters as shown in Fig. A.1. The clusters are arranged in 232 zirconium-niobium horizontal pressure tubes, 12 to a tube, which are enclosed in Zircaloy calandria tubes and separated from the calandria tubes by an annulus gas space as shown in Fig. A.2. Coolant to the fuel is provided by feeder tubes connecting the coolant supply header to each pressure tube; the general arrangement is shown in Fig. A.3. The calandria tank contains D₂O, which acts as a moderator and has its own heat removal system. The calandria tank has a helium cover gas control system and, because the tank is not designed for high pressure, a pressure relief system. This system activates in the event of overpressurization and is designed to accommodate one pressure tube failure. The calandria tank is surrounded by the shield tank, which is filled with H₂O and also has limited heat removal capability. Figure A.4 shows an elevation view of the reactor. Also shown are the reactivity control rods, reactivity control unit (RCUs), the calandria tank overpressure relief pipes, and the liquid poison injection systems, which are described later. All components are replaceable, except for the calandria tank and

the shield tank. Refueling is performed continuously while the reactor is operating, as described later.

Table A.1 CANDU 3 unit data

Reactor	
Type	Horizontal pressure tube
Coolant	Pressurized heavy water
Moderator	Heavy water
Number of fuel channels	232
Fuel	
Fuel	Compacted and sintered natural UO ₂ pellets, 12.15-mm diam, clad in 13.08-mm-OD, 0.42-mm-thick Zircaloy-4 sheath
Form	Fuel bundle assembly of 37 elements
Length of bundle	495.3 mm
Outside diameter	102.4 mm
Bundle weight	23.5 kg (includes 19.1 kg U)
Bundles per fuel channel	12
Heat transport system	
Number of steam generators	2
Steam generator type	Vertical U-tube with integral steam drum and preheater
Number of heat transport pumps	4
Heat transport pump type	Vertical, centrifugal, single suction, double discharge
Reactor outlet header pressure (gage)	9.9 MPa
Reactor outlet temperature	310°C
Reactor coolant flow	5.3 Mg/s
Steam temperature (nominal)	260°C
Steam quality (minimum)	99.75%
Steam pressure (gage)	4.6 MPa
Total fission heat	1440.3 MW(th)
Net electrical output (nominal)	450 MW(e) ^a

^aTypical for a cold water site; net electrical output depends on cooling water temperature and turbine generator and condenser design.

Source: Adapted from Ref. 2.

* Atomic Energy of Canada, Limited, *The CANDU 3 Technical Description*, 74-01371-TED-001, Rev. 3 /89-09-15, 1989.

Figure A.1 37-Element fuel bundle

Figure A.2 Unit cell for 37-element fuel

CANDU 3

Figure A.3 Reactor assembly

CANDU 3

Figure A.4 Reactor structures assembly—front view

Appendix A

A.2.1.1 Fuel

The fuel consists of natural enrichment UO_2 pellets, 12.15-mm diam, clad in Zircaloy-4 sheaths of 13.08 mm OD and 0.42 mm thick. The fuel assemblies are welded into bundles of 37 cylindrical elements in circular array, as shown in Fig. A.1. The fuel assemblies are supported by bearing pads that space them from the inside of the pressure tube. The fuel elements are arranged in circles. The inner circle has 6 elements on a 29.7-mm diameter, the intermediate circle has 12 elements in a 57.4-mm diameter, and the outer circle has 18 elements in a 86.5-mm-diam pitch. The center, of course, has one element. The bundle length is 495.3 mm, and the bundle diameter is 102.4 mm. Each fuel assembly has 21.8 kg of UO_2 and 2.3 kg of Zircaloy-4. There are 12 fuel assemblies in each channel and 2784 bundles in the reactor. The average residence time in the reactor is 72 full-power days, and the maximum is 127 full-power days. The nominal peak bundle power (time average) is 740 kW. The nominal element power is 47.1 kW/m for the outer ring element, 38.3 kW/m for the intermediate ring element, 33.5 kW/m for the inner ring element, and 31.7 kW/m for the center element.

A.2.1.2 Annulus Gas System

Commercial "bone-dry" grade carbon dioxide gas is circulated at low pressure through the annuli between the pressure tubes and calandria tubes. The gas-filled annulus restricts heat transfer from the fuel channel pressure tube to the moderator. The dry gas atmosphere prevents corrosion of fuel channel components. Provision is made for sampling the gas in the annulus gas system to measure residual moisture content. A rapid increase in (or high) moisture content is an indication of leakage from the moderator or main heat transport circuit into the annulus. Great emphasis has been placed on such detection of leaks and location of leaks. The annulus gas acts as an insulator during normal operation, but in the event of loss of coolant to the fuel, the pressure tube is expected to deform and expand against the calandria tube, thereby increasing the heat transfer to the moderator.

A.2.1.3 Moderator System

The moderator system is fully independent from the heat transport system (HTS). It includes two 50% capacity pumps and two 50% capacity plate-type heat exchangers. The moderator system is connected to the moderator purification system, the D_2O sampling system, and the D_2O supply system to enable moderator D_2O to be transferred to and from the D_2O supply system. The calandria extension maintains the moderator level in the calandria within the required range by accommodating moderator swell and shrink resulting from temperature fluctuations.

The heavy water in the calandria functions as a heat sink in the event of a partial loss of primary HTS coolant coincident with failure of the emergency core cooling system (ECCS).

The moderator system is complemented by several auxiliary systems, including the moderator purification, cover gas, liquid poison, and D_2O collection system. They are designed to maintain operating parameters within an optimum operating range.

The moderator purification system maintains the purity of the heavy water and minimizes corrosion of components and crud activation by controlling the pD (pH) and by removing impurities present in the D_2O . The moderator purification system is also used to (1) adjust the concentration of the soluble poisons (boron and gadolinium) in response to reactivity demands and (2) remove the soluble poison after initiation of Shutdown System 2 (SDS2). The system consists of a filter and ion exchangers.

The moderator cover gas system controls the concentration of D_2O by catalytically recombining the deuterium and oxygen gases resulting from the radiolysis of the heavy water moderator to reform heavy water. Helium, which is chemically inert and not activated by neutron irradiation, is used as the cover gas for the moderator system.

The liquid poison system adds negative reactivity to the moderator when required for reactivity adjustments and also provides neutron poison in the moderator to preclude criticality during certain reactor shutdown conditions. The liquid poisons employed are boron, as boric anhydride, and gadolinium, as gadolinium nitrate, dissolved in D_2O .

The moderator D_2O collection system collects any heavy-water leakage from the moderator and associated systems and pumps it into the heavy-water management systems for cleanup and upgrading.

A.2.1.4 Shield Cooling System

The shield cooling system removes the nuclear heat accumulated within the end shield and shield tank assemblies by circulating demineralized water (H_2O) through them. This heat is transferred to the recirculated cooling water system by means of two plate-type heat exchangers. An additional loop is provided, between the heat exchanger outlet and the pump suction line, for system purification. The system also serves as an ultimate heat sink in case of ECCS and moderator heat sink (MHS) failure. Also, in the event of a loss of coolant accident (LOCA), this system is

ultimately relied upon to remove the heat and allow repair work. (Typically, 6 months after the accident, the switchover from ECCS recirculation to shield cooling is expected.*)

The system consists mainly of two 100% duty circulating pumps, two 50% duty heat exchangers, one expansion (head) tank, and an ion exchange purification system with associated piping and valves.

A.2.2 Heat Transport System

A schematic of the primary HTS is shown in Fig. A.5. The major components of the HTS are the 232 reactor fuel channels, two steam generators, four electrically driven heat transport pumps, four reactor inlet headers, two reactor outlet headers, a pressurizer, and the interconnected piping. Heavy-water coolant is fed to the fuel channels from the inlet headers and is returned to the outlet headers at the opposite end of the reactor. The arrangement of the HTS equipment within the reactor building is shown in Fig. A.6.

Each steam generator is connected to two heat transport pumps, which are at the opposite end of the reactor. Each heat transport pump provides coolant flow to one-fourth of the CANDU 3 fuel channels. The coolant flow in the CANDU 3 HTS is in a "figure-of-eight" pattern employed in typical CANDU reactors, with the heat transport pumps in series and the coolant making two core passes per cycle. The equipment arrangement, however, with the steam generators and pumps at opposite ends of the reactor, results in unidirectional coolant flow through the core, which is unique to the CANDU 3 design. This facilitates fueling from one end of the reactor with a single fueling machine. The header arrangement results in reactor fuel channels in each vertical half of the core belonging to the same core pass.[†]

The headers, steam generators, and pumps are all located above the reactor. This ensures natural coolant circulation on loss of power to the heat transport pumps. This configuration also allows the pumps and steam generators to be drained for inspection and maintenance while reactor shutdown heat removal is maintained by the shutdown cooling system (SDC).

* Atomic Energy of Canada, Limited, Technologies, Rockville, Maryland, personal communication to Oak Ridge National Laboratory Staff, March 10, 1992.

[†] This configuration is that described in the CSAR.¹ The configuration could change to interweaving core passes in subsequent design modifications according to discussions with AECL.

A.2.3 Control system

The CANDU 3 control system is a distributed digital computer system and is described in Ref. 1.

A.2.3.1 Reactor Control

The core power distribution is radially and axially flattened. Power flattening is achieved through the use of regional differential fuel burnup in combination with a set of absorber devices called adjuster rods. Long-term control of the power distribution is achieved through on-power refueling. The reactor is controlled by the reactor regulating system (RRS), which includes in-core self-powered flux detectors and zonal flux controllers operated by dedicated dual-redundant control computers. This system provides for global and spatial control of power. In addition, absorber rods provide power maneuvering capabilities for power changes, reactor startup, and reactor shutdown.

The control requirements are dictated by the characteristics of the plant. Both the requirements and the characteristics are quite different from U.S. light-water reactor (LWR) technology. The use of a large D₂O-moderated, natural enrichment core raises problems with spatial instabilities and xenon poisoning, and causes situations where voids in the coolant or moderator could cause reactivity to increase. The RCUs, control rods in U.S. terminology, are telescoping rods that enter from the top of the core, perpendicular to the fuel channels. They are designed so that they move in and out from the top and bottom boundary of the core, although they are driven from the top end only by a cable arrangement. This is shown in Fig. A.7.

A.2.3.2 Distributed Control System

Most Group 1 (see Sect. A.2.5 for a description of the Group 1 and Group 2 separation philosophy) control functions are implemented by a distributed control system (DCS), which uses data highways for signal transmission and programmable microprocessors for the control logic. The DCS consists of a number of channelized local stations distributed throughout the plant outside the reactor building, linked by channelized dual-redundant co-axial cable data highways. Sensors and actuators are connected to input and output modules in the local stations by relatively short cables.

The DCS replaces the control trunk cabling, control distribution frame, relay logic, analog controllers, and comparators used in previous CANDU control systems, as well as the central computers used for signal multiplexing and digital control. The major control functions (reactor

CANDU 3

Figure A.5 HTS simplified composite flow diagram

CANDU 3 **Figure A.6 Reactor building—section**

CANDU 3

Figure A.7 Mechanical zone control unit

regulation, heat transport pressure and inventory control, steam generator pressure and level control, etc.) implemented in the central station computers of previous CANDU power stations, as well as most of the control loops previously not computerized, are distributed among a number of small, powerful DCS microprocessors. However, the system configuration uses the same dual-redundant fault-tolerant concepts used in previous CANDU computerized control systems to ensure a high level of system reliability.

The DCS provides a high rate of data transmission, high system reliability, data security, and comprehensive system fault detection. Automatic failure detection and recovery features protect against cable or device failure. If a module fails, the automatic failure detection features transfer control to the backup module. The system permits replacement of a failed module on-line without affecting the functions performed by the system.

A separate data highway distributed control system is used for control and monitoring of the fueling machine and related systems.

A.2.4 Fuel Handling and Storage

A.2.4.1 Refueling

The CANDU 3 reactor is refueled at power using a single fueling machine located at the outlet end of the reactor. The coolant flow through the reactor in all fuel channels is in the same direction. Fuel pushers, resident in each channel, assist in pushing the fuel from the channel by means of the coolant flow hydraulic impedance.

The fueling machine is operated from the main control room. For refueling, the fueling machine is positioned at the outlet end of the fuel channel and is locked on to the end fitting to obtain a leaktight joint. Figure A.8 shows the fuel handling system. Figure A.9 shows a plan view of the fueling machine vault fuel transfer system and irradiated fuel storage bay (IFSB).

The CANDU 3 fueling machine holds eight pairs of fuel bundles. The machine unloads irradiated fuel bundles through the irradiated fuel port, which leads into the IFSB located outside the reactor building containment wall. The IFSB has a storage capacity for fuel from 6 years of reactor operation, plus a reactor load of fuel. Lifting facilities are provided for the handling and shipping of the irradiated fuel.

The fueling machine, the fuel transfer ports, and irradiated fuel discharge equipment are operated remotely and automatically from the control room. Personnel access to the reactor building is required for in situ maintenance of the fueling machine equipment.

The equilibrium fueling rate for CANDU 3 with 12 reactivity adjuster assemblies is ~85 fuel bundles per full-power week of operation.

The fueling machine requires a supply of D₂O at near ambient temperature and pressures. These vary according to the function being performed. During on-power fueling, the D₂O flow direction is always from the fueling machine into the reactor channel. A reactor-grade D₂O supply is therefore provided for the fueling machine head to prevent downgrading of the HTS D₂O inventory.

A catenary, comprised of high-pressure hoses and control cables, connects the fueling machine to its auxiliary systems (see Fig. A.8). The catenary between the fueling machine carriage and its fixed connections is a double hanging loop that extends and contracts with the travel of the carriage. This catenary also accommodates the rotation of the carriage columns. A catenary overhanging support cart is towed or pushed by the fueling machine carriage. A shorter catenary between the fueling machine head and carriage column catenary connection caters for movement between these two components.

A.2.4.2 Irradiated Fuel Handling and Storage

The irradiated fuel handling and storage equipment is designed to accommodate operation at the average fueling rate of the reactor. Handling and storage space is also provided under water for irradiated parts of the reactivity control mechanisms, which may be removed from the reactor. The irradiated fuel handling equipment consists of (1) transfer equipment in the irradiated fuel transfer room outside containment and (2) handling equipment in the IFSB. The discharge and transfer operations, including tray loading and conveyance to the storage tray, are controlled remotely. Operations under water in the storage bay are done manually, from the manbridge, using hoists and long tools.

A.2.4.3 Defective Fuel Handling

Defective irradiated fuel is separated from other irradiated fuel for handling. At the transfer mechanism trough, the defective bundle is unloaded onto a tray. This tray transports the bundle to the bay. It is then lifted manually, under water, into an eight-station covered carousel. This

ORNL-DWG 93-3210 ETD

CANDU 3

Figure A.8 Fuel-handling systems

Figure A.9 Fueling machine vault, fuel transfer system, and IFSB-plan

Appendix A

carousel permits control of the "off gassing" from the defective fuel bundle. The bundle is stored in this unit until it is appropriate to store it elsewhere or to can it for permanent control of radioactive releases.

A.2.4.4 Irradiated Fuel Storage Bay

The IFSB is located in the reactor auxiliary building. It is constructed of concrete and has a welded stainless steel liner.

The IFSB is comprised of two areas:

1. the receiving area where the fuel is inspected, defective fuel is separated and stored, and the remainder of the fuel is shuttled from the transfer port to the storage area; and
2. the storage area where the fuel is stored before being transferred to some longer-term fuel storage facility.

The storage bay has the capacity to store up to 4.5 station-years of irradiated fuel, plus a reactor core of fuel.

The essential components of the IFSB cooling and purification system are two 100% duty pumps, two 50% duty heat exchangers, two filters, and two ion exchangers. Decay heat is removed from the irradiated fuel in the storage bay by recirculating the bay water through the heat exchangers. Recirculating cooling water is supplied to the secondary side of each heat exchanger to remove heat absorbed by the bay water. In addition to cooling, one or two purification loops will operate as required to maintain the desired radioactivity level and remove particulates suspended in the water.

A.2.4.5 Fuel Handling Control System

The control system utilizes cathode ray tube (CRT)-based color graphics and operator keyboards for a man-machine interface in the main control room. The system configuration is based on a central controller with distributed modules for the connection of process instrumentation and electrical motor controllers. The central controller performs sequential control of fuel handling operations and manages the protective interlock system used for mechanism protection.

The normal overall mode of control for the fuel handling system is automatic with the operator in the main control room observing the sequential operations via the color graphic displays of the plant display system. Capability is also provided to allow the operator, on an interactive basis, to control operations either in a semiautomatic mode, or in a manual mode, using keyboard entries.

A.2.5 Plant Layout (Separation)

In the CANDU 3 design, systems are separated in terms of the "two-group separation philosophy" shown schematically in Fig. A.10. This concept divides systems into two groups, each capable of performing the essential safety functions of reactor shutdown, decay heat removal, and monitoring. In general, Group 1 systems contribute to normal power production, while Group 2 systems have a safety or safety support function. Group 1 systems alone can perform an orderly shutdown and cooldown of the reactor. Group 2 systems can perform all required safety functions in the event of an accident, even one which disables Group 1. Within the Group 2 area, safety systems that perform similar functions, such as Shutdown System 1 (SDS1) and SDS2, are also separated from each other.

To guard against cross-linked and common-mode events and to facilitate the comprehensive seismic qualification of the Group 2 systems, the Group 1 and Group 2 systems are, to the greatest extent possible, located in separate areas of the station. The allocation of key systems to the two groups is shown in Fig. A.11.

All systems, equipment, and structures performing the functions of maintaining reactor coolant pressure boundary integrity, reactor shutdown, decay heat removal, and containment are seismically and environmentally qualified. This includes all Group 2 systems, structures, and components; the reactor building and Class I systems; and safety-related systems within the reactor building. Qualification ensures that the system, component, or structure can withstand the effects of the postulated earthquake or environmental condition. Qualification is achieved by testing and/or analysis.

The CANDU 3 plant is designed for a 0.3-g seismic loading requirement, irrespective of lesser site-imposed requirements.

A.2.6 Electrical Power System

A.2.6.1 Classes of Power

The station service power supplies are classified in order of their levels of availability requirements. Four classes that range from uninterruptible power to that which can be interrupted with limited and acceptable consequences are provided as follows:

CANDU 3

Figure A.10 Two-group separation philosophy

NUREG/CR-6065

Class IV Power Supply: Alternating current (ac) power to auxiliaries and equipment that can tolerate long-duration interruptions without endangering personnel or station equipment. Class IV power is normally available to all systems and loads in the station.

Class III Power Supply: Supplies ac to auxiliaries that are necessary for the safe shutdown of the reactor and turbine and can tolerate short interruptions (up to about 3 min) in their power supplies. Class III power is available to both Group 1 and Group 2 systems. Separate on-site standby generators located in the Group 2 service building provide an alternative power supply to make up the Class III Group 2 system. Connections between the Group 1 and Group 2 Class III supplies are via fully qualified isolation devices. Class III power is also relied upon to operate pumps for heat removal. The Group 2 Class III system, including the standby generators, is seismically qualified to be operational after a design basis earthquake.

Class II Power Supply: Uninterruptible, ac supplies for essential auxiliaries, channelized to match the redundancy requirements of station instrumentation and control systems. Class II power is available to Group 1 and Group 2 systems. The Group 2 Class II distribution system is seismically qualified to be operational after a design basis earthquake.

Class I Power Supply: Uninterruptible, direct current (dc) supplies for essential auxiliaries, channelized to match the redundancy requirements of control logic and reactor safety circuits. Class I power is available to Group 1 and Group 2 systems. The Group 2 Class I system is seismically qualified to be operational after a design basis earthquake.

A.2.6.2 Odd and Even Concepts

The station electrical distribution system is split into two independent divisions from the highest distribution voltage down through control voltages. These divisions are referred to as the "odd/even" systems and are separated in all aspects of equipment, distribution, and cable routing. This ensures redundancy of supply to systems requiring high reliability. There are duplicated systems within each of the two groups, and full separation is maintained between systems and groups.

All the power loads are allocated to one or the other division on the following basis:

- where two loads have a main and a standby function, one is on "odd" and the other on "even" divisions; and
- where two loads with a different primary function have a backup interdependence, then one is on each division.

The RRS and the safety systems have triplicated instrumentation and control channels. These channels are kept completely separate from each other with regard to equipment cabinets, cable trays, conduits, junction boxes, etc. The safety systems are also separated into two subgroups to ensure reliability and independence, particularly for the shutdown systems.

A.2.6.3 Automatic Transfer System

To provide electrical power with high reliability to the Class IV and Class III loads, an automatic transfer system is incorporated that ensures continuity of supply when either the unit supply or the system supply fails. The transfers are manually initiated for normal transfers after startup or before shutdown and are automatically initiated for reactor trips, turbine-generator trips, or loss of the transmission system.

A.2.6.4 Uninterruptible Class II Power Supplies

The instrumentation and computers are fed from three 120-V inverters to ensure complete independence of supply to the triplicated reactor regulating and protection instrumentation.

The Class II essential lighting and selected safety-related valve motors are normally fed from two 600-V inverters, providing segregation between instrumentation and motor loads. Each inverter is normally supplied through a rectifier battery charger system in parallel with a battery. The rectifiers receive their supplies from Group 1 Class III buses.

If there is a Class III power failure, the inverter will continue to be supplied from the battery without interruption. In the event of an inverter malfunction, the load is transferred to the alternative Class III source.

A.2.6.5 Uninterruptible Class I dc Power Supplies

Two Group 1 independent 1250-V storage battery banks with battery chargers are located in separate rooms and provide the power for all motors, switchgear operations, and Class II inverters.

Appendix A

Group 1 battery sets are sized to support all the loads connected for up to 60 min following an interruption to the normal (Class III) sources. All ac power is supplied through static inverters.

Each diesel generator is sized to supply the total safe shutdown load of the unit. The Class III shutdown loads are duplicated, one complete system being fed from each diesel generator.

Each diesel generator set is capable of starting the largest Class III motor across the line while supplying other sequenced loads.

A.2.6.6 Group 2 Power Supply System

The Group 2 power supply system provides an alternative source of electric power to essential Group 1 systems if normal electrical supplies are lost. These events are specifically dealt with by the Group 2 power supply system:

1. a design basis earthquake,
2. a loss of Class IV power (LOP), and
3. a LOCA followed 24 h or later by a site design earthquake.

The Group 2 power supply system also provides on-site backup power to specific Group 1 station loads connected to the Class III buses. The system is controlled from the Group 2 service building secondary control area with buffered links, allowing system control remotely from the main control room.

The Group 2 power supply system is provided by two 100% capacity diesel generator units. The two diesel generator sets, located in the Group 2 service building and housed in separate rooms with fire- and blast-resistant interior walls, are seismically qualified to be operational after a design basis earthquake.

If the normal power sources fail, the diesel generators will start automatically. They also start automatically on a loss-of-coolant signal, but are not connected unless a LOP occurs. The diesel generators come up to speed and accept key loads within 30 s and full load within 2 min of the start signal. The fuel system has the capacity to supply the diesel generators for 7 d. During normal plant operation, the Group 2 electrical distribution system is supplied from the Group 1 Class III system.

The Group 2 system is seismically and environmentally qualified.

Each diesel generator set is capable of starting the largest Class III (Group 2) motor across-the-line while supplying other sequenced loads.

The engines operate on a diesel fuel oil. The fuel is stored in two tanks, each having the capacity to supply a diesel generator for 7 d of continuous operation at nominal load. Each diesel has an indoor day tank with capacity for 8 h of operation. The fuel pumps that transfer fuel between the storage tank and the day tank are duplicated. The fuel is gravity fed from the day tank to the diesel.

The diesels are air-started. Two air reservoirs are provided for each diesel. Each starting system has two air compressors, one driven by an electric motor and the other by an internal combustion engine to provide complete "black start" capability of the diesel.

A.2.7 Service Systems

A.2.7.1 Group 1 Recirculated Cooling Water System

The Group 1 recirculated cooling water system serves the following functions:

1. provide heat removal capabilities with adequate pressure to the various users in the plant at all operating conditions;
2. provide sufficient cooling to all of the Group 1 loads classified as essential, on LOP supplies;
3. provide, together with the Group 2 service water, SDC and feedwater systems, a reliable heat sink for decay heat removal and heat transport system cooldown;
4. provide chemistry control of the service water to prevent fouling and corrosion of the piping and equipment;
5. provide means for overpressure protection in the system to protect all isolable components with a volume in excess of 42.5 L;
6. accommodate swell in the system and ensure that the system remains full at different load conditions;
7. provide means for a normal makeup water supply from the demineralized water system and a backup supply in case of large leakages or demineralized water system failure; and

8. prevent draining of the higher portion of the recirculated cooling water piping when all pumps are shut down.

The supply portions of the system (pumps and heat exchangers) are located in the Group 1 pumphouse. The following key components are cooled by the closed-loop recirculated cooling water system.

Inside the reactor building:

1. gas analysis system coolers,
2. heat transport pumps,
3. D₂O collection tank cooler,
4. fueling machine auxiliaries and heat exchanger,
5. moderator system heat exchangers,
6. reactor building coolers,
7. shutdown cooling heat exchanger,
8. moderator cover gas compressors,
9. moderator system pumps, and
10. heat transport D₂O feed pumps.

Outside the reactor building:

1. D₂O sampling coolers,
2. IFSB coolers,
3. end shield cooling heat exchangers,
4. chilled water system,
5. ECCS heat exchangers.

The equipment located in the turbine building requiring cooling water is also supplied by the recirculated cooling water system.

The recirculated cooling water system supply equipment consists of three pumps and four heat exchangers. Two pumps and three heat exchangers are required for normal operation at full reactor power. Only one pump and one heat exchanger are required during reactor shutdown. The pumps are supplied with Class III power.

The pumps draw water from a common header and discharge into a common manifold. Following distribution to the users, the water returns are combined before entering the recirculated cooling water heat exchangers, where the heat is rejected to the raw service water system.

A.2.7.2 Group 1 Raw Service Water System

The raw service water system is a once-through Group 1 system used for cooling the recirculated cooling water system (see Sect. 10.2.1) and cooling those systems and equipment whose inventory cannot be adequately cooled by the recirculated cooling water system.

The raw service water system comprises four 50% duty pumps and two filters. These pumps, located in the pumphouse, draw water from the forebay and supply water to the recirculated cooling water heat exchangers (also located in the Group 1 pumphouse) and various loads in the turbine building through underground piping. The raw service water pumps and the discharge piping from the pumps to the recirculated cooling water system heat exchangers are arranged in two trains.

All pumps are connected to the Group 1 Class III power buses (two pumps on the "odd" bus and the two on the "even" bus). Each flow path with one pump and one filter available is capable of meeting the system demands during loss of Class IV operation, with Class III available.

Each pump is isolated with a check valve and butterfly valve on the discharge side, permitting maintenance work on the pump at all times. Backup pumps start automatically or are stopped manually in accordance with the signals from the differential pressure switches mounted on the pump discharge header. The check valves at the pump discharge and in the common supply lines are equipped with mechanisms to allow testing during operation.

A.2.7.3 Compressed Air System

The compressed air system supplies instrument air, service air, and breathing air, filtered and dried as required, to both Group 1 and Group 2 areas of the station. In addition, the system provides backup receivers in the Group 1 area capable of supplying instrument air requirements during changeover from Class IV to Class III power, and backup local air reservoirs capable of supplying instrument air to essential users during accident conditions or on loss of Group 1 supply. To reduce or prevent postaccident pressurization of the reactor building, the system is capable of reducing or isolating instrument, breathing, and service air to the reactor building.

A.2.7.4 Reactor Building Ventilation System

The reactor building ventilation system provides air exchange and air distribution, maintains the reactor building at a slightly lower than atmospheric pressure,

Appendix A

provides filtration of activity, and allows easy access to all equipment associated with the system.

Air exchange in accessible areas of the reactor building prevents buildup of activity released by local sources or spread by movement of equipment or personnel.

Maintaining a negative pressure in the reactor building from its surrounding prevents the release of activity through airlock enclosures or past door seals.

Ventilation exhaust air discharged from the building is continuously monitored for activity and filtered, if necessary, before release to the exhaust stack. Containment isolation is by two valves in series in each of the ventilation duct penetrations in the containment wall. The isolation valves are automatically closed in the event of a LOCA or activity release.

A.2.8 Fire Protection

The design for fire protection follows CSA Standard CAN-N293-M87 "Fire Protection for CANDU Nuclear Power Plants."

The fire protection design considers the possibility of failures of automatic or manual fire systems to extinguish a fire and the potential for interruption of equipment functions due to fire extinguishing agents.

The distinct separation between Group 1 and Group 2 guarantees that if a fire can be confined to its area of origin, the functions of at least one group are maintained.

Buildings are laid out such that they are connected only at access points. This greatly reduces the potential for fire spread between buildings. Connections between buildings are provided with fire walls equipped with fire doors. Within larger buildings, a number of fire areas are established. Each fire area is separated from another by fire walls. These fire areas establish the practical limits of any single fire.

Each fire area contains one or more fire zones. These zones contain one or more rooms having a common fire hazard protection by a common fire protection system. Fire zones are normally established to slow the spreading of fire, heat, and smoke. In certain large open areas, such as reactor buildings, turbine hall, etc., fire zones are separated by

open space only. The establishment of fire zones in these areas are for fire detection purposes only.

The spread of fire, heat, or smoke across fire zones through the ventilation system is prevented by using separate ventilation systems or by providing fire dampers in ducts crossing zone boundaries.

Areas containing combustible materials that would hinder manual fire fighting because of heat and smoke are equipped with fire venting, except for areas containing radioactive materials.

All penetrations for cables, piping, and air ducts through fire walls and floors are sealed with a fireproof material.

The control of the fire detection system is by a micro-processor. The state of the system and all circuits are constantly monitored. Display of system troubles and fire alarm messages is on CRTs and printers. In addition to alarm functions, the system will also control fire dampers and ventilation fans and supervise sprinkler valves and fire pumps.

The central fire alarm panel, a display CRT, and a printer is provided in the main control center area. An auxiliary display CRT or printer is provided in the secondary control area.

Fire detection is based on a zoned system to facilitate the location of an alarm source. Each building is divided into a number of fire zones. When a detector senses a fire, the zone from which the alarm came is indicated on the display CRT and printer, and the local alarm device for that zone is actuated automatically. Fire alarm signals are distinctly different from signals for other plant emergencies. Response instructions can also be given over the plant public address system.

A.3 Special Safety Systems

Special safety systems are systems that are specifically incorporated in the plant to mitigate the consequences of a serious process failure requiring reactor shutdown, decay heat removal, and retention of released radioactivity. Special safety systems perform no function in the normal operation of the plant. They consist of the following:

1. SDS1,
2. SDS2,

3. ECCS, and
4. containment system (containment structures and containment isolation system).

The CANDU designs are significantly different than from U.S. LWRs. Major considerations are the unique conditions attending the use of natural uranium fuel with D₂O coolant and moderator. This results in a large reactor with potential for spatial instabilities, which tends to drive the need for computer control systems. Also, the reactor exhibits a positive void coefficient of reactivity. In the event of a large-break LOCA, the void and attendant reactivity increase is such that the normal reactivity control units are inadequate to shut down the reactor. Therefore, two fast-acting, independent shutdown systems are used; one is mechanical, and the other uses injection of liquid poison into the moderator.

The reactor may not be operated without all the special safety systems being functional. Process systems that provide reliable services such as electrical power, cooling water, and air supplies to the special safety systems are referred to as safety-related or safety support systems and are described in Sect. 7.2 of the CSR.

The design methods used to ensure that the safety requirements for each type of system or structure are satisfied include redundancy, diversity, separation, qualification, quality assurance, and the use of appropriate design codes and standards.

A.3.1 Shutdown Systems

The CANDU 3 utilizes two shutdown systems, SDS1 and SDS2.

The primary method of quickly terminating reactor operation when certain parameters enter an unacceptable range is the release of 24 spring-assisted gravity-drop absorber elements or "shutoff rods." SDS1 employs a logic system having three independent channels that detect the requirement for reactor trip and de-energize dc clutches to release the shutoff rods into the moderator. The reactor unit may not be operated without SDS1 being functional. (SDS2 uses a liquid injection system, which is described later.)

A.3.1.1 Functional Requirements

The two shutdown systems are designed in compliance with Atomic Energy Control Board (AECB) Regulatory Document R8 "Requirements for Shutdown Systems for

CANDU Nuclear Plants"* and must meet the following key requirements:

1. For events requiring prompt shutdown action, each shutdown system, acting alone, can ensure that
 - the reactor is rendered subcritical and maintained subcritical,
 - the reference dose limits are not exceeded, and
 - the integrity of the HTS is maintained (excluding break points).

Emergency core cooling and containment functions may be credited as appropriate.

2. For relevant events listed in Table 1,* each shutdown system shall ensure that fuel in the reactor with no defects before the event does not fail as a consequence of the event (excluding fuel in the failed channel).
3. Each shutdown system must be environmentally qualified to the most severe conditions under which it is required to function.
4. Each shutdown system must meet an unavailability target of $<10^{-3}$ year/year (<9 h/year).
5. The two shutdown systems must incorporate the principles of redundancy, diversity, and separation throughout their design.
6. The two shutdown systems must be completely independent of the process systems.

For purposes of assessing the performance of SDS1, the following conservative requirements are used:

1. For all relevant process failures (see Table A.2), SDS1, with the two most effective shutoff rods assumed out of action, shall have sufficient speed and negative reactivity depth to reduce the reactor power to levels consistent with available cooling. (The detector types are identified in Table A.3.)
2. For an in-core loss-of-coolant event, the depth (with one row of two shutoff rods plus the most effective rod assumed out of service) shall be adequate to shut down the reactor and maintain a shutdown state until operator action can be credited.

A.3.1.2 System Description

Reactor and process measurements

The design philosophy is based on triplicated measurements of each variable, with protective action initiated when any two of the three trip channels are tripped by any

* Atomic Energy Control Board, Regulatory Document R8, "Requirements for Shutdown Systems in CANDU Nuclear Plants," 1987.

Table A.2 Coverage of process failures by SDS1 and independently by SDS2

No.	Process failure	Trip parameter	Alternative trip parameter
1	Loss of regulation from high power		
	Fast	High rate neutron power	High neutron power/high heat transport pressure
	Slow	High neutron power	High heat transport pressure/manual ^a
2	Loss of regulation from decay power levels		
	Pressurized/pumps On	High rate neutron power	High heat transport pressure
	Fast	High heat transport pressure	High neutron power ^a /manual ^a
3	Slow		
	Pressurized/pumps Off	High rate neutron power	Low gross coolant flow ^{b,c}
	Fast	Low gross coolant/flow ^{b,c}	High heat transport pressure
4	Slow		
	Depressurized/pumps Off		
	Fast	High rate neutron power	High heat transport pressure ^{b,c} Low gross coolant flow ^{b,c}
5	Slow	Low gross coolant flow ^{b,c}	Low heat transport pressure ^{b,c} /manual ^a
	Depressurized/pumps On		
	Fast	High rate neutron power	Low heat transport pressure ^{b,c}
6	Slow	Low heat transport pressure ^{b,c}	Manual
	Loss of Class IV power	Low gross coolant flow ^b	High heat transport pressure
	Loss of coolant into containment		
7	Large	High rate neutron power	High neutron power/high reactor building pressure
8	Intermediate	High neutron power	High reactor building pressure
	Small		
	With regulation	High reactor building pressure	Low heat transport pressure ^b /low pressurized level
9	With regulation, pressurizer isolated	High reactor building pressure	Low heat transport pressure
	Without regulation	High reactor building pressure	High neutron power

Table A.2 (continued)

No.	Process failure	Trip parameter	Alternative trip parameter
10	Very small		
	With regulation	Low heat transport pressure ^b	Low pressurizer level/manual
	With regulation, pressurizer isolated	Low heat transport pressure ^b	Manual
	Without regulation	High neutron power	Manual ^a
11	Loss of coolant into calandria		
	With regulation	Low heat transport pressure ^b	Low pressurizer level/manual ^a
	With regulation, Pressurizer isolated	Low heat transport pressure ^b	Manual ^a
	Without regulation	High neutron power	Manual ^a
12	Secondary side failures		
	Steam main break with feed pumps on		
	Inside containment	High reactor building pressure	Low steam generator level ^a Low steam generator feedline pressure ^d Low steam transport pressure
	Outside containment	Low steam generator level	Low heat transport pressure ^a /low steam Generator feedline Pressure ^{a,e} /manual ^a
13	Steam main break with feed pumps off		
	Inside containment	High reactor building pressure	Low steam generator feedline pressure ^{a,e} /low steam generator level ^a
	Outside containment	Low steam generator feedline pressure ^{a,e}	Low steam generator level/high heat transport pressure ^a
	Feedline break upstream of check valves	Low steam generator feedline pressure ^{a,e}	Low steam generator level High heat transport pressure Manual
14	Downstream of check valves	High reactor building pressure	Low steam generator level/low steam generator Feedline pressure ^{a,e} /high heat transport pressure, ^{a,f} /manual ^{a,f}

Table A.2 (continued)

No.	Process failure	Trip parameter	Alternative trip parameter
15	Loss of feedwater control (e.g., closure of feedwater valves to a steam generator)	Low steam generator level	High heat transport pressure ^{a,f} /manual ^f
16	Feedwater pumps trip	Low steam generator level	High heat transport pressure ^{a,f} Low steam generator feedline pressure ^{a,e}

^aAlternative trip parameters that provide trip coverage over a limited range of event scale (e.g., break size).

^bThe low coolant flow and low HTS pressure trips are conditioned out on log power < 0.3%.

^cTrip acts as high power; trip in effect because it is increasing power; this instigates a trip by removing the conditioned-out state.

^dFeedline pressure may precede steam generator low level.

^eThe low steam generator feedline pressure trip is conditioned out when log power < 10%.

^fIf 4% feedwater flow is available after trip.

Source: Adapted from Ref. 1.

Table A.3 SDS1 trip parameters

No.	Trip parameter	Detector type
1	Neutron power	Vertical in-core detectors
2	Rate log neutron power	Ion chambers
3	HTS flow	Differential pressure transmitters
4	HTS pressure	Pressure transmitters
5	Reactor building pressure	Pressure transmitters
6	Pressurizer level	Differential pressure transmitters
7	Steam generator level	Differential pressure transmitters on both steam generators
8	Steam generator feedline pressure	Pressure transmitters on individual feedlines
9	Moderator level	Differential pressure transmitters

variable or combination of variables. This is referred to as "general" coincident logic, as opposed to "local" coincidence logic employed in the SDS2 design. (With "local," two of three signals for a given variable must trip to give a channel trip.) A single-loop component or power supply failure will not incapacitate or spuriously invoke the operation of the safety system.

As indicated in Table A.2, there are nine measured variables that can initiate a reactor trip through SDS1. The selection of variables is such that, to the maximum extent practicable, there are redundant sensing parameters for all

categories of process failures identified (Table A.2). The reactor trip can also be manually initiated by the operator. The nine measured variables are listed below.

1. Neutron power: Inconel in-core flux detectors are provided in each of three channels for overpower or loss-of-regulation protection. The detectors are located in the vertical in-core flux detector assemblies and are in guide tubes separate from any regulating system detectors. The detectors are of the straight individually replaceable type and are three lattice pitches long. A linear amplifier converts each detector current to a corresponding voltage signal. The voltage signals are processed in the trip computers to compensate for the overpromptness of the Inconel detector signal. After compensation, the output signal continues to lead the heat flux from fuel to coolant. Low pass filter compensation for SDS2, on the other hand, is greater such that the signal closely matches fuel to coolant heat flux. The purpose of this is to favor trips of SDS1 and avoid unnecessary trips of SDS2.
2. Rate of logarithmic neutron power: Six uncompensated ion chambers, located in separate housings on each side of the calandria (three on each side), are provided for SDS1. Each housing also contains a regulating system ion chamber, or startup instrumentation, and an SDS2 ion chamber in separate cavities within the housing, plus a test shutter.
3. HTS pressure: HTS pressure is measured at three widely separated locations on each side of the two reactor outlet headers. The pressure transmitters are mounted on channelized instrument racks. Regular loop testing is conducted from the main control room. Both high pressure and low pressure are used as trip signals.

These pressure transmitters also provide the signal for the heat transport liquid relief valves (LRVs). Two LRVs connect the HTS to the bleed condenser. Pushbuttons are located in the main control room to open these valves for testing. Individual indicators monitor valve status.

4. HTS flow: HTS flow is measured in a total of 14 feeders. Flow readings from seven feeders are used for SDS1, while the other seven readings are used for SDS2. The logic is arranged such that each trip channel has at least two measurements, one from each coolant pass. The trip is conditioned out automatically at very low power or shutdown conditions when coolant flow is much below normal.
5. Reactor building pressure: A triplicated measurement of the reactor building pressure is provided for SDS1. The equipment associated with each channel is mounted on instrument racks. Each set of racks is used for one channel only.

Reactor building pressure is normally held slightly negative with respect to atmospheric by the reactor building ventilation system. If the pressure rises above the set point, the reactor will be tripped by SDS1.
6. Steam generator level: The steam generator low level trip provides protection against secondary-side failures.
7. Pressurizer level: Low pressurizer level is a trip parameter effective for small LOCAs. The trip is conditioned out automatically at very low power levels to allow for draining the pressurizer during maintenance.
8. Steam generator feedline pressure: Each channel monitors the pressure in the two steam generator feedlines between the feedwater control valve and the steam generator. This trip parameter protects against secondary-side failures that could result in the loss of the steam generators as a heat sink.
9. Moderator level: Moderator level is a trip parameter effective for loss of moderator cooling and moderator pipe break accidents. A trip is given on both high and low moderator levels. The moderator level trip is the only one that is peculiar to SDS1.

Logic processing and testing. There are three independent channels, having completely independent and physically separated power supplies, trip parameter sensors, instrumentation, trip computers, and annunciation. When any two of the three channels trip, the shutoff rods are dropped.

The trip logic, trip testing, and display functions for both shutdown systems make use of trip computers, display/test computers, and CRT displays on the main control room and secondary control area panels and consoles. This technology has been used in Darlington, Nuclear Generating Station.

One trip computer per channel is used in each shutdown system. The trip computers replace all the analog compensators of the neutron overpower trip, all analog trip comparators, all programmable digital comparators, and relay logic used in previous designs. The final two-out-of-three voting will continue to be done using relays. The final two relay voting logic modules control two separate banks of clutch coils (12 rods each) as shown in Fig. A.12.

The trip network is monitored to provide a positive indication of the state of the trip logic, by verifying the correct operation of all contacts in the two-out-of-three networks when a channel is tested.

Equipment layout. The shutoff unit housings are located on the reactivity mechanism deck. This permits controlled access to the clutches, motors, potentiometers, gearboxes, and winches for removal or for maintenance one at a time.

Instrumentation. The detector types used in shutdown systems are as follows:

1. Displays: All the information required on the tripping parameters and the status and operation of the system can be displayed on CRTs in the main control room and in the secondary control area at the operator's command.
2. Power supplies: Separately channeled Group 2(a), Class I and Class II power supplies are provided for each channel of SDS1. The logic is arranged so that any loss of power to a channel results in a channel trip.

The dc clutches, operated from rectified, redundant Class II power, release on loss of power.

Channel power supplies are individually monitored, and any loss is annunciated. The power supplies to the neutron instrumentation and the process transmitters are arranged so that a trip occurs on a general loss of Class II power. Fuse failures or events causing loss of power to individual transmitters are annunciated. These individual power losses also result in an irrational signal to the trip computer and a subsequent channel trip.

ORNL-DWG 93-3214 ETD

(a) Typical logic for actuating shutoff rods

(b) Typical logic for actuating poison injection system

Figure A.12 Schematics of logic for actuating mechanical elements of shutdown systems

3. Annunciation: The status of all trip parameters is sent to the plant display system through a fiber-optic link for annunciation and event sequencing. During upset conditions, the time and sequence of various parameters exceeding their limits may be printed out on demand.

A.3.2 Shutdown System 2

SDS2 is the second system for quickly terminating fission power when certain parameters enter an unacceptable range. This occurs via the rapid injection of concentrated gadolinium nitrate solution into the moderator through horizontal nozzle assemblies. SDS2 employs a logic system with three independent channels that sense the requirement for shutdown and open fast-acting valves that release high-pressure helium to inject the gadolinium poison into the moderator.

This system incorporates design features to prevent unnecessary injections when the SDS1 has acted normally; however, there is no physical coupling between SDS1 and SDS2.

A.3.2.1 Functional Requirement

SDS2 is designed in compliance with AECB Regulatory Document R-8 "Requirements for Shutdown Systems for CANDU Nuclear Power Plants."* For purposes of assessing the performance of SDS2, the most effective nozzle is assumed out of action. The remaining injectors shall be of sufficient speed and negative reactivity to reduce the reactor power to levels consistent with available cooling for all process failures identified in Table A.2.

A.3.2.2 SDS2 System Description

Figure A.13 shows a simplified schematic diagram of SDS2.

A vessel containing high-pressure helium supplies the source of energy for rapid poison injection. The tank is connected, through six quick-opening valves arranged in three successive pairs, to a helium header that services the poison tanks. The quick-opening valves are air-to-close, spring-to-open so that they fail safe on loss of air supply or electrical power. The six cylindrical poison tanks are mounted on the outside wall of the reactor vault. Each of these poison tanks contains gadolinium nitrate solution. The nominal solution concentration is 8000 mg of

gadolinium per kilogram of D₂O and is verified by an on-line recirculating sampling system.

Each poison tank is connected by a stainless steel pipe to a horizontal in-core injection tube nozzle that spans the calandria and is immersed in the moderator. Six Zircaloy-2 nozzles penetrate the calandria horizontally and at right angles to the fuel channel tubes. Holes are drilled into the nozzle along its length to form four rows of jets, which permit complete dispersion of the poison into the moderator.

There is a liquid-to-liquid interface between the poison solution and the moderator, as shown in Fig. A.13. Movement of the interface is caused by the poison very slowly migrating by diffusion from an area of high concentration to an area of low concentration. Also, physical motion of the liquid back and forth in the line causes a small amount of mixing of the poison solution with the moderator. This motion is caused by variations in the moderator level.

Two conductivity probes are installed in the poison injection line downstream of each poison tank. One is located close to the bottom of the poison tank to monitor the poison concentration and alarm on low poison concentration. The second probe is located close to the bellows assembly of the shield tank to detect when poison solution reaches the downstream top of the U-section. Upon alarm from any of the latter probes, the associated poison injection line must be backflushed to pull the poison interface back to the ball valve.

Each poison tank contains a floating polyethylene ball that seats at the top of the poison tank before injection to restrict the movement of poison upward due to variations in moderator level. When an injection is initiated, the helium gas pressure transfers the poison to the calandria, and the ball falls to the tank bottom. In the bottom position, the ball seats at the poison tank outlet and prevents the release of high-pressure helium to the calandria.

Each poison tank can be isolated by manual isolating valves located in the gas and poison legs to permit maintenance and testing on a poison tank without disabling the shutdown system. The operator is warned by alarm if valve closure occurs on more than one poison tank.

Measurements are made of helium makeup supply pressure, helium supply tank pressure (by two different methods), injection tank level, and injection tank ball

*Atomic Energy Control Board, Regulatory Document R8, "Requirements for Shutdown Systems in CANDU Nuclear Plants," 1987.

CANDU 3

Figure A.13 Schematic diagram of liquid injection system used for SDS2

location. Deviation from specified limits by any measurement initiates an alarm in the main control room. Limit switches are provided on each of the six quick-opening valves, three vent valves, and helium makeup valve at the closed and opened positions.

A.3.2.3 Equipment Layout

The quick-opening valves and poison tanks are located outside the reactor vault, where they are accessible during reactor operation. The poison tanks are situated at the vault wall to minimize injection time.

The ball valves in the poison injection line are inside the reactor vault to minimize the time for the poison to reach the calandria. The drain valves are adjacent to these ball valves to ensure the poison interface is at the ball valve after backflushing. Hence, these ball valves and drain valves have extended spindles to allow operation from the outside of the vault wall.

The ion chambers and in-core detectors for SDS2 are horizontally mounted, and their cables are routed separately from those of SDS1.

The cubicles containing the trip computers and relay logic for each channel are located in a Group 2 control equipment area (adjacent to the secondary control area). (This control equipment area is separated from the control equipment area for SDS1.) Because local coincidence is used, there are cross-connections among the three channel trip computers.

A section of the safety systems panels and console in the main control room is allocated solely to SDS2. The SDS2 alarm windows are on a vertical panel, while the trip test and channel select switches, display CRTs, and the manual trip buttons for SDS2 are mounted on the console. These are connected to the SDS2 trip and display computers in the secondary control area by channelized fiber-optic data links.

A.3.2.4 Reactor and Process Measurements

The design philosophy is based on triplicating the measurement of each variable and initiating protective action when any two of the three trip channels are tripped by the same variable (i.e., local coincidence logic). A single-loop component or power supply failure will not incapacitate or spuriously invoke the operation of the safety system.

Eight measured parameters can initiate a reactor SDS2, as shown in Table A.4. These are the same parameters that initiate SDS1, except for moderator level. The selection of parameters is such that, where practicable, there are redundant sensing parameters for all categories of process failures identified. The system can also be manually tripped by the operator from the main control room or the secondary control area.

- Displays: All the information required on the tripping parameters and the status and operation of the system can be displayed on CRTs in the main control room and the secondary control area, at the operator's command.
- Power supplies: Separately channeled Group 2(b) Class I and Class II power supplies are connected to each of the SDS2 channels. The logic and instrumentation have been designed so that a channel trips on loss of power.

Table A.4 SDS2 trip parameters and detectors used

Trip parameter	Detector type
Neutron power	Horizontal in-core detectors
Rate log neutron power	Ion chambers
HTS flow	Differential pressure transmitter
HTS pressure	Pressure transmitter
Reactor building pressure	Pressure transmitter
Pressurizer level	Differential pressure transmitter
Steam generator level	Differential pressure transmitter on both steam generators
Steam generator feedline pressure	Pressure transmitter on individual feedlines

A.3.2.5 Logic Processing

There are three independent channels, separate from the three used for SDS1. Local coincidence is used, that is, two out of three channels indicating a trip for the same parameter will initiate poison injection. The combination of a channel trip for one parameter combined with a different channel tripped for another variable will not initiate a poison injection. A six-helium valve configuration ensures a very simple and reliable design. (See Fig. A.12.)

Appendix A

There are three alternate helium paths, each with injection valves and an interspace vent valve. Special logic prevents the testing of two different valve pairs within 10 min of each other. This ensures that the interspace between the helium injection valves is depressurized, and it prevents spurious partial injections.

SDS2 has computerization of the trip logic, system testing, and monitoring and display functions. Implementation is the same as for SDS1. The reactor may not be operated at power if SDS2 is unavailable. Interlocks are provided as follows for interface with other systems.

A.3.3 Emergency Core Cooling System

A.3.3.1 System Functional Requirements

The ECCS is designed in accordance with the requirements outlined in AECB Regulatory Document R-9.*

1. Cooling requirements: The system must be designed to maintain or re-establish sufficient cooling of the fuel and fuel channels for all LOCA specified in Tables 1 and 2 of Document R-9 to prevent fuel failure or limit the release of fission products from the fuel and to maintain fuel channel integrity.
2. Environmental Requirements: Emergency core cooling equipment, required to operate or continue operating following exposure to severe environmental conditions following a loss of coolant, must be environmentally qualified to withstand the worst of these conditions.
3. Unavailability requirements: The system must be designed to meet the unavailability target of 10^{-3} year/year (<9 h/year). Each component of the system and subsystems will be monitored and/or tested on-power to demonstrate that this target is met. Calculations will be used to verify that the system unavailability target is met. Valves located inside containment will be accessible to permit testing and maintenance during normal reactor operation.

The design of the system must take into account the long-term reliability of those components that must continue to function during the long-term recirculation mode.

Redundancy must be provided such that failure of any single component in the system will not impair the system to the extent that it will not meet its minimum allowable performance requirements.

4. Seismic requirements: Equipment/components in the system and subsystems needed to maintain cooling of the fuel must be designed to withstand an earthquake of site design earthquake intensity.
5. Tornado requirements: A loss of coolant is not postulated during or following a tornado, and as a result the ECCS is not required to withstand a tornado.
6. Separation and independence requirements: The ECCS must be physically and operationally independent from other systems, except for those that are required to assist in the system operation.

The layout of the system is such that failure of piping in another system or in the ECCS will not impair the rest of the system.
7. Penetration requirements: The system piping penetrating containment must comply with the requirements of AECB Regulatory Document R-7.†
8. Leakage control requirements: Components/equipment in the system outside containment must be enclosed such that any leakage that may occur during the long-term recovery mode can be controlled.
9. Shielding requirements: Shielding must be provided for equipment located outside the reactor building to allow operator access to adjacent areas during the ECCS operation in the recovery mode.

A.3.3.2 Summary Description

The ECCS supplies emergency coolant to the reactor headers in the event of a LOCA.

The system operation is divided into two parts: short-term injection and long-term recirculation. Short-term injection consists of two stages: high- and low-pressure injection. During the high-pressure injection (HPI) stage, water from the accumulator tanks is injected into the HTS by pressurized gas. As this water is depleted, low-pressure injection (LPI) automatically takes over, injecting water from a grade level tank via the emergency core cooling pumps. The water level in the grade level tank is continuously monitored via triplicated level measurements. A connection is provided to this tank for demineralized water makeup and for initial filling.

When this water supply is depleted, the long-term operation automatically begins by recirculating a mixture

*Atomic Energy Control Board, Regulatory Document R9, "Requirements for Emergency Core Cooling System in CANDU Nuclear Plants," 1987.

†Atomic Energy Control Board, Regulatory Document R7, "Requirements for Containment Systems for CANDU Nuclear Power Plants," 1987.

of H₂O and D₂O from the reactor building sump back into the HTS via the heat exchangers and pumps.

The ECCS is triggered when the HTS pressure drops to a predetermined value and any one of the emergency core cooling conditioning signals is activated. Figure A.14 is a schematic diagram of the ECCS.

System components

1. **Accumulator water tanks:** The water tanks are normally isolated from the upstream gas tank by gas isolation valves and on the downstream side by the HPI valves. Because the water in the accumulator tanks is normally stagnant, facilities for chemical control are provided.
2. **Accumulator gas tank:** The tank is cylindrical with hemispherical heads. Pressurized gas stored in this tank is used to inject water from the water tanks into the HTS following a loss of coolant. An air compressor, backed up by a compressed nitrogen supply, maintains the gas tank pressure.
3. **Grade level tank:** This tank is maintained at atmospheric pressure and is insulated. The stored water is maintained at about 21°C by recirculating water through an external electric heater, if required in winter. Chemical addition is provided to minimize corrosion.
4. **Emergency core cooling pumps:** Two 100% duty pumps, energized from Group 2 Class III buses, ensure long-term reliability and postdesign-basis-earthquake operation. Instrumentation is supplied to detect failure of the operating pump and to automatically start the standby pump.
5. **Heat exchangers:** Two 100% plate-type heat exchangers in the recovery pump discharge line maintain the coolant flow at or below 60°C at the entry to the HTS. The temperature at the pumps is ~70°C when first pumping the mixture of D₂O and H₂O from the reactor building.

The heat exchangers remove residual and decay heat from the coolant. To ensure long-term reliability and operation of the ECCS after a site design earthquake, the cooling water to the heat exchanger, normally supplied by the recirculated cooling water system, is backed up by the seismically qualified Group 2 raw service water system.

6. **Valves:** Redundant valves, in parallel, are provided wherever power-operated valves are required to open for system operation. Most valves are provided with electric actuators which fail "as is."

Instrumentation and control. The ECCS is controlled by dedicated computers that perform the initiation, monitoring, display, and testing functions.

Each signal essential for system operation is triplicated so that a single-signal loop component or power supply failure does not incapacitate or spuriously invoke the operation of the system. Triplication includes isolation between loops of the three channels and the use of unique transmitter mounting racks, electrical cubicles, initiation computers, and power supplies for each channel.

The logic used with the three channels is such that a trip of any two channels in the heat transport pressure monitoring loops in conjunction with any two-out-of-three conditioning signal trips will generate the LOCA signal (LOCS). Both the break-size-dependent and break-location-dependent LOCA mitigation features in the early design described in the CSR¹ have been eliminated.* Emergency core coolant is applied uniformly to both the reactor inlet and outlet headers for any LOCA signal.*

Electrical supply to valves. The controls and power supplies for each valve of a pair of valves are separate and independent. They are referred to as the "odd" and "even" circuits.

All electrical valves required to operate to allow HPI from the accumulator tanks are supplied from Group 2, Class II power. Those required to operate for LPI from grade level tank and the long-term recirculation phase are supplied from Group 2, Class III power.

A.3.3.3 System Operation

General. The ECCS does not operate during normal reactor operation but remains fully poised to be activated on a LOCA.

Following a LOCA, the HTS pressure drops, the pressurizer level is depleted, the pressure inside the reactor building rises, and the shutdown systems initiate a reactor trip.

Blowdown. Following a loss of coolant, the heat transport pressure drops at a rate dependent on the size of the break. The time from the loss of coolant until the heat transport

* Atomic Energy of Canada, Limited, Technologies, Rockville, Maryland, personal communication to Oak Ridge National Laboratory Staff, March 10, 1992.

CANDU 3

Figure A.14 ECCS

pressure reaches the injection pressure is known as the blowdown period.

For large-size breaks, fuel cooling may or may not be maintained depending on the break size and location. For small breaks, the initial ECCS injection pressure is such that fuel cooling is maintained during blowdown. Therefore, the purpose of injection is to restore cooling for large breaks and maintain cooling for small breaks.

Emergency core cooling initiation. The ECCS is initiated on an LOCS. To generate this signal, the HTS pressure has to fall to a predetermined value, and one of the conditioning variables (high reactor building pressure or low pressurizer level) has to be activated. A low pressurizer level signal is used as a conditioning variable for detection of a small loss of coolant. The conditioning signals are provided to prevent spurious operation of the system.

The LOCS alone will initiate ECI. However, the scram signal comes first; the LOCS is a separate signal that comes later.

The system logic performs the following functions:

- opens the gas isolation valves, the HPI valves, and D₂O isolation valves;
- starts one of the emergency core cooling pumps;
- opens the grade level tank isolation valves;
- starts the Group 2 Class III diesels;
- opens the MSSVs; and
- trips the heat transport pumps.

In addition to these, a separate signal for steam generator crash cooldown, independent of the ECCS, is provided.

The rupture disks in the ECCS burst when the gas isolation and HPI valves open. Flow into the primary circuit begins when the HTS pressure falls below the high-pressure emergency core coolant injection pressure.

For large breaks, rapid ("crash") steam generator cooldown is effected to reduce the transfer of heat from the steam generator secondary side to the primary coolant. In the steady-state emergency core cooling period, the steam generators provide a long-term heat sink for "small" breaks. This is achieved by opening the MSSVs. Water to

the steam generators is supplied by the feedwater system, backed up by the Group 2 feedwater system (FW2).

During the full sequence of emergency core cooling operation, decay heat removal is by transfer of heat to the steam generators or by discharge of fluid through the break. The latter mode predominates for the large breaks. The former mode predominates for small breaks.

Short-term emergency core cooling. The water injected from the accumulator tanks under pressure is directed via the reactor headers to the fuel channels to refill the core. On low water level in the accumulator tanks, the HPI valves are closed to prevent air from being entrained into the HTS.

While HPI from the accumulator tanks is under way, one of the two emergency core cooling pumps is recirculating water via the bypass loop. If one pump fails to start (indicated by a low pump differential pressure), the standby pump starts automatically. The flow of emergency core coolant from the grade level tank via the emergency core cooling pumps begins when the pressure downstream of the check valves falls below the pressure generated by the pumps.

Long-term emergency core cooling operations. The low-pressure operation starts following the short-term injection reactor building sump stage. A triplicated, high-level signal in the reactor building sump or a triplicated low-level signal in the ECCS grade level tank initiates opening of the cooling water valves to the emergency core cooling heat exchanger and the recovery line isolation valves to the reactor building sump. The low-level signal in the grade level tank closes the valves in the pump suction line from the tank. The mixture of the heat transport coolant and water from the emergency core cooling tanks collected on the floor and sump of the reactor building is then returned to the HTS by the emergency core cooling pumps. For large breaks, decay heat is removed from the core via the coolant discharged from the break, and this heat is transferred to the recirculated cooling water (or the Group 2 raw service water as a backup) via the heat exchanger.

For small breaks, decay heat is transferred to the steam generators and rejected via the MSSVs. These valves have a total capacity of over 100% steam flow at normal steam generator pressure.

The steam generator feedwater supply during operation after a loss of coolant is provided by the main feedwater

Appendix A

pumps on Class IV power or by the auxiliary feed pump, which draws water from the deaerator and the demineralized water storage tank. An alternative source of feedwater to the steam generators is provided by the FW2. The feedwater to the steam generators is required during the long-term emergency core cooling operation following a small break.

A.3.4 Containment System

A.3.4.1 System Functional Requirements

The basic function of the containment system is to form a continuous, pressure-confining envelope about the reactor core and HTS to limit the release of radioactive material resulting from an accident to the external environment. This accident could be either a failure of fuel cooling or an accident that releases radioactive material into the containment without a rise in containment internal pressure.

To achieve this overall function, the containment system must include the following related safety functions:

1. Isolation: to ensure closure of all openings in containment when an accident occurs.
2. Pressure/activity reduction: to control and assist in reducing the internal pressure and free radioactive material released into containment by an accident.
3. Hydrogen control: to limit concentrations of hydrogen/deuterium within containment after an accident to prevent detonation or deflagration.
4. Monitoring: to monitor conditions within containment and the status of containment equipment before, during, and after an accident.

In addition to its safety role, the containment structure also serves the following functions:

1. To limit the release of radioactive materials from the reactor to the environment during normal operations.
2. To provide external shielding against radiation sources within containment during normal operations and after an accident.
3. To protect reactor systems against external events such as tornados, floods, etc.

A.3.4.2 Design Basis

The containment system complies with AECB Regulatory Document R-7, "Requirements for Containment Systems

for CANDU Nuclear Power Plants."* The design pressure for the containment is the maximum building pressure resulting from any failure of the HTS coupled with unavailability of the most effective active pressure reduction system.

The containment design pressure may be exceeded during a secondary-side failure (e.g., a main steam-main break), provided that no structural damage to containment (cracking) results.

The maximum leakage rate (used in safety analyses) is 5% of containment free volume per day at the design pressure. The containment is designed for a test-acceptance leakage rate of 2%/d at the design pressure.

The containment is designed for an unavailability of not more than 10^{-3} year/year (<9 h/year).

Test facilities and procedures are provided to confirm that the containment system (including required safety support systems) operates when required and to demonstrate the reliability of the system.

The containment envelope, including the containment isolation devices, for example, in the reactor building ventilation system, is seismically qualified for a design basis earthquake.

Control measures are included to limit hydrogen/deuterium content within any significant enclosed subvolume of containment following an accident to below the deflagration limit.

A.3.4.3 System Description

The containment system includes a reinforced concrete containment structure (the reactor building) with a reinforced concrete dome and an internal steel liner, access airlocks, equipment hatch, building air coolers for pressure reduction, hydrogen deflagration system,[†] and a containment isolation system consisting of valves or dampers in the ventilation ducts and certain process lines penetrating the containment envelope. The containment envelope

* Atomic Energy Control Board, Regulatory Document R7, "Requirements for Containment Systems for CANDU Nuclear Power Plants," 1987.

[†] Atomic Energy of Canada, Limited, Technologies, Rockville, Maryland, personal communication to Oak Ridge National Laboratory Staff, March 10, 1992.

consists of the building structure, piping and ducts, and airlocks and a hatch (see Fig. A.15).

Containment components and subsystems. The containment system comprises the following structures, components, and subsystems:

1. A reinforced concrete containment structure, 1.2 m thick, with a reinforced concrete dome and base slab, with a 6-mm steel liner covering the inside of the concrete walls, dome, and base slab.
2. Steel pipe and ducting, forming part of the containment boundary where they penetrate containment.
3. Piping and cable penetrations, which provide an engineered seal at the point where piping, ducting, and electric cables penetrate containment.
4. Containment isolation: Dual valves or dampers on process penetrations that are automatically closed on high containment pressure or activity within containment.
5. Airlock, emergency airlock, and equipment hatch.
6. Reactor building air coolers: The air coolers operate during normal plant operation to cool the building and maintain a suitable environment for personnel working within the reactor building. The air coolers are also used to cool the reactor building atmosphere, condense released steam, and thereby reduce containment internal pressure following a failure of the HTS or steam system within containment.

By promoting steam condensation, the air coolers also act to remove soluble radioactive material (except noble gases) from the containment atmosphere and to sweep hydrogen/deuterium buildups from the reactor vault following an accident.

The air coolers operate on Group 1 power and cooling, and because they are not needed more than 24 h after an accident, are not required to be seismically qualified.

The design basis for the building air coolers is established by normal operational heat loads and postaccident heat removal requirements.

In addition to handling air flow under normal operational conditions, the fan motors for building air coolers operating on Class III power are also rated to handle continuously the steam/water/air mixture and the temperature existing at the design value of overpressure under accident conditions.

7. Hydrogen igniters: Located at the bottom of the steam generators box and in the upper part of the reactor building, to ensure that hydrogen/deuterium releases are ignited at low concentrations (about 6%), thus ensuring that concentrations sufficient for a detonation or deflagration do not occur.

Instrumentation and monitoring. Containment has the following instrumentation and monitoring capabilities:

1. Containment isolation:
 - Pressure and activity measurements (triplicated) required to initiate isolation.
 - Status and testing indications on all isolation devices, and airlock seals and doors.
2. Gross leakage monitoring: Measurements of building temperatures, pressure, humidities, and inflows/outflows (plus related computation).
3. Containment systems: Status of and controls over containment subsystems and equipment such as air coolers, hydrogen igniters, etc.
4. Postaccident monitoring: Qualified instrumentation for monitoring containment pressures, temperatures, radioactivity, and hydrogen content before, during, and after an accident.

Associated systems. The reactor building vapor recovery system and ventilation system control the reactor building humidity and airborne activity at low levels during normal operations. They also would be used for long-term postaccident cleanup and plant rehabilitation.

However, these systems are not required to mitigate or limit the consequences of any accident and are not part of the containment system.

A.3.4.4 Operating Modes

Normal operating conditions. Containment ventilation dampers are all normally open. The pressure within containment is slightly less than atmospheric pressure, with small pressure variations because of operation of the vapor recovery system and pressure balancing within the reactor building.

Off-normal conditions. For extremely small HTS leaks, the vapor recovery system removes moisture, but the relative humidity (dewpoint) may rise slightly.

For very small HTS leaks, the building coolers condense the steam. Building air temperatures may rise slightly.

CANDU 3

Figure A.15 Reactor containment system

For larger breaks, building coolers are insufficient to reduce the building pressure following steam ingress. The pressure rises and, at a set overpressure, containment pressure sensors initiate containment closure. Other sensors associated with the reactor cause a reactor trip. The containment is also automatically isolated in the event of a high radioactivity signal, which may or may not occur following a LOCA.

Following a reactor trip, energy is to be removed from the HTS and from within the reactor building by the steam generators, or the shutdown cooling heat exchangers, or the emergency core cooling heat exchangers, depending on the size of the break and the time after shutdown. The reactor building pressure rises to a peak, which depends on the location and size of break. Subsequent pressure reduction is due to condensation on the walls, plus cooling provided by the air coolers.

Initial containment atmosphere cleanup can be performed by the D₂O vapor recovery dryers. In the long term, the containment envelope may be vented to the atmosphere through the dryers and the reactor building ventilation system filter train.

The D₂O vapor recovery system can be operated at building overpressures up to the containment design pressure. Discharge through the ventilation system filter

train is restricted to near-atmospheric pressure conditions and is a postaccident rehabilitative function.

A.4 Summary of CANDU 3 Design Overview

The material in this chapter was obtained directly from the CSR¹ and the Technical Outline.² The depth involved in this condensation was deemed to be sufficient to orient the reader with regard to CANDU 3 design, particularly as it differs from standard U.S. LWR practice, and should be adequate to allow understanding of the rest of this report. However, the reader interested in more details is referred to the original sources.

References

1. Atomic Energy of Canada, Limited, "CANDU 3 Conceptual Safety Report," Vols. 1 and 2, 1989.*
2. Atomic Energy of Canada, Limited, "The CANDU 3 Technical Outline," Rev. 11, June 1992.*

* Available in NRC PDR for inspection and copying for a fee.

Appendix B

System Cut Set Results

B.1 Presentation of System Cut Set Results

This section presents the cut sets developed for each system in the analysis. The fault trees were analyzed and the results produced using the Integrated Reliability and Risk Analysis System (IRRAS) Version 4.0 (Ref. 1). Some of the system models are complex and result in a large number of cut sets. In these cases, the reports have been shortened to show only those cut sets with three or less failures. The system results are presented in the same order as in Chap. 5. Table B.1 presents a legend for identifying the equipment represented by the basic event designators. Table B.2 presents the system cut set results.

B.2 Discussion of System Cut Set Results

The fault tree analysis identifies potential failure mechanisms in the systems used to mitigate accident scenarios. The fault trees were constructed using the available information, and they reflect the analyst's understanding of how the systems are intended to function. This section presents a discussion of important results from the fault tree analysis.

B.2.1 Reactor Regulating System

The reactor regulating system (RRS) controls reactor power fluctuations during normal reactor power operations. Three potential single failures were identified for the RRS. These included potential failure of the operator to initiate RRS, possible mechanical binding of the RRS control absorbers, and possible failure of the absorber coils to release.

B.2.2 Shutdown System 1

Shutdown System 1 (SDS1) is a special safety system that requires a reliability of 1×10^{-3} with no single failures. The fault tree model resulted in two potential single failures identified. These potential single failures involve mechanical binding of shut-off rods or failure of rod coils to release. There would have to be a failure of at least three rods or coils since the system is designed for success even if the two most effective rods are unavailable. Failures of this sort would most likely be common-mode failures.

B.2.3 Shutdown System 2

Shutdown System 2 (SDS2) is also a special safety system. For SDS2, no potential single point failures were identified.

B.2.4 Moderator Liquid Poison

The moderator liquid poison system (MLP) is used in failure to shutdown (FTSD) sequences. The MLP for the most part is a passive gravity-fed system. All identified potential MLP failures were single failures, including failure of the operator to actuate the system.

B.2.5 Group 1 Feedwater System

No single failure mechanisms were identified for the Group 1 feedwater system (FW1). FW1 does depend on plant air; if plant air is lost and not restored within 1.5 h, the FW1 boiler level control valves will fail closed.

B.2.6 Group 2 Feedwater

No potential single failure mechanisms were identified for the Group 2 feedwater system (FW2). Except for failure of the plant control system (PCS) to supply an initiation signal to FW2, all FW2 failures required at least two component failures. A potential operator failure to supply makeup water to the supply tank, coupled with a tank level indicator failure, could disable FW2. The supply tank has a 10-h supply and therefore must be refilled when the tank is emptied.

B.2.7 Auxiliary Feedwater

The auxiliary feedwater system (AFW) is a very simple system consisting of a diesel-driven pump and a discharge valve. Three potential single failures were identified for the AFW. These include pump failure due to loss of diesel power, mechanical pump failure, and failure of the AFW discharge valve to open.

B.2.8 Heat Transport System

The heat transport system (HTS) fault tree is only used in this report for large-break loss-of-coolant analyses. The present HTS design includes four HTS pumps, each of which feeds one-fourth of the CANDU 3 fuel channels. Mechanical failure of any of these pumps would constitute a single failure, since insufficient cooling of one-fourth of

Appendix B

the fuel channels would occur. HTS pump failure could also occur due to loss of Class IV power (LOP).

B.2.9 Condenser Steam Discharge Valves

The primary observation for the condenser steam discharge valves (CSDs) is that they require plant air to operate. The CSDs could also fail if the plant control system, which would send the signals to actuate the valves, fails. No single point failures were identified for the CSDs.

B.2.10 Atmospheric Steam Discharge Valves

The atmospheric steam discharge valves (ASDs) are used to remove heat from the main steam system when the condenser is not available. The comments made above for the CSDs hold for the ASDs. Failure of plant air, then, represents a potential common-mode failure mechanism for the ASDs and CSDs.

B.2.11 Shutdown Cooling System

The shutdown cooling system (SDC) is a manually initiated system. Human error to initiate the system was the main contributor to potential SDC failure. It should be recognized, however, that SDC initiation is expected to be a well-rehearsed event.

B.2.12 Moderator Cooling System

The moderator cooling system (MCS) is used as the last line of defense for heat removal from the CANDU 3 fuel channels. The MCS fault tree analysis identified three potential single failures and three potential system-related failures. The single failures are failure of the MCS isolation valve to close and failure of either of the MCS pumps. The system failures are failure of even or odd Group 1 Class III power or failure of the recirculating cooling water (RCW).

B.2.13 Emergency Core Cooling System

The overall emergency core cooling system (ECCS) [high-pressure injection (HPI), low-pressure injection (LPI), and ECC recirculation (REC)] is a special safety system and therefore requires a reliability of 1×10^{-3} with no single failures. The fault tree analysis identified no potential single point failures for HPI, LPI, and REC. All other ECCS cut sets involve either ECCS signal failure or potential failures of at least two pieces of equipment.

B.2.14 Bleed Condenser System

The fault tree analysis for bleed condenser system (BCS) suggests that the support systems are an important contributor to failure to bottle the bleed condenser. The D₂O tank level control valve and one of the two bleed condenser level control valves are assumed to be supplied from Group 1 Class II power. Therefore, electric power support could result in a failure to isolate the bleed condenser. Loss of signal from the PCS could also directly result in BCS failure.

B.2.15 Steam Generator Isolation

The fault tree analysis for steam generator isolation (ISO) suggests three potential single failures and two potential system failure mechanisms. The potential single failures include failure of the operator to isolate the flow, isolation valve signal failure, and failure of the isolation valve to close. The isolation valve is air-operated and fails open on loss of air or Group 2 Class I power.

B.2.16 Liquid Relief Valve Closure

The fault tree analysis identified two potential single failures and three system failures that influence liquid relief valve closure (LRC). Both liquid relief valves must close to avoid losing inventory from the primary system. Mechanical failure of either of the valves would result in LRC failure. These valves also require air and Group 2 Class I power for closure. This means that failure of the air system or loss of Group 2 Class I power would result in failure of the LRC. Finally, LRC failure could result from loss of signal from the PCS.

B.2.17 Crash Cooling

No potential single failure mechanisms were identified for the crash cooling (CC) system. Support system failures that could lead to CC failure are failure of plant air, failure of Group 2 Class II power, and failure of main steam safety valves (MSSVs) to receive an initiation signal from the ECCS.

B.2.18 Main Steam Safety Valves

The fault tree analysis did not identify any potential single failure mechanisms for the main steam safety valves (MSSVs). All cut sets involved failure of pairs of MSSVs.

B.2.19 Emergency Generators

The diesel generators were not modeled in detail since little information was available regarding the diesel generator design.

Reference

1. K. D. Russell et al., Idaho National Engineering Laboratory, *Integrated Reliability and Risk Analysis System*, USNRC Report NUREG/CR-5813, ID 83415, January 1992.*

* Available from National Technical Information Service, Springfield, VA 22161.

Table B.1 Basic event designator descriptions

<u>Code</u>	<u>Code description</u>
<u>Systems</u>	
F-	front-line systems
F-AFW	auxiliary feedwater system
F-BCS	bleed condenser isolation
F-CON	steam dump
F-D2O	D ₂ O makeup system
F-FW1	group 1 feedwater system
F-FW2	group 2 feedwater system
F-GEN	backup diesel generator power
F-HPI	high-pressure injection mode of ECCS
F-HTS	heat transport system
F-LPI	low-pressure injection mode of ECCS
F-LRC	liquid relief valves close
F-LRO	liquid relief valves open
F-MCS	moderator cooling system
F-MLP	moderator liquid poison system
F-MSV	main steam safety valves
F-REC	recirculation mode of ECCS
F-RRS	reactor regulating system
F-SD1	shutdown system 1
F-SD2	shutdown system 2
F-SDC	shutdown cooling system
S-	support systems
S-ECC	ECCS control system
S-EL	electric power systems
S-FIW	fire water system
S-AIR	plant air system
S-PCS	plant control system
S-RCW	recirculated cooling water system
S-RSW	group 1 raw service water system
S-SW2	group 2 raw service water system

Components

ASA	alternate sensor A
ASB	alternate sensor B
ATA	alternate transmitter A
ATB	alternate transmitter B
CI	conductivity indicator
CR	control rod (shutdown rod)
DIESEL	diesel motor
FV	flow valve

Table B.1 (cont.)

Components

ASD#	atmospheric steam discharge valve (with designator)
BV	bypass valve
CNV	control or regulating valve
CV	check valve
D2LV	D ₂ O level control valve
DISV	discharge valve
DV	drain valve
HE	human error (operator error)
HX#	heat exchanger (with designator)
IISV	inlet isolation valve
INV	injection valve
ISV#	isolation valve (with designator)
IV	inlet valve
LA	level alarm
LI	level indicator
MSSV#	main steam safety valve (with designator)
OISV	outlet isolation valve
OV	outlet valve
PI	pressure indicator
PIPE	pipe or header
PMP#	pump (with designator)
PS	primary sensor
PT	primary transmitter
PT#	poison tank (with designator)
REL#	relay (with designator)
RESPWR	onsite power restored
RSS	recirculating sampling system
SDV#	steam discharge valve (with designator)
SIG	signal fault
SIG-LP-HTS	low pressure in heat transport system signal
SIG-HP-RBL	high pressure in reactor building signal
SIG-LI-PSZ	low level in pressurizer signal
SIG-SD2	SDS2 initiation signal
SIG-SGP	high steam generator pressure signal
SG#	steam generator (with designator)
SV	suction valve
TC	trip computer
TL	trip logic
TK	tank
V# or VLV#	valve (with designator)
VV#	vent valve (with designator)

Table B.1 (cont.)

Failure modes

BD	mechanical binding
BR or BK	break or rupture
CG	clog (flow restriction)
CM	common mode
COIL	coil fails to release
CONC	improper concentration
FC	fails closed (fails to open)
FO	fails open (fails to close)
LEVEL	improper level

Function

CI	coolant injection (high-pressure ECCS)
GI	gas injection (high-pressure ECCS)

Electric power designator

I	Class I
II	Class II
III	Class III
IV	Class IV
1	Group 1
2	Group 2
O	Odd bus
E	Even bus

Table B.2 System cut set results

System: RRS

Cut No.	Size	CUT SETS
1	1	F-RRS-HE
2	1	F-RRS-CR-BD
3	1	F-RRS-CR-COIL
4	2	F-RRS-O, F-RRS-E

System: SD1

Cut No.	Size	CUT SETS
1	1	F-SD1-CR-BD-CM
2	1	F-SD1-CR-COIL-CM
3	2	F-SD1-TC-D, F-SD1-TC-E
4	2	F-SD1-TC-D, F-SD1-TC-F
5	2	F-SD1-TC-E, F-SD1-TC-F
6	2	F-SD1-TLA-REL1, F-SD1-TLA-REL2
7	2	F-SD1-TLA-REL1, F-SD1-TLA-REL3
8	2	F-SD1-TLA-REL2, F-SD1-TLA-REL3
9	2	F-SD1-TLB-REL1, F-SD1-TLB-REL2
10	2	F-SD1-TLB-REL1, F-SD1-TLB-REL3
11	2	F-SD1-TLB-REL2, F-SD1-TLB-REL3

System: SD2

Cut No.	Size	CUT SETS
1	2	F-SD2-ISV1-PT1, F-SD2-ISV1-PT2
2	2	F-SD2-ISV1-PT1, F-SD2-ISV1-PT3
3	2	F-SD2-ISV1-PT1, F-SD2-ISV1-PT4
4	2	F-SD2-ISV1-PT1, F-SD2-ISV1-PT5
5	2	F-SD2-ISV1-PT1, F-SD2-ISV1-PT6
6	2	F-SD2-ISV1-PT1, F-SD2-ISV2-PT2
7	2	F-SD2-ISV1-PT1, F-SD2-ISV2-PT3
8	2	F-SD2-ISV1-PT1, F-SD2-ISV2-PT4
9	2	F-SD2-ISV1-PT1, F-SD2-ISV2-PT5

Table B.2 (cont.)

10	2	F-SD2-ISV1-PT1, F-SD2-ISV2-PT6
11	2	F-SD2-ISV1-PT2, F-SD2-ISV1-PT3
12	2	F-SD2-ISV1-PT2, F-SD2-ISV1-PT4
13	2	F-SD2-ISV1-PT2, F-SD2-ISV1-PT5
14	2	F-SD2-ISV1-PT2, F-SD2-ISV1-PT6
15	2	F-SD2-ISV1-PT2, F-SD2-ISV2-PT1
16	2	F-SD2-ISV1-PT2, F-SD2-ISV2-PT3
17	2	F-SD2-ISV1-PT2, F-SD2-ISV2-PT4
18	2	F-SD2-ISV1-PT2, F-SD2-ISV2-PT5
19	2	F-SD2-ISV1-PT2, F-SD2-ISV2-PT6
20	2	F-SD2-ISV1-PT3, F-SD2-ISV1-PT4
21	2	F-SD2-ISV1-PT3, F-SD2-ISV1-PT5
22	2	F-SD2-ISV1-PT3, F-SD2-ISV1-PT6
23	2	F-SD2-ISV1-PT3, F-SD2-ISV2-PT1
24	2	F-SD2-ISV1-PT3, F-SD2-ISV2-PT2
25	2	F-SD2-ISV1-PT3, F-SD2-ISV2-PT4
26	2	F-SD2-ISV1-PT3, F-SD2-ISV2-PT5
27	2	F-SD2-ISV1-PT3, F-SD2-ISV2-PT6
28	2	F-SD2-ISV1-PT4, F-SD2-ISV1-PT5
29	2	F-SD2-ISV1-PT4, F-SD2-ISV1-PT6
30	2	F-SD2-ISV1-PT4, F-SD2-ISV2-PT1
31	2	F-SD2-ISV1-PT4, F-SD2-ISV2-PT2
32	2	F-SD2-ISV1-PT4, F-SD2-ISV2-PT3
33	2	F-SD2-ISV1-PT4, F-SD2-ISV2-PT5
34	2	F-SD2-ISV1-PT4, F-SD2-ISV2-PT6
35	2	F-SD2-ISV1-PT5, F-SD2-ISV1-PT6
36	2	F-SD2-ISV1-PT5, F-SD2-ISV2-PT1
37	2	F-SD2-ISV1-PT5, F-SD2-ISV2-PT2
38	2	F-SD2-ISV1-PT5, F-SD2-ISV2-PT3
39	2	F-SD2-ISV1-PT5, F-SD2-ISV2-PT4
40	2	F-SD2-ISV1-PT5, F-SD2-ISV2-PT6
41	2	F-SD2-ISV1-PT6, F-SD2-ISV2-PT1
42	2	F-SD2-ISV1-PT6, F-SD2-ISV2-PT2
43	2	F-SD2-ISV1-PT6, F-SD2-ISV2-PT3
44	2	F-SD2-ISV1-PT6, F-SD2-ISV2-PT4
45	2	F-SD2-ISV1-PT6, F-SD2-ISV2-PT5
46	2	F-SD2-ISV2-PT1, F-SD2-ISV2-PT2
47	2	F-SD2-ISV2-PT1, F-SD2-ISV2-PT3
48	2	F-SD2-ISV2-PT1, F-SD2-ISV2-PT4
49	2	F-SD2-ISV2-PT1, F-SD2-ISV2-PT5
50	2	F-SD2-ISV2-PT1, F-SD2-ISV2-PT6
51	2	F-SD2-ISV2-PT2, F-SD2-ISV2-PT3
52	2	F-SD2-ISV2-PT2, F-SD2-ISV2-PT4
53	2	F-SD2-ISV2-PT2, F-SD2-ISV2-PT5
54	2	F-SD2-ISV2-PT2, F-SD2-ISV2-PT6
55	2	F-SD2-ISV2-PT3, F-SD2-ISV2-PT4

Table B.2 (cont.)

56	2	F-SD2-ISV2-PT3, F-SD2-ISV2-PT5
57	2	F-SD2-ISV2-PT3, F-SD2-ISV2-PT6
58	2	F-SD2-ISV2-PT4, F-SD2-ISV2-PT5
59	2	F-SD2-ISV2-PT4, F-SD2-ISV2-PT6
60	2	F-SD2-ISV2-PT5, F-SD2-ISV2-PT6
61	2	F-SD2-TC-G, F-SD2-TC-H
62	2	F-SD2-TC-G, F-SD2-TC-J
63	2	F-SD2-TC-G, F-SD2-TL-H
64	2	F-SD2-TC-G, F-SD2-TL-J
65	2	F-SD2-TC-H, F-SD2-TC-J
66	2	F-SD2-TC-H, F-SD2-TL-G
67	2	F-SD2-TC-H, F-SD2-TL-J
68	2	F-SD2-TC-J, F-SD2-TL-G
69	2	F-SD2-TC-J, F-SD2-TL-H
70	2	F-SD2-TL-G, F-SD2-TL-H
71	2	F-SD2-TL-G, F-SD2-TL-J
72	2	F-SD2-TL-H, F-SD2-TL-J
73	3	F-SD2-ISV1-PT1, F-SD2-LEVEL-PT2, F-SD2-LI-PT2
74	3	F-SD2-ISV1-PT1, F-SD2-LEVEL-PT3, F-SD2-LI-PT3
75	3	F-SD2-ISV1-PT1, F-SD2-LEVEL-PT4, F-SD2-LI-PT4
76	3	F-SD2-ISV1-PT1, F-SD2-LEVEL-PT5, F-SD2-LI-PT5
77	3	F-SD2-ISV1-PT1, F-SD2-LEVEL-PT6, F-SD2-LI-PT6
78	3	F-SD2-ISV1-PT2, F-SD2-LEVEL-PT1, F-SD2-LI-PT1
79	3	F-SD2-ISV1-PT2, F-SD2-LEVEL-PT3, F-SD2-LI-PT3
80	3	F-SD2-ISV1-PT2, F-SD2-LEVEL-PT4, F-SD2-LI-PT4
81	3	F-SD2-ISV1-PT2, F-SD2-LEVEL-PT5, F-SD2-LI-PT5
82	3	F-SD2-ISV1-PT2, F-SD2-LEVEL-PT6, F-SD2-LI-PT6
83	3	F-SD2-ISV1-PT3, F-SD2-LEVEL-PT1, F-SD2-LI-PT1
84	3	F-SD2-ISV1-PT3, F-SD2-LEVEL-PT2, F-SD2-LI-PT2
85	3	F-SD2-ISV1-PT3, F-SD2-LEVEL-PT4, F-SD2-LI-PT4
86	3	F-SD2-ISV1-PT3, F-SD2-LEVEL-PT5, F-SD2-LI-PT5
87	3	F-SD2-ISV1-PT3, F-SD2-LEVEL-PT6, F-SD2-LI-PT6
88	3	F-SD2-ISV1-PT4, F-SD2-LEVEL-PT1, F-SD2-LI-PT1
89	3	F-SD2-ISV1-PT4, F-SD2-LEVEL-PT2, F-SD2-LI-PT2
90	3	F-SD2-ISV1-PT4, F-SD2-LEVEL-PT3, F-SD2-LI-PT3
91	3	F-SD2-ISV1-PT4, F-SD2-LEVEL-PT5, F-SD2-LI-PT5
92	3	F-SD2-ISV1-PT4, F-SD2-LEVEL-PT6, F-SD2-LI-PT6
93	3	F-SD2-ISV1-PT5, F-SD2-LEVEL-PT1, F-SD2-LI-PT1
94	3	F-SD2-ISV1-PT5, F-SD2-LEVEL-PT2, F-SD2-LI-PT2
95	3	F-SD2-ISV1-PT5, F-SD2-LEVEL-PT3, F-SD2-LI-PT3
96	3	F-SD2-ISV1-PT5, F-SD2-LEVEL-PT4, F-SD2-LI-PT4
97	3	F-SD2-ISV1-PT5, F-SD2-LEVEL-PT6, F-SD2-LI-PT6
98	3	F-SD2-ISV1-PT6, F-SD2-LEVEL-PT1, F-SD2-LI-PT1
99	3	F-SD2-ISV1-PT6, F-SD2-LEVEL-PT2, F-SD2-LI-PT2
100	3	F-SD2-ISV1-PT6, F-SD2-LEVEL-PT3, F-SD2-LI-PT3
101	3	F-SD2-ISV1-PT6, F-SD2-LEVEL-PT4, F-SD2-LI-PT4

Table B.2 (cont.)

102	3	F-SD2-ISV1-PT6, F-SD2-LEVEL-PT5, F-SD2-LI-PT5
103	3	F-SD2-ISV2-PT1, F-SD2-LEVEL-PT2, F-SD2-LI-PT2
104	3	F-SD2-ISV2-PT1, F-SD2-LEVEL-PT3, F-SD2-LI-PT3
105	3	F-SD2-ISV2-PT1, F-SD2-LEVEL-PT4, F-SD2-LI-PT4
106	3	F-SD2-ISV2-PT1, F-SD2-LEVEL-PT5, F-SD2-LI-PT5
107	3	F-SD2-ISV2-PT1, F-SD2-LEVEL-PT6, F-SD2-LI-PT6
108	3	F-SD2-ISV2-PT2, F-SD2-LEVEL-PT1, F-SD2-LI-PT1
109	3	F-SD2-ISV2-PT2, F-SD2-LEVEL-PT3, F-SD2-LI-PT3
110	3	F-SD2-ISV2-PT2, F-SD2-LEVEL-PT4, F-SD2-LI-PT4
111	3	F-SD2-ISV2-PT2, F-SD2-LEVEL-PT5, F-SD2-LI-PT5
112	3	F-SD2-ISV2-PT2, F-SD2-LEVEL-PT6, F-SD2-LI-PT6
113	3	F-SD2-ISV2-PT3, F-SD2-LEVEL-PT1, F-SD2-LI-PT1
114	3	F-SD2-ISV2-PT3, F-SD2-LEVEL-PT2, F-SD2-LI-PT2
115	3	F-SD2-ISV2-PT3, F-SD2-LEVEL-PT4, F-SD2-LI-PT4
116	3	F-SD2-ISV2-PT3, F-SD2-LEVEL-PT5, F-SD2-LI-PT5
117	3	F-SD2-ISV2-PT3, F-SD2-LEVEL-PT6, F-SD2-LI-PT6
118	3	F-SD2-ISV2-PT4, F-SD2-LEVEL-PT1, F-SD2-LI-PT1
119	3	F-SD2-ISV2-PT4, F-SD2-LEVEL-PT2, F-SD2-LI-PT2
120	3	F-SD2-ISV2-PT4, F-SD2-LEVEL-PT3, F-SD2-LI-PT3
121	3	F-SD2-ISV2-PT4, F-SD2-LEVEL-PT5, F-SD2-LI-PT5
122	3	F-SD2-ISV2-PT4, F-SD2-LEVEL-PT6, F-SD2-LI-PT6
123	3	F-SD2-ISV2-PT5, F-SD2-LEVEL-PT1, F-SD2-LI-PT1
124	3	F-SD2-ISV2-PT5, F-SD2-LEVEL-PT2, F-SD2-LI-PT2
125	3	F-SD2-ISV2-PT5, F-SD2-LEVEL-PT3, F-SD2-LI-PT3
126	3	F-SD2-ISV2-PT5, F-SD2-LEVEL-PT4, F-SD2-LI-PT4
127	3	F-SD2-ISV2-PT5, F-SD2-LEVEL-PT6, F-SD2-LI-PT6
128	3	F-SD2-ISV2-PT6, F-SD2-LEVEL-PT1, F-SD2-LI-PT1
129	3	F-SD2-ISV2-PT6, F-SD2-LEVEL-PT2, F-SD2-LI-PT2
130	3	F-SD2-ISV2-PT6, F-SD2-LEVEL-PT3, F-SD2-LI-PT3
131	3	F-SD2-ISV2-PT6, F-SD2-LEVEL-PT4, F-SD2-LI-PT4
132	3	F-SD2-ISV2-PT6, F-SD2-LEVEL-PT5, F-SD2-LI-PT5
133	3	F-SD2-P11, F-SD2-P12, F-SD2-TK-HI
134	3	F-SD2-V1, F-SD2-V3, F-SD2-V5
135	3	F-SD2-V1, F-SD2-V3, F-SD2-V6
136	3	F-SD2-V1, F-SD2-V4, F-SD2-V5
137	3	F-SD2-V1, F-SD2-V4, F-SD2-V6
138	3	F-SD2-V2, F-SD2-V3, F-SD2-V5
139	3	F-SD2-V2, F-SD2-V3, F-SD2-V6
140	3	F-SD2-V2, F-SD2-V4, F-SD2-V5
141	3	F-SD2-V2, F-SD2-V4, F-SD2-V6

Table B.2 (cont.)

System: MLP

Cut No.	Size	CUT SETS
1	1	F-MLP-FV
2	1	F-MLP-HE
3	1	F-MLP-IV
4	1	F-MLP-LA

System: FW1

Cut No.	Size	CUT SETS
1	1	S-AIR
2	2	F-FW1-BV, F-FW1-ISV1
3	2	F-FW1-BV, F-FW1-ISV2
4	2	F-FW1-CNV2, S-EL-II-1-O
5	2	F-FW1-DV2, S-EL-IV-O
6	2	F-FW1-HE, S-RCW
7	2	F-FW1-ISV1, S-EL-II-1-O
8	2	F-FW1-ISV1, S-PCS
9	2	F-FW1-ISV2, S-EL-II-1-O
10	2	F-FW1-ISV2, S-PCS
11	2	F-FW1-PMP2, S-EL-IV-O
12	2	S-EL-II-1-E, S-EL-II-1-O
13	2	S-EL-IV-E, S-EL-IV-O
14	2	S-FIW, S-RCW
15	3	F-FW1-CNV1, F-FW1-CNV2, F-FW1-CNV3
16	3	F-FW1-CNV1, F-FW1-CNV2, S-PCS
17	3	F-FW1-CNV1, F-FW1-CNV3, S-EL-II-1-E
18	3	F-FW1-CNV1, S-EL-II-1-E, S-PCS
19	3	F-FW1-DV1, F-FW1-DV2, F-FW1-DV3
20	3	F-FW1-DV1, F-FW1-DV2, F-FW1-PMP3
21	3	F-FW1-DV1, F-FW1-DV2, S-PCS
22	3	F-FW1-DV1, F-FW1-DV3, F-FW1-PMP2
23	3	F-FW1-DV1, F-FW1-DV3, S-EL-IV-E
24	3	F-FW1-DV1, F-FW1-PMP2, F-FW1-PMP3
25	3	F-FW1-DV1, F-FW1-PMP2, S-PCS
26	3	F-FW1-DV1, F-FW1-PMP3, S-EL-IV-E
27	3	F-FW1-DV1, S-EL-IV-E, S-PCS
28	3	F-FW1-DV2, F-FW1-DV3, F-FW1-PMP1

Table B.2 (cont.)

29	3	F-FW1-DV2, F-FW1-PMP1, F-FW1-PMP3
30	3	F-FW1-DV2, F-FW1-PMP1, S-PCS
31	3	F-FW1-DV3, F-FW1-PMP1, F-FW1-PMP2
32	3	F-FW1-DV3, F-FW1-PMP1, S-EL-IV-E
33	3	F-FW1-PMP1, F-FW1-PMP2, F-FW1-PMP3
34	3	F-FW1-PMP1, F-FW1-PMP2, S-PCS
35	3	F-FW1-PMP1, F-FW1-PMP3, S-EL-IV-E
36	3	F-FW1-PMP1, S-EL-IV-E, S-PCS

System: FW2

Cut No.	Size	CUT SETS
1	1	S-PCS
2	2	F-FW2-HE, F-FW2-LI-TK
3	2	F-FW2-IV1, F-FW2-IV2
4	2	F-FW2-IV1, F-FW2-OV2
5	2	F-FW2-IV1, F-FW2-PMP2
6	2	F-FW2-IV1, S-EL-III-2-E
7	2	F-FW2-IV2, F-FW2-OV1
8	2	F-FW2-IV2, F-FW2-PMP1
9	2	F-FW2-IV2, S-EL-III-2-O
10	2	F-FW2-OV1, F-FW2-OV2
11	2	F-FW2-OV1, F-FW2-PMP2
12	2	F-FW2-OV1, S-EL-III-2-E
13	2	F-FW2-OV2, F-FW2-PMP1
14	2	F-FW2-OV2, S-EL-III-2-O
15	2	F-FW2-PMP1, F-FW2-PMP2
16	2	F-FW2-PMP1, S-EL-III-2-E
17	2	F-FW2-PMP2, S-EL-III-2-O
18	2	S-EL-II-2-E, S-EL-II-2-O
19	2	S-EL-III-2-E, S-EL-III-2-O
20	3	F-FW2-ISV1-SG1, F-FW2-ISV1-SG2, S-EL-II-2-E
21	3	F-FW2-ISV2-SG1, F-FW2-ISV2-SG2, S-EL-II-2-O

Table B.2 (cont.)

System: AFW

Cut No.	Size	CUT SETS
1	1	F-AFW-DIESEL
2	1	F-AFW-DV
3	1	F-AFW-PMP
4	1	S-PCS

System: HTS

Cut No.	Size	CUT SETS
1	1	F-HTS-PMP1
2	1	F-HTS-PMP2
3	1	F-HTS-PMP3
4	1	F-HTS-PMP4
5	1	S-EL-IV-E
6	1	S-EL-IV-O

System: CSD

Cut No.	Size	CUT SETS
1	1	S-AIR
2	1	S-PCS
3	2	F-CSD-SDV1, F-CSD-SDV2
4	2	F-CSD-SDV1, S-EL-II-2-E
5	2	F-CSD-SDV2, S-EL-II-2-O
6	2	F-CSD-SDV3, F-CSD-SDV4
7	2	F-CSD-SDV3, S-EL-II-2-E
8	2	F-CSD-SDV4, S-EL-II-2-O
9	2	S-EL-II-2-O, S-EL-II-2-E

Table B.2 (cont.)

System: ASD

Cut No.	Size	CUT SETS
1	1	S-AIR
2	1	S-PCS
3	2	F-ASD-ASD1, F-ASD-ASD2
4	2	F-ASD-ASD1, S-EL-II-2-E
5	2	F-ASD-ASD2, S-EL-II-2-O
6	2	S-EL-II-2-E, S-EL-II-2-O

System: SDC

Cut No.	Size	CUT SETS
1	1	F-SDC-HE
2	1	S-PCS
3	2	F-SDC-HX1, F-SDC-HX2
4	2	F-SDC-HX1, S-RCW
5	2	F-SDC-IISV1, F-SDC-IISV2
6	2	F-SDC-IISV1, S-EL-II-2-E
7	2	F-SDC-IISV2, S-EL-II-2-O
8	2	F-SDC-OISV1, F-SDC-OISV2
9	2	F-SDC-OISV1, S-EL-II-2-E
10	2	F-SDC-OISV2, S-EL-II-2-O
11	2	F-SDC-PMP1, F-SDC-PMP2
12	2	F-SDC-PMP1, S-EL-III-2-E
13	2	F-SDC-PMP2, S-EL-III-2-O
14	2	S-EL-II-2-E, S-EL-II-2-O
15	2	S-EL-III-2-E, S-EL-III-2-O
16	2	S-RCW, S-SW2

Table B.2 (cont.)

System: MCS

Cut No.	Size	CUT SETS
1	1	F-MCS-ISV-FC
2	1	F-MCS-PMP1
3	1	F-MCS-PMP2
4	1	S-EL-III-1-E
5	1	S-EL-III-1-O
6	1	S-RCW

System: HPI

Cut No.	Size	CUT SETS
1	1	S-ECC
2	2	F-HPI-INV1, F-HPI-INV2
3	2	F-HPI-INV1, S-EL-II-2-E
4	2	F-HPI-INV1A, F-HPI-INV1B
5	2	F-HPI-INV1A, S-EL-II-2-E
6	2	F-HPI-INV1B, S-EL-II-2-O
7	2	F-HPI-INV2, S-EL-II-2-O
8	2	F-HPI-INV2A, F-HPI-INV2B
9	2	F-HPI-INV2A, S-EL-II-2-E
10	2	F-HPI-INV2B, S-EL-II-2-O
11	2	F-HPI-ISV1-GI, F-HPI-ISV2-GI
12	2	F-HPI-ISV1-GI, S-EL-II-2-E
13	2	F-HPI-ISV2-GI, S-EL-II-2-O
14	2	F-HPI-LI-CITK, F-HPI-TK-CI
15	2	F-HPI-OV1A, F-HPI-OV1B
16	2	F-HPI-OV1A, S-EL-II-2-E
17	2	F-HPI-OV1B, S-EL-II-2-O
18	2	F-HPI-OV2A, F-HPI-OV2B
19	2	F-HPI-OV2A, S-EL-II-2-E
20	2	F-HPI-OV2B, S-EL-II-2-O
21	2	F-HPI-PI-GI-TK, F-HPI-TK-GI
22	2	F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS
23	2	F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS
24	2	F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS
25	2	S-EL-II-2-E, S-EL-II-2-O

Table B.2 (cont.)

System: LPI

Cut No.	Size	CUT SETS
1	1	S-ECC
2	2	F-HPI-ISV1-GI, F-HPI-ISV2-GI
3	2	F-HPI-ISV1-GI, S-EL-III-2-E
4	2	F-HPI-ISV2-GI, S-EL-III-2-O
5	2	F-LPI-INV1, F-LPI-INV2
6	2	F-LPI-INV1, S-EL-III-2-E
7	2	F-LPI-INV2, S-EL-III-2-O
8	2	F-LPI-ISV1, F-LPI-ISV2
9	2	F-LPI-ISV1, S-EL-III-2-E
10	2	F-LPI-ISV2, S-EL-III-2-O
11	2	F-LPI-LI-TK, F-LPI-TK
12	2	F-LPI-PMP1, F-LPI-PMP2
13	2	F-LPI-PMP1, S-EL-III-2-E
14	2	F-LPI-PMP2, S-EL-III-2-O
15	2	S-EL-III-2-E, S-EL-III-2-O

System: REC

Cut No.	Size	CUT SETS
1	1	S-ECC
2	2	F-LPI-ISV1, F-LPI-ISV2
3	2	F-LPI-ISV1, S-EL-III-2-E
4	2	F-LPI-ISV2, S-EL-III-2-O
5	2	F-REC-HX1, F-REC-HX2
6	2	F-REC-ISV1, F-REC-ISV2
7	2	F-REC-ISV1, S-EL-III-2-E
8	2	F-REC-ISV2, S-EL-III-2-O
9	2	S-EL-III-2-E, S-EL-III-2-O
10	2	S-RCW, S-SW2

Table B.2 (cont.)

System: BCS

Cut No.	Size	CUT SETS
1	1	S-EL-II-1-O
2	1	S-PCS
3	2	F-BCS-CNV1, F-BCS-CNV1-TK
4	2	F-BCS-CNV1-TK, F-BCS-CNV2
5	2	F-BCS-CNV1-TK, S-AIR
6	2	F-BCS-CNV1-TK, S-EL-II-1-E

System: ISO

Cut No.	Size	CUT SETS
1	1	F-ISO-HE
2	1	F-ISO-SIG
3	1	F-ISO-VLV-FO
4	1	S-AIR
5	1	S-EL-II-1-O

System: LRC

Cut No.	Size	CUT SETS
1	1	F-LRC-VLV1
2	1	F-LRC-VLV2
3	1	S-AIR
4	1	S-EL-II-1-E
5	1	S-EL-II-1-O
6	1	S-PCS

Table B.2 (cont.)

System: CC

Cut No.	Size	CUT SETS
1	1	S-AIR
2	1	S-ECC
3	1	S-EL-II-2-E
4	1	S-EL-II-2-O
5	2	F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1
6	2	F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1
7	2	F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1
8	2	F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2
9	2	F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2
10	2	F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2
11	2	F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1
12	2	F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1
13	2	F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2
14	2	F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2
15	2	F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1
16	2	F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2

System: MSV

Cut No.	Size	CUT SETS
1	2	F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1
2	2	F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1
3	2	F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1
4	2	F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2
5	2	F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2
6	2	F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2
7	2	F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1
8	2	F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1
9	2	F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2
10	2	F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2
11	2	F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1
12	2	F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2

Table B.2 (cont.)

System: GEN

Cut No.	Size	CUT SETS
1	1	RESPWR

Appendix C

Event Tree Analysis Results

C.1 Introduction

Analysis of the event trees discussed in Chap. 6 results in the sequence cut sets, which are used to categorize the sequences as EC-I, EC-II, etc. This appendix is provided to present the sequence cut sets along with the information used as the basis for categorizing the analyzed events as well as the other initiators represented by those events. The intention in providing this information is to show the intermediate steps used to arrive at the categorization results presented in Chap. 7.

A set of two tables is presented for each analyzed event. The first table is the cut set listing for the event sequences. Four additional columns are included to give information regarding the types of failures that make up each cut set and whether or not the cut set is a determinant failure. The first three columns simply show how many of each type of failure (component failure, human error, or support system failure) make up the cut set. The last column indicates whether the cut set is a determinant failure. A determinant failure is a cut set that results in the sequence being classified in the most limiting category, with EC-I being the most limiting and EC-IV the least limiting. There can be more than one determinant failure as there may be multiple cut sets that would result in the sequence being classified in its most limiting category. If all cut sets for a sequence had ≥ 3 failures, no determinant cut sets are shown.

The cut set listing was limited to only those cut sets involving three failures or less. Since a sequence cut set having ≥ 3 failures results in an EC-IV categorization and only those with < 3 failures can be determinant cut sets, showing cut sets with more than three failures provides little value. Also, that if a sequence resulted in all cuts having > 3 failures, no cut set listing is provided for that sequence.

The second table in each set provides the categorization information for the sequences for all initiators represented by the event. This table lists each sequence for the analyzed event with a brief description of the determinant failure(s). Subsequent columns contain the initiating events (IEs), their frequency, and the resulting bin and category for each sequence based on the IE frequency and the determinant failure(s). The bin information is from the flow chart in Chap. 3 that delineates the categorization process.

C.2 Large-Break Loss-of-Coolant Event Analysis Results

This section provides the analysis results for the large-break loss-of-coolant. Table C.1 shows the cut set information, and Table C.2 shows the sequence categorization results.

C.3 Small-Break Loss-of-Coolant Event Analyses Results

Two small-break loss-of-coolant events were analyzed: liquid relief valve failure and feeder tube break. Table C.3 is the cut set information for liquid relief valve failure, and Table C.4 presents the sequence categorization results for events represented by the liquid relief valve failure event. Tables C.5 and C.6 provide this information for the feeder tube break.

C.4 Loss of Class IV Power Event Analysis Results

This section provides the analysis results for the loss of Class IV power event. Table C.7 lists the cut set information, and Table C.8 gives the sequence categorization results.

C.5 Undercooling Event Analyses Results

Two undercooling events were analyzed: feedwater piping break in the reactor building and feedwater piping break in the turbine building. Table C.9 lists the cut set information for feedwater piping breaks in the reactor building, and Table C.10 presents the sequence categorization results for events represented by this event. Tables C.11 and C.12 provide this information for the feedwater piping break in the turbine building.

C.6 SCRAM Event Analysis Results

This section provides the analysis results for the SCRAM event. Table C.13 lists the cut set information, and Table C.14 provides the sequence categorization results.

Table C.1 Feeder tube header break sequence cut sets

Initiating Event - <i>Feeder Tube Header Break</i>	Sequence: <i>LB-A</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
NONE	NA	NA	NA	NA

Initiating Event - <i>Feeder Tube Header Break</i>	Sequence: <i>LB-B</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-REC-ISV1, F-REC-ISV2	2			Y
F-REC-ISV1, S-EL-III-2-E	1		1	
F-REC-ISV2, S-EL-III-2-O	1		1	
F-REC-HX1, F-REC-HX2	2			Y

Initiating Event - <i>Feeder Tube Header Break</i>	Sequence: <i>LB-C</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-RCW, S-SW2			2	
F-MCS-PMP1, F-REC-ISV1, F-REC-ISV2	3			
F-MCS-PMP2, F-REC-ISV1, F-REC-ISV2	3			
F-REC-ISV1, F-REC-ISV2, S-EL-III-1-O	2		1	
F-REC-ISV1, F-REC-ISV2, S-RCW	2		1	
F-MCS-ISV-FC, F-REC-ISV1, F-REC-ISV2	3			
F-REC-ISV1, F-REC-ISV2, S-EL-III-1-E	2		1	
F-REC-ISV1, S-EL-III-1-E, S-EL-III-2-E	1		2	
F-MCS-PMP1, F-REC-ISV2, S-EL-III-2-O	2		1	
F-MCS-PMP2, F-REC-ISV2, S-EL-III-2-O	2		1	

Table C.1 (cont.)

F-REC-ISV1, S-EL-III-2-E, S-RCW	1		2	
F-REC-ISV2, S-EL-III-1-E, S-EL-III-2-O	1		2	
F-REC-ISV2, S-EL-III-2-O, S-RCW	1		2	
F-REC-ISV2, S-EL-III-1-O, S-EL-III-2-O	1		2	
F-REC-ISV1, S-EL-III-1-O, S-EL-III-2-E	1		2	
F-MCS-ISV-FC, F-REC-ISV2, S-EL-III-2-O	2		1	
F-MCS-PMP2, F-REC-ISV1, S-EL-III-2-E	2		1	
F-MCS-PMP1, F-REC-ISV1, S-EL-III-2-E	2		1	
F-MCS-ISV-FC, F-REC-ISV1, S-EL-III-2-E	2		1	
F-REC-HX1, F-REC-HX2, S-RCW	2		1	
F-MCS-ISV-FC, F-REC-HX1, F-REC-HX2	3			
F-REC-HX1, F-REC-HX2, S-EL-III-1-E	2		1	
F-MCS-PMP2, F-REC-HX1, F-REC-HX2	3			
F-MCS-PMP1, F-REC-HX1, F-REC-HX2	3			
F-REC-HX1, F-REC-HX2, S-EL-III-1-O	2		1	

Initiating Event - <i>Feeder Tube Header Break</i>	Sequence: <i>LB-D</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-LPI-ISV1, F-LPI-ISV2	2			Y
F-LPI-PMP1, F-LPI-PMP2	2			Y
F-LPI-INV1, F-LPI-INV2	2			Y
F-LPI-PMP1, S-EL-III-2-E	1		1	
F-LPI-PMP2, S-EL-III-2-O	1		1	
F-LPI-ISV2, S-EL-III-2-O	1		1	
F-HPI-ISV1-GI, S-EL-III-2-E	1		1	
F-LPI-LI-TK, F-LPI-TK	2			Y
F-HPI-ISV2-GI, S-EL-III-2-O	1		1	
F-LPI-INV2, S-EL-III-2-O	1		1	
F-LPI-ISV1, S-EL-III-2-E	1		1	
F-LPI-INV1, S-EL-III-2-E	1		1	
S-EL-III-2-E, S-EL-III-2-O			2	

Table C.1 (cont.)

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-E</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-LPI-INV1, F-LPI-INV2, S-RCW	2		1	
F-LPI-ISV1, F-LPI-ISV2, S-EL-III-1-O	2		1	
F-LPI-INV1, F-LPI-INV2, F-MCS-ISV-FC	3			
F-LPI-ISV1, F-LPI-ISV2, F-MCS-PMP1	3			
F-LPI-ISV1, F-LPI-ISV2, S-EL-III-1-E	2		1	
F-LPI-ISV1, F-LPI-ISV2, F-MCS-ISV-FC	3			
F-LPI-ISV1, F-LPI-ISV2, F-MCS-PMP2	3			
F-LPI-INV1, F-LPI-INV2, S-EL-III-1-E	2		1	
F-LPI-INV1, F-LPI-INV2, F-MCS-PMP1	3			
F-LPI-PMP1, F-LPI-PMP2, F-MCS-PMP1	3			
F-LPI-PMP1, F-LPI-PMP2, S-EL-III-1-E	2		1	
F-LPI-PMP1, F-LPI-PMP2, S-EL-III-1-O	2		1	
F-LPI-PMP1, F-LPI-PMP2, F-MCS-PMP2	3			
F-LPI-PMP1, F-LPI-PMP2, F-MCS-ISV-FC	3			
F-LPI-INV1, F-LPI-INV2, S-EL-III-1-O	2		1	
F-LPI-PMP1, F-LPI-PMP2, S-RCW	2		1	
F-LPI-ISV1, F-LPI-ISV2, S-RCW	2		1	
F-LPI-INV1, F-LPI-INV2, F-MCS-PMP2	3			
F-LPI-PMP2, F-MCS-ISV-FC, S-EL-III-2-O	2		1	
F-LPI-PMP2, S-EL-III-2-O, S-RCW	1		2	
F-LPI-PMP2, F-MCS-PMP2, S-EL-III-2-O	2		1	
F-LPI-PMP2, S-EL-III-1-E, S-EL-III-2-O	1		2	
F-HPI-ISV1-GI, S-EL-III-1-O, S-EL-III-2-E	1		2	
F-LPI-PMP2, F-MCS-PMP1, S-EL-III-2-O	2		1	
F-HPI-ISV1-GI, F-MCS-PMP1, S-EL-III-2-E	2		1	
F-HPI-ISV1-GI, S-EL-III-2-E, S-RCW	1		2	
F-LPI-ISV1, S-EL-III-1-O, S-EL-III-2-E	1		2	
F-HPI-ISV1-GI, F-MCS-ISV-FC, S-EL-III-2-E	2		1	
F-HPI-ISV1-GI, F-MCS-PMP2, S-EL-III-2-E	2		1	

Table C.1 (cont.)

F-LPI-PMP2, S-EL-III-1-O, S-EL-III-2-O	1		2	
F-HPI-ISV1-GI, S-EL-III-1-E, S-EL-III-2-E	1		2	
F-LPI-PMP1, S-EL-III-2-E, S-RCW	1		2	
F-LPI-LI-TK, F-LPI-TK, F-MCS-PMP2	3			
F-LPI-LI-TK, F-LPI-TK, F-MCS-ISV-FC	3			
F-LPI-LI-TK, F-LPI-TK, S-EL-III-1-E	2		1	
F-LPI-LI-TK, F-LPI-TK, F-MCS-PMP1	3			
F-LPI-LI-TK, F-LPI-TK, S-RCW	2		1	
F-LPI-LI-TK, F-LPI-TK, S-EL-III-1-O	2		1	
F-LPI-ISV2, S-EL-III-2-O, S-RCW	1		2	
F-LPI-PMP1, F-MCS-PMP2, S-EL-III-2-E	2		1	
F-LPI-PMP1, F-MCS-ISV-FC, S-EL-III-2-E	2		1	
F-LPI-PMP1, S-EL-III-1-E, S-EL-III-2-E	1		2	
F-LPI-PMP1, F-MCS-PMP1, S-EL-III-2-E	2		1	
F-HPI-ISV2-GI, F-MCS-PMP1, S-EL-III-2-O	2		1	
F-LPI-PMP1, S-EL-III-1-O, S-EL-III-2-E	1		2	
F-HPI-ISV2-GI, S-EL-III-1-O, S-EL-III-2-O	1		2	
F-LPI-INV1, S-EL-III-1-E, S-EL-III-2-E	1		2	
F-LPI-INV1, F-MCS-PMP2, S-EL-III-2-E	2		1	
F-LPI-INV1, F-MCS-PMP1, S-EL-III-2-E	2		1	
F-LPI-INV1, S-EL-III-1-O, S-EL-III-2-E	1		2	
F-LPI-INV1, F-MCS-ISV-FC, S-EL-III-2-E	2		1	
F-HPI-ISV2-GI, S-EL-III-1-E, S-EL-III-2-O	1		2	
F-LPI-INV1, S-EL-III-2-E, S-RCW	1		2	
F-LPI-ISV1, S-EL-III-1-E, S-EL-III-2-E	1		2	
F-LPI-ISV1, F-MCS-PMP1, S-EL-III-2-E	2		1	
F-LPI-ISV1, F-MCS-PMP2, S-EL-III-2-E	2		1	
F-LPI-ISV1, F-MCS-ISV-FC, S-EL-III-2-E	2		1	
F-LPI-INV2, F-MCS-ISV-FC, S-EL-III-2-O	2		1	
F-LPI-ISV1, S-EL-III-2-E, S-RCW	1		2	
F-LPI-INV2, S-EL-III-2-O, S-RCW	1		2	
F-LPI-ISV2, F-MCS-ISV-FC, S-EL-III-2-O	2		1	
F-LPI-ISV2, F-MCS-PMP2, S-EL-III-2-O	2		1	
F-HPI-ISV2-GI, S-EL-III-2-O, S-RCW	1		2	

Table C.1 (cont.)

F-HPI-ISV2-GI, F-MCS-ISV-FC, S-EL-III-2-O	2		1	
F-LPI-ISV2, S-EL-III-1-E, S-EL-III-2-O	1		2	
F-LPI-INV2, F-MCS-PMP2, S-EL-III-2-O	2		1	
F-HPI-ISV2-GI, F-MCS-PMP2, S-EL-III-2-O	2		1	
F-LPI-INV2, S-EL-III-1-O, S-EL-III-2-O	1		2	
F-LPI-ISV2, S-EL-III-1-O, S-EL-III-2-O	1		2	
F-LPI-INV2, F-MCS-PMP1, S-EL-III-2-O	2		1	
F-LPI-ISV2, F-MCS-PMP1, S-EL-III-2-O	2		1	
F-LPI-INV2, S-EL-III-1-E, S-EL-III-2-O	1		2	
F-MCS-PMP1, S-EL-III-2-E, S-EL-III-2-O	1		2	
S-EL-III-1-O, S-EL-III-2-E, S-EL-III-2-O			3	
S-EL-III-1-E, S-EL-III-2-E, S-EL-III-2-O			3	
F-MCS-PMP2, S-EL-III-2-E, S-EL-III-2-O	1		2	
S-EL-III-2-E, S-EL-III-2-O, S-RCW			3	
F-MCS-ISV-FC, S-EL-III-2-E, S-EL-III-2-O	1		2	

Initiating Event - Feeder Tube Header Break		Sequence: <i>LB-F</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-ECC			1	Y
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS	2			Y
F-HPI-OV2A, F-HPI-OV2B	2			Y
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS	2			Y
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS	2			Y
F-HPI-INV2A, F-HPI-INV2B	2			Y
F-HPI-ISV1-GI, F-HPI-ISV2-GI	2			Y
F-HPI-OV1A, F-HPI-OV1B	2			Y
F-HPI-INV1, F-HPI-INV2	2			Y
F-HPI-INV1A, F-HPI-INV1B	2			Y
F-HPI-PI-GI-TK, F-HPI-TK-GI	2			Y
F-HPI-INV1B, S-EL-II-2-O	1		1	
F-HPI-ISV2-GI, S-EL-II-2-O	1		1	
F-HPI-ISV1-GI, S-EL-II-2-E	1		1	

Table C.1 (cont.)

F-HPI-LI-CITK, F-HPI-TK-CI	2			Y
F-HPI-INV1, S-EL-II-2-E	1		1	
F-HPI-INV1A, S-EL-II-2-E	1		1	
F-HPI-OV1A, S-EL-II-2-E	1		1	
F-HPI-INV2B, S-EL-II-2-O	1		1	
F-HPI-OV1B, S-EL-II-2-O	1		1	
F-HPI-INV2, S-EL-II-2-O	1		1	
F-HPI-OV2A, S-EL-II-2-E	1		1	
F-HPI-OV2B, S-EL-II-2-O	1		1	
F-HPI-INV2A, S-EL-II-2-E	1		1	
S-EL-II-2-E, S-EL-II-2-O			2	

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-G</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-MCS-PMP2, S-ECC	1		1	
F-MCS-ISV-FC, S-ECC	1		1	
S-ECC, S-EL-III-1-E			2	
S-ECC, S-RCW			2	
F-MCS-PMP1, S-ECC	1		1	
S-ECC, S-EL-III-1-O			2	
F-HPI-OV2A, F-HPI-OV2B, F-MCS-PMP2	3			
F-HPI-OV2A, F-HPI-OV2B, S-EL-III-1-E	2		1	
F-HPI-OV2A, F-HPI-OV2B, F-MCS-ISV-FC	3			
F-HPI-OV2A, F-HPI-OV2B, F-MCS-PMP1	3			
F-HPI-OV2A, F-HPI-OV2B, S-RCW	2		1	
F-HPI-OV2A, F-HPI-OV2B, S-EL-III-1-O	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, F-MCS-ISV-FC	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, F-MCS-PMP2	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, S-RCW	2		1	
F-HPI-OV1A, F-HPI-OV1B, F-MCS-PMP1	3			
F-HPI-OV1A, F-HPI-OV1B, S-EL-III-1-E	2		1	
F-HPI-INV2A, F-HPI-INV2B, F-MCS-PMP2	3			

Table C.1 (cont.)

F-HPI-INV2A, F-HPI-INV2B, S-EL-III-1-E	2		1	
F-HPI-INV2A, F-HPI-INV2B, F-MCS-ISV-FC	3			
F-HPI-INV2A, F-HPI-INV2B, F-MCS-PMP1	3			
F-HPI-INV2A, F-HPI-INV2B, S-EL-III-1-O	2		1	
F-HPI-OV1A, F-HPI-OV1B, F-MCS-ISV-FC	3			
F-HPI-OV1A, F-HPI-OV1B, F-MCS-PMP2	3			
F-HPI-OV1A, F-HPI-OV1B, S-RCW	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, S-EL-III-1-E	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, F-MCS-PMP1	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, S-EL-III-1-O	2		1	
F-HPI-ISV1-GI, F-HPI-ISV2-GI, S-RCW	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, F-MCS-PMP1	3			
F-HPI-ISV1-GI, F-HPI-ISV2-GI, F-MCS-ISV-FC	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, S-EL-III-1-E	2		1	
F-HPI-ISV1-GI, F-HPI-ISV2-GI, F-MCS-PMP2	3			
F-HPI-ISV1-GI, F-HPI-ISV2-GI, F-MCS-PMP1	3			
F-HPI-ISV1-GI, F-HPI-ISV2-GI, S-EL-III-1-O	2		1	
F-HPI-ISV1-GI, F-HPI-ISV2-GI, S-EL-III-1-E	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, F-MCS-PMP2	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, F-MCS-ISV-FC	3			
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, S-RCW	2		1	
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, F-MCS-ISV-FC	3			
F-EPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, S-EL-III-1-O	2		1	
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, F-MCS-PMP2	3			
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, S-EL-III-1-E	2		1	
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, S-EL-III-1-O	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, S-RCW	2		1	
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, F-MCS-PMP1	3			
F-HPI-INV2A, F-HPI-INV2B, S-RCW	2		1	
F-HPI-OV1A, F-HPI-OV1B, S-EL-III-1-O	2		1	
F-HPI-INV1A, F-HPI-INV1B, F-MCS-ISV-FC	3			
F-HPI-INV1, F-HPI-INV2, S-RCW	2		1	
F-HPI-INV1A, F-HPI-INV1B, F-MCS-PMP2	3			
F-HPI-INV1A, F-HPI-INV1B, S-RCW	2		1	

Table C.1 (cont.)

F-HPI-INV1A, F-HPI-INV1B, S-EL-III-1-E	2		1	
F-HPI-INV1, F-HPI-INV2, F-MCS-ISV-FC	3			
F-HPI-INV1, F-HPI-INV2, F-MCS-PMP1	3			
F-HPI-INV1, F-HPI-INV2, S-EL-III-1-O	2		1	
F-HPI-INV1, F-HPI-INV2, S-EL-III-1-E	2		1	
F-HPI-INV1A, F-HPI-INV1B, S-EL-III-1-O	2		1	
F-HPI-INV1, F-HPI-INV2, F-MCS-PMP2	3			
F-HPI-INV1A, F-HPI-INV1B, F-MCS-PMP1	3			
F-HPI-INV1, F-MCS-PMP1, S-EL-II-2-E	2		1	
F-HPI-INV1, S-EL-II-2-E, S-EL-III-1-E	1		2	
F-HPI-INV1, S-EL-II-2-E, S-EL-III-1-O	1		2	
F-HPI-INV1, F-MCS-PMP2, S-EL-II-2-E	2		1	
F-HPI-INV1, F-MCS-ISV-FC, S-EL-II-2-E	2		1	
F-HPI-ISV2-GI, F-MCS-ISV-FC, S-EL-II-2-O	2		1	
F-HPI-ISV2-GI, F-MCS-PMP2, S-EL-II-2-O	2		1	
F-HPI-ISV2-GI, S-EL-II-2-O, S-RCW	1		2	
F-HPI-LI-CITK, F-HPI-TK-CI, S-EL-III-1-O	2		1	
F-HPI-PI-GI-TK, F-HPI-TK-GI, S-RCW	2		1	
F-HPI-INV1B, F-MCS-ISV-FC, S-EL-II-2-O	2		1	
F-HPI-INV1B, S-EL-II-2-O, S-RCW	1		2	
F-HPI-INV1B, F-MCS-PMP2, S-EL-II-2-O	2		1	
F-HPI-PI-GI-TK, F-HPI-TK-GI, S-EL-III-1-O	2		1	
F-HPI-PI-GI-TK, F-HPI-TK-GI, F-MCS-PMP1	3			
F-HPI-PI-GI-TK, F-HPI-TK-GI, F-MCS-PMP2	3			
F-HPI-PI-GI-TK, F-HPI-TK-GI, F-MCS-ISV-FC	3			
F-HPI-PI-GI-TK, F-HPI-TK-GI, S-EL-III-1-E	2		1	
F-HPI-ISV2-GI, S-EL-II-2-O, S-EL-III-1-E	1		2	
F-HPI-ISV2-GI, F-MCS-PMP1, S-EL-II-2-O	2		1	
F-HPI-ISV1-GI, S-EL-II-2-E, S-EL-III-1-O	1		2	
F-HPI-INV1, S-EL-II-2-E, S-RCW	1		2	
F-HPI-ISV1-GI, F-MCS-PMP1, S-EL-II-2-E	2		1	
F-HPI-INV2, S-EL-II-2-O, S-EL-III-1-O	1		2	
F-HPI-INV2, F-MCS-PMP1, S-EL-II-2-O	2		1	
F-HPI-INV2, F-MCS-PMP2, S-EL-II-2-O	2		1

3 of 4

Table C.1 (cont.)

F-HPI-INV2, F-MCS-ISV-FC, S-EL-II-2-O	2		1	
F-HPI-INV2, S-EL-II-2-O, S-EL-III-1-E	1		2	
F-HPI-ISV1-GI, S-EL-II-2-E, S-EL-III-1-E	1		2	
F-HPI-ISV1-GI, F-MCS-PMP2, S-EL-II-2-E	2		1	
F-HPI-ISV1-GI, S-EL-II-2-E, S-RCW	1		2	
F-HPI-LI-CITK, F-HPI-TK-CI, F-MCS-PMP1	3			
F-HPI-ISV2-GI, S-EL-II-2-O, S-EL-III-1-O	1		2	
F-HPI-LI-CITK, F-HPI-TK-CI, S-EL-III-1-E	2		1	
F-HPI-LI-CITK, F-HPI-TK-CI, F-MCS-PMP2	3			
F-HPI-LI-CITK, F-HPI-TK-CI, F-MCS-ISV-FC	3			
F-HPI-ISV1-GI, F-MCS-ISV-FC, S-EL-II-2-E	2		1	
F-HPI-INV1B, S-EL-II-2-O, S-EL-III-1-E	1		2	
F-HPI-LI-CITK, F-HPI-TK-CI, S-RCW	2		1	
F-HPI-INV1B, F-MCS-PMP1, S-EL-II-2-O	2		1	
F-HPI-OV1A, F-MCS-PMP2, S-EL-II-2-E	2		1	
F-HPI-OV1A, S-EL-II-2-E, S-EL-III-1-E	1		2	
F-HPI-OV1A, F-MCS-ISV-FC, S-EL-II-2-E	2		1	
F-HPI-OV1A, F-MCS-PMP1, S-EL-II-2-E	2		1	
F-HPI-OV1A, S-EL-II-2-E, S-RCW	1		2	
F-HPI-OV1A, S-EL-II-2-E, S-EL-III-1-O	1		2	
F-HPI-INV2A, S-EL-II-2-E, S-RCW	1		2	
F-HPI-OV1B, S-EL-II-2-O, S-EL-III-1-E	1		2	
F-HPI-OV1B, F-MCS-ISV-FC, S-EL-II-2-O	2		1	
F-HPI-INV2B, S-EL-II-2-O, S-RCW	1		2	
F-HPI-OV1B, S-EL-II-2-O, S-RCW	1		2	
F-HPI-INV2B, F-MCS-ISV-FC, S-EL-II-2-O	2		1	
F-HPI-INV2A, S-EL-II-2-E, S-EL-III-1-E	1		2	
F-HPI-INV2A, F-MCS-PMP1, S-EL-II-2-E	2		1	
F-HPI-INV2A, F-MCS-PMP2, S-EL-II-2-E	2		1	
F-HPI-INV2A, S-EL-II-2-E, S-EL-III-1-O	1		2	
F-HPI-INV2A, F-MCS-ISV-FC, S-EL-II-2-E	2		1	
F-HPI-INV2B, S-EL-II-2-O, S-EL-III-1-O	1		2	
F-HPI-INV2B, S-EL-II-2-O, S-EL-III-1-E	1		2	
F-HPI-INV2B, F-MCS-PMP2, S-EL-II-2-O	2		1	

Table C.1 (cont.)

F-HPI-INV2B, F-MCS-PMP1, S-EL-II-2-O	2		1	
F-HPI-OV1B, F-MCS-PMP1, S-EL-II-2-O	2		1	
F-HPI-OV1B, F-MCS-PMP2, S-EL-II-2-O	2		1	
F-HPI-INV1A, S-EL-II-2-E, S-EL-III-1-O	1		2	
F-HPI-INV1A, F-MCS-PMP1, S-EL-II-2-E	2		1	
F-HPI-OV1B, S-EL-II-2-O, S-EL-III-1-O	1		2	
F-HPI-INV1A, S-EL-II-2-E, S-EL-III-1-E	1		2	
F-HPI-OV2A, F-MCS-PMP1, S-EL-II-2-E	2		1	
F-HPI-INV1A, F-MCS-PMP2, S-EL-II-2-E	2		1	
F-HPI-INV1A, S-EL-II-2-E, S-RCW	1		2	
F-HPI-INV1B, S-EL-II-2-O, S-EL-III-1-O	1		2	
F-HPI-INV1A, F-MCS-ISV-FC, S-EL-II-2-E	2		1	
F-HPI-OV2A, S-EL-II-2-E, S-EL-III-1-E	1		2	
F-HPI-OV2A, S-EL-II-2-E, S-EL-III-1-O	1		2	
F-HPI-OV2A, F-MCS-PMP2, S-EL-II-2-E	2		1	
F-HPI-OV2B, F-MCS-PMP2, S-EL-II-2-O	2		1	
F-HPI-OV2B, S-EL-II-2-O, S-RCW	1		2	
F-HPI-OV2B, S-EL-II-2-O, S-EL-III-1-E	1		2	
F-HPI-INV2, S-EL-II-2-O, S-RCW	1		2	
F-HPI-OV2B, F-MCS-ISV-FC, S-EL-II-2-O	2		1	
F-HPI-OV2A, S-EL-II-2-E, S-RCW	1		2	
F-HPI-OV2B, F-MCS-PMP1, S-EL-II-2-O	2		1	
F-HPI-OV2A, F-MCS-ISV-FC, S-EL-II-2-E	2		1	
F-HPI-OV2B, S-EL-II-2-O, S-EL-III-1-O	1		2	
F-MCS-ISV-FC, S-EL-II-2-E, S-EL-II-2-O	1		2	
S-EL-II-2-E, S-EL-II-2-O, S-RCW			3	
F-MCS-PMP2, S-EL-II-2-E, S-EL-II-2-O	1		2	
S-EL-II-2-E, S-EL-II-2-O, S-EL-III-1-O			3	
S-EL-II-2-E, S-EL-II-2-O, S-EL-III-1-E			3	
F-MCS-PMP1, S-EL-II-2-E, S-EL-II-2-O	1		2	

Table C.1 (cont.)

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-H</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-HTS-PMP3	1			Y
F-HTS-PMP4	1			Y
F-HTS-PMP2	1			Y
F-HTS-PMP1	1			Y
S-EL-IV-E			1	
S-EL-IV-O			1	

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-I</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-REC-ISV1, F-REC-ISV2, S-EL-IV-O	2		1	
F-REC-ISV1, F-REC-ISV2, S-EL-IV-E	2		1	
F-HTS-PMP2, F-REC-ISV1, F-REC-ISV2	3			
F-HTS-PMP1, F-REC-ISV1, F-REC-ISV2	3			
F-HTS-PMP3, F-REC-ISV1, F-REC-ISV2	3			
F-HTS-PMP4, F-REC-ISV1, F-REC-ISV2	3			
F-HTS-PMP3, F-REC-ISV1, S-EL-III-2-E	2		1	
F-REC-ISV2, S-EL-III-2-O, S-EL-IV-E	1		2	
F-HTS-PMP2, F-REC-ISV1, S-EL-III-2-E	2		1	
F-HTS-PMP4, F-REC-ISV1, S-EL-III-2-E	2		1	
F-HTS-PMP1, F-REC-ISV1, S-EL-III-2-E	2		1	
F-HTS-PMP2, F-REC-ISV2, S-EL-III-2-O	2		1	
F-REC-ISV2, S-EL-III-2-O, S-EL-IV-O	1		2	
F-HTS-PMP3, F-REC-ISV2, S-EL-III-2-O	2		1	
F-HTS-PMP1, F-REC-ISV2, S-EL-III-2-O	2		1	
F-HTS-PMP4, F-REC-ISV2, S-EL-III-2-O	2		1	
F-REC-ISV1, S-EL-III-2-E, S-EL-IV-O	1		2	
F-REC-ISV1, S-EL-III-2-E, S-EL-IV-E	1		2	
F-HTS-PMP3, F-REC-HX1, F-REC-HX2	3			
F-HTS-PMP4, F-REC-HX1, F-REC-HX2	3			

Table C.1 (cont.)

F-HTS-PMP2, F-REC-HX1, F-REC-HX2	3			
F-REC-HX1, F-REC-HX2, S-EL-IV-O	2		1	
F-HTS-PMP1, F-REC-HX1, F-REC-HX2	3			
F-REC-HX1, F-REC-HX2, S-EL-IV-E	2		1	

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-J</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-HTS-PMP3, S-RCW, S-SW2	1		2	
F-HTS-PMP4, S-RCW, S-SW2	1		2	
F-HTS-PMP2, S-RCW, S-SW2	1		2	
F-HTS-PMP1, S-RCW, S-SW2	1		2	
S-EL-IV-E, S-RCW, S-SW2			3	
S-EL-IV-O, S-RCW, S-SW2			3	

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-K</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-LPI-INV1, F-LPI-INV2, S-EL-IV-E	2		1	
F-HTS-PMP4, F-LPI-ISV1, F-LPI-ISV2	3			
F-LPI-INV1, F-LPI-INV2, S-EL-IV-O	2		1	
F-HTS-PMP3, F-LPI-ISV1, F-LPI-ISV2	3			
F-HTS-PMP2, F-LPI-ISV1, F-LPI-ISV2	3			
F-LPI-ISV1, F-LPI-ISV2, S-EL-IV-O	2		1	
F-HTS-PMP1, F-LPI-ISV1, F-LPI-ISV2	3			
F-HTS-PMP2, F-LPI-INV1, F-LPI-INV2	3			
F-HTS-PMP3, F-LPI-INV1, F-LPI-INV2	3			
F-HTS-PMP3, F-LPI-PMP1, F-LPI-PMP2	3			
F-HTS-PMP2, F-LPI-PMP1, F-LPI-PMP2	3			
F-HTS-PMP4, F-LPI-PMP1, F-LPI-PMP2	3			
F-HTS-PMP1, F-LPI-PMP1, F-LPI-PMP2	3			
F-LPI-PMP1, F-LPI-PMP2, S-EL-IV-O	2		1	
F-HTS-PMP4, F-LPI-INV1, F-LPI-INV2	3			

Table C.1 (cont.)

F-LPI-PMP1, F-LPI-PMP2, S-EL-IV-E	2		1	
F-LPI-ISV1, F-LPI-ISV2, S-EL-IV-E	2		1	
F-HTS-PMP1, F-LPI-INV1, F-LPI-INV2	3			
F-LPI-PMP2, S-EL-III-2-O, S-EL-IV-O	1		2	
F-LPI-PMP2, S-EL-III-2-O, S-EL-IV-E	1		2	
F-HTS-PMP1, F-LPI-PMP2, S-EL-III-2-O	2		1	
F-HTS-PMP2, F-LPI-PMP2, S-EL-III-2-O	2		1	
F-HPI-ISV1-GI, F-HTS-PMP4, S-EL-III-2-E	2		1	
F-HTS-PMP3, F-LPI-PMP2, S-EL-III-2-O	2		1	
F-HPI-ISV1-GI, F-HTS-PMP3, S-EL-III-2-E	2		1	
F-HPI-ISV1-GI, S-EL-III-2-E, S-EL-IV-E	1		2	
F-HTS-PMP4, F-LPI-ISV1, S-EL-III-2-E	2		1	
F-HPI-ISV1-GI, S-EL-III-2-E, S-EL-IV-O	1		2	
F-HPI-ISV1-GI, F-HTS-PMP1, S-EL-III-2-E	2		1	
F-HTS-PMP4, F-LPI-PMP2, S-EL-III-2-O	2		1	
F-HPI-ISV1-GI, F-HTS-PMP2, S-EL-III-2-E	2		1	
F-LPI-PMP1, S-EL-III-2-E, S-EL-IV-E	1		2	
F-HTS-PMP1, F-LPI-LI-TK, F-LPI-TK	3			
F-LPI-LI-TK, F-LPI-TK, S-EL-IV-O	2		1	
F-HTS-PMP2, F-LPI-LI-TK, F-LPI-TK	3			
F-HTS-PMP3, F-LPI-LI-TK, F-LPI-TK	3			
F-LPI-LI-TK, F-LPI-TK, S-EL-IV-E	2		1	
F-HTS-PMP4, F-LPI-LI-TK, F-LPI-TK	3			
F-LPI-ISV2, S-EL-III-2-O, S-EL-IV-E	1		2	
F-HTS-PMP1, F-LPI-PMP1, S-EL-III-2-E	2		1	
F-LPI-PMP1, S-EL-III-2-E, S-EL-IV-O	3			
F-HTS-PMP2, F-LPI-PMP1, S-EL-III-2-E	2		1	
F-HTS-PMP3, F-LPI-PMP1, S-EL-III-2-E	2		1	
F-HPI-ISV2-GI, F-HTS-PMP3, S-EL-III-2-O	2		1	
F-HTS-PMP4, F-LPI-PMP1, S-EL-III-2-E	2		1	
F-HPI-ISV2-GI, F-HTS-PMP4, S-EL-III-2-O	2		1	
F-HTS-PMP2, F-LPI-INV1, S-EL-III-2-E	2		1	
F-HTS-PMP1, F-LPI-INV1, S-EL-III-2-E	2		1	
F-HTS-PMP3, F-LPI-INV1, S-EL-III-2-E	2		1	

Table C.1 (cont.)

F-HTS-PMP4, F-LPI-INV1, S-EL-III-2-E	2		1	
F-LPI-INV1, S-EL-III-2-E, S-EL-IV-O	1		2	
F-HPI-ISOV2-GI, F-HTS-PMP2, S-EL-III-2-O	2		1	
F-LPI-INV1, S-EL-III-2-E, S-EL-IV-E	1		2	
F-HTS-PMP2, F-LPI-ISOV1, S-EL-III-2-E	2		1	
F-HTS-PMP3, F-LPI-ISOV1, S-EL-III-2-E	2		1	
F-HTS-PMP1, F-LPI-ISOV1, S-EL-III-2-E	2		1	
F-LPI-ISOV1, S-EL-III-2-E, S-EL-IV-O	1		2	
F-LPI-INV2, S-EL-III-2-O, S-EL-IV-O	1		2	
F-LPI-ISOV1, S-EL-III-2-E, S-EL-IV-E	1		2	
F-LPI-INV2, S-EL-III-2-O, S-EL-IV-E	1		2	
F-LPI-ISOV2, S-EL-III-2-O, S-EL-IV-O	1		2	
F-HTS-PMP1, F-LPI-ISOV2, S-EL-III-2-O	2		1	
F-HPI-ISOV2-GI, S-EL-III-2-O, S-EL-IV-E	1		2	
F-HPI-ISOV2-GI, S-EL-III-2-O, S-EL-IV-O	1		2	
F-HTS-PMP2, F-LPI-ISOV2, S-EL-III-2-O	2		1	
F-HTS-PMP1, F-LPI-INV2, S-EL-III-2-O	2		1	
F-HPI-ISOV2-GI, F-HTS-PMP1, S-EL-III-2-O	2		1	
F-HTS-PMP4, F-LPI-INV2, S-EL-III-2-O	2		1	
F-HTS-PMP4, F-LPI-ISOV2, S-EL-III-2-O	2		1	
F-HTS-PMP3, F-LPI-INV2, S-EL-III-2-O	2		1	
F-HTS-PMP3, F-LPI-ISOV2, S-EL-III-2-O	2		1	
F-HTS-PMP2, F-LPI-INV2, S-EL-III-2-O	2		1	
F-HTS-PMP3, S-EL-III-2-E, S-EL-III-2-O	1		2	
F-HTS-PMP4, S-EL-III-2-E, S-EL-III-2-O	1		2	
F-HTS-PMP2, S-EL-III-2-E, S-EL-III-2-O	1		2	
F-HTS-PMP1, S-EL-III-2-E, S-EL-III-2-O	1		2	
S-EL-III-2-E, S-EL-III-2-O, S-EL-IV-E			3	
S-EL-III-2-E, S-EL-III-2-O, S-EL-IV-O			3	

Table C.1 (cont.)

Initiating Event - Feeder Tube Header Break		Sequence: LB-M		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-HTS-PMP1, S-ECC	1		1	
S-ECC, S-EL-IV-O			2	
F-HTS-PMP2, S-ECC	1		1	
S-ECC, S-EL-IV-E			2	
F-HTS-PMP3, S-ECC	1		1	
F-HTS-PMP4, S-ECC	1		1	
F-HPI-OV2A, F-HPI-OV2B, F-HTS-PMP1	3			
F-HPI-OV2A, F-HPI-OV2B, F-HTS-PMP2	3			
F-HPI-OV2A, F-HPI-OV2B, S-EL-IV-O	2		1	
F-HPI-OV2A, F-HPI-OV2B, F-HTS-PMP3	3			
F-HPI-OV2A, F-HPI-OV2B, S-EL-IV-E	2		1	
F-HPI-OV2A, F-HPI-OV2B, F-HTS-PMP4	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, S-EL-IV-O	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, F-HTS-PMP1	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, S-EL-IV-E	2		1	
F-HPI-OV1A, F-HPI-OV1B, F-HTS-PMP3	3			
F-HPI-OV1A, F-HPI-OV1B, F-HTS-PMP2	3			
F-HPI-INV2A, F-HPI-INV2B, F-HTS-PMP1	3			
F-HPI-INV2A, F-HPI-INV2B, F-HTS-PMP2	3			
F-HPI-INV2A, F-HPI-INV2B, S-EL-IV-O	2		1	
F-HPI-INV2A, F-HPI-INV2B, F-HTS-PMP3	3			
F-HPI-INV2A, F-HPI-INV2B, F-HTS-PMP4	3			
F-HPI-OV1A, F-HPI-OV1B, S-EL-IV-O	2		1	
F-HPI-OV1A, F-HPI-OV1B, F-HTS-PMP1	3			
F-HPI-OV1A, F-HPI-OV1B, S-EL-IV-E	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, F-HTS-PMP2	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, F-HTS-PMP3	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, F-HTS-PMP4	3			
F-HPI-ISV1-GI, F-HPI-ISV2-GI, S-EL-IV-E	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, F-HTS-PMP3	3			
F-HPI-ISV1-GI, F-HPI-ISV2-GI, S-EL-IV-O	2		1	

Table C.1 (cont.)

F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, F-HTS-PMP2	3			
F-HPI-ISV1-GI, F-HPI-ISV2-GI, F-HTS-PMP1	3			
F-HPI-ISV1-GI, F-HPI-ISV2-GI, F-HTS-PMP3	3			
F-HPI-ISV1-GI, F-HPI-ISV2-GI, F-HTS-PMP4	3			
F-HPI-ISV1-GI, F-HPI-ISV2-GI, F-HTS-PMP2	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, F-HTS-PMP1	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, S-EL-IV-O	2		1	
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, S-EL-IV-E	2		1	
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, S-EL-IV-O	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, F-HTS-PMP4	3			
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, F-HTS-PMP1	3			
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, F-HTS-PMP2	3			
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, F-HTS-PMP4	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, S-EL-IV-E	2		1	
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, F-HTS-PMP3	3			
F-HPI-INV2A, F-HPI-INV2B, S-EL-IV-E	2		1	
F-HPI-OV1A, F-HPI-OV1B, F-HTS-PMP4	3			
F-HPI-INV1A, F-HPI-INV1B, S-EL-IV-O	2		1	
F-HPI-INV1, F-HPI-INV2, S-EL-IV-E	2		1	
F-HPI-INV1A, F-HPI-INV1B, F-HTS-PMP1	3			
F-HPI-INV1A, F-HPI-INV1B, S-EL-IV-E	2		1	
F-HPI-INV1A, F-HPI-INV1B, F-HTS-PMP2	3			
F-HPI-INV1, F-HPI-INV2, S-EL-IV-O	2		1	
F-HPI-INV1, F-HPI-INV2, F-HTS-PMP3	3			
F-HPI-INV1, F-HPI-INV2, F-HTS-PMP4	3			
F-HPI-INV1, F-HPI-INV2, F-HTS-PMP2	3			
F-HPI-INV1A, F-HPI-INV1B, F-HTS-PMP4	3			
F-HPI-INV1, F-HPI-INV2, F-HTS-PMP1	3			
F-HPI-INV1A, F-HPI-INV1B, F-HTS-PMP3	3			
F-HPI-INV1, F-HTS-PMP3, S-EL-II-2-E	2		1	
F-HPI-INV1, F-HTS-PMP2, S-EL-II-2-E	2		1	
F-HPI-INV1, F-HTS-PMP4, S-EL-II-2-E	2		1	
F-HPI-INV1, F-HTS-PMP1, S-EL-II-2-E	2		1	
F-HPI-INV1, S-EL-II-2-E, S-EL-IV-O	1		2	

Table C.1 (cont.)

F-HPI-ISV2-GI, S-EL-II-2-O, S-EL-IV-O	1		2	
F-HPI-ISV2-GI, F-HTS-PMP1, S-EL-II-2-O	2		1	
F-HPI-ISV2-GI, S-EL-II-2-O, S-EL-IV-E	1		2	
F-HPI-LI-CITK, F-HPI-TK-CI, F-HTS-PMP4	3			
F-HPI-PI-GI-TK, F-HPI-TK-GI, S-EL-IV-E	2		1	
F-HPI-INV1B, S-EL-II-2-O, S-EL-IV-O	1		2	
F-HPI-INV1B, S-EL-II-2-O, S-EL-IV-E	1		2	
F-HPI-INV1B, F-HTS-PMP1, S-EL-II-2-O	2		1	
F-HPI-PI-GI-TK, F-HPI-TK-GI, F-HTS-PMP4	3			
F-HPI-PI-GI-TK, F-HPI-TK-GI, F-HTS-PMP3	3			
F-HPI-PI-GI-TK, F-HPI-TK-GI, F-HTS-PMP1	3			
F-HPI-PI-GI-TK, F-HPI-TK-GI, S-EL-IV-O	2		1	
F-HPI-PI-GI-TK, F-HPI-TK-GI, F-HTS-PMP2	3			
F-HPI-ISV2-GI, F-HTS-PMP2, S-EL-II-2-O	2		1	
F-HPI-ISV2-GI, F-HTS-PMP3, S-EL-II-2-O	2		1	
F-HPI-ISV1-GI, F-HTS-PMP4, S-EL-II-2-E	2		1	
F-HPI-INV1, S-EL-II-2-E, S-EL-IV-E	1		2	
F-HPI-ISV1-GI, F-HTS-PMP3, S-EL-II-2-E	2		1	
F-HPI-INV2, F-HTS-PMP4, S-EL-II-2-O	2		1	
F-HPI-INV2, F-HTS-PMP3, S-EL-II-2-O	2		1	
F-HPI-INV2, F-HTS-PMP1, S-EL-II-2-O	2		1	
F-HPI-INV2, S-EL-II-2-O, S-EL-IV-O	1		2	
F-HPI-INV2, F-HTS-PMP2, S-EL-II-2-O	2		1	
F-HPI-ISV1-GI, F-HTS-PMP2, S-EL-II-2-E	2		1	
F-HPI-ISV1-GI, F-HTS-PMP1, S-EL-II-2-E	2		1	
F-HPI-ISV1-GI, S-EL-II-2-E, S-EL-IV-E	1		2	
F-HPI-LI-CITK, F-HPI-TK-CI, F-HTS-PMP3	3			
F-HPI-ISV2-GI, F-HTS-PMP4, S-EL-II-2-O	2		1	
F-HPI-LI-CITK, F-HPI-TK-CI, F-HTS-PMP2	3			
F-HPI-LI-CITK, F-HPI-TK-CI, F-HTS-PMP1	3			
F-HPI-LI-CITK, F-HPI-TK-CI, S-EL-IV-O	2		1	
F-HPI-ISV1-GI, S-EL-II-2-E, S-EL-IV-O	1		2	
F-HPI-INV1B, F-HTS-PMP2, S-EL-II-2-O	2		1	
F-HPI-LI-CITK, F-HPI-TK-CI, S-EL-IV-E	2		1	

Table C.1 (cont.)

F-HPI-INV1B, F-HTS-PMP3, S-EL-II-2-O	2		1	
F-HPI-OV1A, F-HTS-PMP1, S-EL-II-2-E	2		1	
F-HPI-OV1A, F-HTS-PMP2, S-EL-II-2-E	2		1	
F-HPI-OV1A, S-EL-II-2-E, S-EL-IV-O	1		2	
F-HPI-OV1A, F-HTS-PMP3, S-EL-II-2-E	2		1	
F-HPI-OV1A, S-EL-II-2-E, S-EL-IV-E	1		2	
F-HPI-OV1A, F-HTS-PMP4, S-EL-II-2-E	2		1	
F-HPI-INV2A, S-EL-II-2-E, S-EL-IV-E	1		2	
F-HPI-OV1B, F-HTS-PMP2, S-EL-II-2-O	2		1	
F-HPI-OV1B, S-EL-II-2-O, S-EL-IV-O	1		2	
F-HPI-INV2B, S-EL-II-2-O, S-EL-IV-E	1		2	
F-HPI-OV1B, S-EL-II-2-O, S-EL-IV-E	1		2	
F-HPI-INV2B, S-EL-II-2-O, S-EL-IV-O	1		2	
F-HPI-INV2A, F-HTS-PMP2, S-EL-II-2-E	2		1	
F-HPI-INV2A, F-HTS-PMP3, S-EL-II-2-E	2		1	
F-HPI-INV2A, F-HTS-PMP1, S-EL-II-2-E	2		1	
F-HPI-INV2A, F-HTS-PMP4, S-EL-II-2-E	2		1	
F-HPI-INV2A, S-EL-II-2-E, S-EL-IV-O	1		2	
F-HPI-INV2B, F-HTS-PMP4, S-EL-II-2-O	2		1	
F-HPI-INV2B, F-HTS-PMP2, S-EL-II-2-O	2		1	
F-HPI-INV2B, F-HTS-PMP1, S-EL-II-2-O	2		1	
F-HPI-INV2B, F-HTS-PMP3, S-EL-II-2-O	2		1	
F-HPI-OV1B, F-HTS-PMP3, S-EL-II-2-O	2		1	
F-HPI-OV1B, F-HTS-PMP1, S-EL-II-2-O	2		1	
F-HPI-INV1A, F-HTS-PMP4, S-EL-II-2-E	2		1	
F-HPI-INV1A, F-HTS-PMP3, S-EL-II-2-E	2		1	
F-HPI-OV1B, F-HTS-PMP4, S-EL-II-2-O	2		1	
F-HPI-INV1A, F-HTS-PMP2, S-EL-II-2-E	2		1	
F-HPI-OV2A, F-HTS-PMP3, S-EL-II-2-E	2		1	
F-HPI-INV1A, F-HTS-PMP1, S-EL-II-2-E	2		1	
F-HPI-INV1A, S-EL-II-2-E, S-EL-IV-E	1		2	
F-HPI-INV1B, F-HTS-PMP4, S-EL-II-2-O	2		1	
F-HPI-INV1A, S-EL-II-2-E, S-EL-IV-O	1		2	
F-HPI-OV2A, F-HTS-PMP2, S-EL-II-2-E	2		1	

Table C.1 (cont.)

F-HPI-OV2A, F-HTS-PMP4, S-EL-II-2-E	2		1	
F-HPI-OV2A, F-HTS-PMP1, S-EL-II-2-E	2		1	
F-HPI-OV2B, F-HTS-PMP1, S-EL-II-2-O	2		1	
F-HPI-OV2B, S-EL-II-2-O, S-EL-IV-E	1		2	
F-HPI-OV2B, F-HTS-PMP2, S-EL-II-2-O	2		1	
F-HPI-INV2, S-EL-II-2-O, S-EL-IV-E	1		2	
F-HPI-OV2B, S-EL-II-2-O, S-EL-IV-O	1		2	
F-HPI-OV2A, S-EL-II-2-E, S-EL-IV-E	1		2	
F-HPI-OV2B, F-HTS-PMP3, S-EL-II-2-O	2		1	
F-HPI-OV2A, S-EL-II-2-E, S-EL-IV-O	1		2	
F-HPI-OV2B, F-HTS-PMP4, S-EL-II-2-O	2		1	
S-EL-II-2-E, S-EL-II-2-O, S-EL-IV-O			3	
S-EL-II-2-E, S-EL-II-2-O, S-EL-IV-E			3	
F-HTS-PMP1, S-EL-II-2-E, S-EL-II-2-O	1		2	
F-HTS-PMP4, S-EL-II-2-E, S-EL-II-2-O	1		2	
F-HTS-PMP2, S-EL-II-2-E, S-EL-II-2-O	1		2	
F-HTS-PMP3, S-EL-II-2-E, S-EL-II-2-O	1		2	

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-N</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-HTS-PMP3, F-MCS-ISV-FC, S-ECC	2		1	
F-HTS-PMP3, S-ECC, S-RCW	1		2	
F-HTS-PMP3, F-MCS-PMP2, S-ECC	2		1	
F-HTS-PMP2, S-ECC, S-EL-III-1-O	1		2	
F-HTS-PMP2, F-MCS-PMP1, S-ECC	2		1	
F-HTS-PMP2, F-MCS-PMP2, S-ECC	2		1	
F-HTS-PMP2, F-MCS-ISV-FC, S-ECC	2		1	
F-HTS-PMP2, S-ECC, S-EL-III-1-E	1		2	
F-HTS-PMP3, S-ECC, S-EL-III-1-E	1		2	
F-HTS-PMP3, F-MCS-PMP1, S-ECC	2		1	
F-HTS-PMP4, F-MCS-PMP1, S-ECC	2		1	
F-HTS-PMP4, S-ECC, S-EL-III-1-E	1		2	

Table C.1 (cont.)

F-HTS-PMP4, S-ECC, S-EL-III-1-O	1		2	
F-HTS-PMP4, F-MCS-PMP2, S-ECC	2		1	
F-HTS-PMP4, F-MCS-ISV-FC, S-ECC	2		1	
F-HTS-PMP3, S-ECC, S-EL-III-1-O	1		2	
F-HTS-PMP4, S-ECC, S-RCW	1		2	
F-HTS-PMP2, S-ECC, S-RCW	1		2	
F-HTS-PMP1, S-ECC, S-EL-III-1-O	1		2	
S-ECC, S-EL-IV-O, S-RCW			3	
S-ECC, S-EL-III-1-O, S-EL-IV-E			3	
F-MCS-ISV-FC, S-ECC, S-EL-IV-O	1		2	
F-MCS-PMP1, S-ECC, S-EL-IV-E	1		2	
S-ECC, S-EL-III-1-E, S-EL-IV-E			3	
F-MCS-ISV-FC, S-ECC, S-EL-IV-E	1		2	
F-MCS-PMP2, S-ECC, S-EL-IV-E	1		2	
F-MCS-PMP2, S-ECC, S-EL-IV-O	1		2	
S-ECC, S-EL-III-1-E, S-EL-IV-O			3	
F-HTS-PMP1, S-ECC, S-EL-III-1-E	1		2	
F-HTS-PMP1, F-MCS-PMP2, S-ECC	2		1	
F-HTS-PMP1, F-MCS-PMP1, S-ECC	2		1	
F-HTS-PMP1, F-MCS-ISV-FC, S-ECC	2		1	
F-HTS-PMP1, S-ECC, S-RCW	1		2	
F-MCS-PMP1, S-ECC, S-EL-IV-O	1		2	
S-ECC, S-EL-III-1-O, S-EL-IV-O			3	
S-ECC, S-EL-IV-E, S-RCW			3	

Table C.1 (cont.)

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-O</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-SD1-CR-BD-CM			1	Y
F-SD1-CR-COIL-CM			1	Y
F-SD1-TLB-REL2, F-SD1-TLB-REL3	2			Y
F-SD1-TLB-REL1, F-SD1-TLB-REL2	2			Y
F-SD1-TLA-REL1, F-SD1-TLA-REL2	2			Y
F-SD1-TLB-REL1, F-SD1-TLB-REL3	2			Y
F-SD1-TLA-REL2, F-SD1-TLA-REL3	2			Y
F-SD1-TLA-REL1, F-SD1-TLA-REL3	2			Y
F-SD1-TC-D, F-SD1-TC-E	2			Y
F-SD1-TC-D, F-SD1-TC-F	2			Y
F-SD1-TC-E, F-SD1-TC-F	2			Y

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-P</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-REC-ISV1, F-REC-ISV2, F-SD1-CR-BD-CM	2		1	
F-REC-ISV1, F-REC-ISV2, F-SD1-CR-COIL-CM	2		1	
F-REC-ISV2, F-SD1-CR-BD-CM, S-EL-III-2-O	1		2	
F-REC-ISV1, F-SD1-CR-COIL-CM, S-EL-III-2-E	1		2	
F-REC-ISV1, F-SD1-CR-BD-CM, S-EL-III-2-E	1		2	
F-REC-ISV2, F-SD1-CR-COIL-CM, S-EL-III-2-O	1		2	
F-REC-HX1, F-REC-HX2, F-SD1-CR-BD-CM	2		1	
F-REC-HX1, F-REC-HX2, F-SD1-CR-COIL-CM	2		1	

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-Q</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-SD1-CR-BD-CM, S-RCW, S-SW2			3	
F-SD1-CR-COIL-CM, S-RCW, S-SW2			3	

Table C.1 (cont.)

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-R</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-LPI-INV1, F-LPI-INV2, F-SD1-CR-COIL-CM	2		1	
F-LPI-ISV1, F-LPI-ISV2, F-SD1-CR-COIL-CM	2		1	
F-LPI-PMP1, F-LPI-PMP2, F-SD1-CR-BD-CM	2		1	
F-LPI-ISV1, F-LPI-ISV2, F-SD1-CR-BD-CM	2		1	
F-LPI-PMP1, F-LPI-PMP2, F-SD1-CR-COIL-CM	2		1	
F-LPI-INV1, F-LPI-INV2, F-SD1-CR-BD-CM	2		1	
F-LPI-PMP2, F-SD1-CR-BD-CM, S-EL-III-2-O	1		2	
F-LPI-PMP2, F-SD1-CR-COIL-CM, S-EL-III-2-O	1		2	
F-HPI-ISV1-GI, F-SD1-CR-COIL-CM, S-EL-III-2-E	1		2	
F-LPI-PMP1, F-SD1-CR-BD-CM, S-EL-III-2-E	1		2	
F-LPI-PMP1, F-SD1-CR-COIL-CM, S-EL-III-2-E	1		2	
F-LPI-LI-TK, F-LPI-TK, F-SD1-CR-BD-CM	2		1	
F-LPI-LI-TK, F-LPI-TK, F-SD1-CR-COIL-CM	2		1	
F-LPI-ISV2, F-SD1-CR-BD-CM, S-EL-III-2-O	1		2	
F-HPI-ISV1-GI, F-SD1-CR-BD-CM, S-EL-III-2-E	1		2	
F-HPI-ISV2-GI, F-SD1-CR-COIL-CM, S-EL-III-2-O	1		2	
F-LPI-INV1, F-SD1-CR-BD-CM, S-EL-III-2-E	1		2	
F-LPI-INV1, F-SD1-CR-COIL-CM, S-EL-III-2-E	1		2	
F-LPI-ISV1, F-SD1-CR-BD-CM, S-EL-III-2-E	1		2	
F-LPI-INV2, F-SD1-CR-BD-CM, S-EL-III-2-O	1		2	
F-LPI-INV2, F-SD1-CR-COIL-CM, S-EL-III-2-O	1		2	
F-LPI-ISV2, F-SD1-CR-COIL-CM, S-EL-III-2-O	1		2	
F-LPI-ISV1, F-SD1-CR-COIL-CM, S-EL-III-2-E	1		2	
F-HPI-ISV2-GI, F-SD1-CR-BD-CM, S-EL-III-2-O	1		2	
F-SD1-CR-COIL-CM, S-EL-III-2-E, S-EL-III-2-O			3	
F-SD1-CR-BD-CM, S-EL-III-2-E, S-EL-III-2-O			3	

Table C.1 (cont.)

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-T</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-SD1-CR-BD-CM, S-ECC			2	
F-SD1-CR-COIL-CM, S-ECC			2	
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, F-SD1-CR-COIL-CM	2		1	
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, F-SD1-CR-BD-CM	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, F-SD1-CR-BD-CM	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, F-SD1-CR-COIL-CM	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, F-SD1-CR-BD-CM	2		1	
F-HPI-OV1A, F-HPI-OV1B, F-SD1-CR-COIL-CM	2		1	
F-HPI-OV2A, F-HPI-OV2B, F-SD1-CR-COIL-CM	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, F-SD1-CR-COIL-CM	2		1	
F-HPI-ISV1-GI, F-HPI-ISV2-GI, F-SD1-CR-BD-CM	2		1	
F-SD1-TLB-REL2, F-SD1-TLB-REL3, S-ECC	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL3, S-ECC	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL2, S-ECC	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL2, S-ECC	2		1	
F-SD1-TLA-REL2, F-SD1-TLA-REL3, S-ECC	2		1	
F-HPI-ISV1-GI, F-HPI-ISV2-GI, F-SD1-CR-COIL-CM	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL3, S-ECC	2		1	
F-HPI-OV1A, F-HPI-OV1B, F-SD1-CR-BD-CM	2		1	
F-HPI-OV2A, F-HPI-OV2B, F-SD1-CR-BD-CM	2		1	
F-HPI-INV1, F-HPI-INV2, F-SD1-CR-COIL-CM	2		1	
F-HPI-INV1, F-HPI-INV2, F-SD1-CR-BD-CM	2		1	
F-HPI-INV1A, F-HPI-INV1B, F-SD1-CR-COIL-CM	2		1	
F-HPI-INV2A, F-HPI-INV2B, F-SD1-CR-COIL-CM	2		1	
F-HPI-INV2A, F-HPI-INV2B, F-SD1-CR-BD-CM	2		1	
F-HPI-INV1A, F-HPI-INV1B, F-SD1-CR-BD-CM	2		1	
F-HPI-INV1A, F-SD1-CR-BD-CM, S-EL-II-2-E	1		2	
F-HPI-INV1B, F-SD1-CR-COIL-CM, S-EL-II-2-O	1		2	
F-HPI-ISV1-GI, F-SD1-CR-COIL-CM, S-EL-II-2-E	1		2	
F-HPI-ISV1-GI, F-SD1-CR-BD-CM, S-EL-II-2-E	1		2	
F-HPI-LI-CITY, F-HPI-TK-CI, F-SD1-CR-BD-CM	2		1	

Table C.1 (cont.)

F-HPI-PI-GI-TK, F-HPI-TK-GI, F-SD1-CR-COIL-CM	2		1	
F-HPI-INV1, F-SD1-CR-BD-CM, S-EL-II-2-E	1		2	
F-HPI-INV2, F-SD1-CR-COIL-CM, S-EL-II-2-O	1		2	
F-HPI-INV1, F-SD1-CR-COIL-CM, S-EL-II-2-E	1		2	
F-HPI-INV1B, F-SD1-CR-BD-CM, S-EL-II-2-O	1		2	
F-HPI-PI-GI-TK, F-HPI-TK-GI, F-SD1-CR-BD-CM	2		1	
F-HPI-OV1A, F-SD1-CR-BD-CM, S-EL-II-2-E	1		2	
F-HPI-LI-CITK, F-HPI-TK-CI, F-SD1-CR-COIL-CM	2		1	
F-HPI-ISV2-GI, F-SD1-CR-COIL-CM, S-EL-II-2-O	1		2	
F-HPI-OV2A, F-SD1-CR-BD-CM, S-EL-II-2-E	1		2	
F-HPI-ISV2-GI, F-SD1-CR-BD-CM, S-EL-II-2-O	1		2	
F-HPI-OV2B, F-SD1-CR-COIL-CM, S-EL-II-2-O	1		2	
F-HPI-OV2B, F-SD1-CR-BD-CM, S-EL-II-2-O	1		2	
F-HPI-OV1B, F-SD1-CR-BD-CM, S-EL-II-2-O	1		2	
F-HPI-OV1B, F-SD1-CR-COIL-CM, S-EL-II-2-O	1		2	
F-HPI-OV1A, F-SD1-CR-COIL-CM, S-EL-II-2-E	1		2	
F-HPI-OV2A, F-SD1-CR-COIL-CM, S-EL-II-2-E	1		2	
F-HPI-INV2B, F-SD1-CR-BD-CM, S-EL-II-2-O	1		2	
F-HPI-INV2B, F-SD1-CR-COIL-CM, S-EL-II-2-O	1		2	
F-HPI-INV1A, F-SD1-CR-COIL-CM, S-EL-II-2-E	1		2	
F-HPI-INV2A, F-SD1-CR-BD-CM, S-EL-II-2-E	1		2	
F-HPI-INV2A, F-SD1-CR-COIL-CM, S-EL-II-2-E	1		2	
F-HPI-INV2, F-SD1-CR-BD-CM, S-EL-II-2-O	1		2	
F-SD1-CR-COIL-CM, S-EL-II-2-E, S-EL-II-2-O			3	
F-SD1-CR-BD-CM, S-EL-II-2-E, S-EL-II-2-O			3	
F-SD1-TC-D, F-SD1-TC-F, S-ECC	2		1	
F-SD1-TC-E, F-SD1-TC-F, S-ECC	2		1	
F-SD1-TC-D, F-SD1-TC-E, S-ECC	2		1	

Table C.1 (cont.)

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-U</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-MCS-PMP1, F-SD1-CR-BD-CM, S-ECC	1		2	
F-SD1-CR-COIL-CM, S-ECC, S-EL-III-1-E			3	
F-MCS-PMP1, F-SD1-CR-COIL-CM, S-ECC	1		2	
F-SD1-CR-BD-CM, S-ECC, S-EL-III-1-O			3	
F-SD1-CR-BD-CM, S-ECC, S-EL-III-1-E			3	
F-SD1-CR-COIL-CM, S-ECC, S-EL-III-1-O			3	
F-MCS-PMP2, F-SD1-CR-COIL-CM, S-ECC	1		2	
F-MCS-ISV-FC, F-SD1-CR-BD-CM, S-ECC	1		2	
F-SD1-CR-COIL-CM, S-ECC, S-RCW			3	
F-MCS-ISV-FC, F-SD1-CR-COIL-CM, S-ECC	1		2	
F-SD1-CR-BD-CM, S-ECC, S-RCW			3	
F-MCS-PMP2, F-SD1-CR-BD-CM, S-ECC	1		2	

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-V</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-SD1-CR-COIL-CM, S-EL-IV-O	1		1	
F-HTS-PMP1, F-SD1-CR-BD-CM	1		1	
F-SD1-CR-BD-CM, S-EL-IV-O			2	
F-HTS-PMP1, F-SD1-CR-COIL-CM	1		1	
F-SD1-CR-COIL-CM, S-EL-IV-E			2	
F-HTS-PMP2, F-SD1-CR-BD-CM	1		1	
F-HTS-PMP3, F-SD1-CR-COIL-CM	1		1	
F-HTS-PMP4, F-SD1-CR-BD-CM	1		1	
F-HTS-PMP3, F-SD1-CR-BD-CM	1		1	
F-SD1-CR-BD-CM, S-EL-IV-E			2	
F-HTS-PMP2, F-SD1-CR-COIL-CM	1		1	
F-HTS-PMP4, F-SD1-CR-COIL-CM	1		1	
F-HTS-PMP4, F-SD1-TLB-REL1, F-SD1-TLB-REL3	3			
F-HTS-PMP3, F-SD1-TLB-REL1, F-SD1-TLB-REL3	3			

Table C.1 (cont.)

F-SD1-TLB-REL2, F-SD1-TLB-REL3, S-EL-IV-E	2		1	
F-HTS-PMP2, F-SD1-TLB-REL1, F-SD1-TLB-REL3	3			
F-SD1-TLB-REL2, F-SD1-TLB-REL3, S-EL-IV-O	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL3, S-EL-IV-O	2		1	
F-HTS-PMP4, F-SD1-TLA-REL1, F-SD1-TLA-REL2	3			
F-HTS-PMP3, F-SD1-TLA-REL1, F-SD1-TLA-REL2	3			
F-SD1-TLB-REL1, F-SD1-TLB-REL3, S-EL-IV-E	2		1	
F-HTS-PMP1, F-SD1-TLB-REL2, F-SD1-TLB-REL3	3			
F-HTS-PMP2, F-SD1-TLB-REL2, F-SD1-TLB-REL3	3			
F-HTS-PMP3, F-SD1-TLB-REL1, F-SD1-TLB-REL2	3			
F-HTS-PMP2, F-SD1-TLB-REL1, F-SD1-TLB-REL2	3			
F-HTS-PMP4, F-SD1-TLB-REL1, F-SD1-TLB-REL2	3			
F-HTS-PMP1, F-SD1-TLB-REL1, F-SD1-TLB-REL2	3			
F-SD1-TLB-REL1, F-SD1-TLB-REL2, S-EL-IV-O	2		1	
F-HTS-PMP4, F-SD1-TLB-REL2, F-SD1-TLB-REL3	3			
F-HTS-PMP3, F-SD1-TLB-REL2, F-SD1-TLB-REL3	3			
F-SD1-TLB-REL1, F-SD1-TLB-REL2, S-EL-IV-E	2		1	
F-HTS-PMP2, F-SD1-TLA-REL1, F-SD1-TLA-REL2	3			
F-HTS-PMP1, F-SD1-TLB-REL1, F-SD1-TLB-REL3	3			
F-HTS-PMP4, F-SD1-TLA-REL1, F-SD1-TLA-REL3	3			
F-HTS-PMP2, F-SD1-TLA-REL1, F-SD1-TLA-REL3	3			
F-SD1-TLA-REL2, F-SD1-TLA-REL3, S-EL-IV-E	2		1	
F-HTS-PMP1, F-SD1-TLA-REL1, F-SD1-TLA-REL3	3			
F-SD1-TLA-REL1, F-SD1-TLA-REL3, S-EL-IV-O	2		1	
F-HTS-PMP1, F-SD1-TLA-REL1, F-SD1-TLA-REL2	3			
F-SD1-TLA-REL1, F-SD1-TLA-REL3, S-EL-IV-E	2		1	
F-SD1-TLA-REL2, F-SD1-TLA-REL3, S-EL-IV-O	2		1	
F-HTS-PMP3, F-SD1-TLA-REL1, F-SD1-TLA-REL3	3			
F-SD1-TLA-REL1, F-SD1-TLA-REL2, S-EL-IV-E	2		1	
F-HTS-PMP4, F-SD1-TLA-REL2, F-SD1-TLA-REL3	3			
F-HTS-PMP1, F-SD1-TLA-REL2, F-SD1-TLA-REL3	3			
F-HTS-PMP3, F-SD1-TLA-REL2, F-SD1-TLA-REL3	3			
F-SD1-TLA-REL1, F-SD1-TLA-REL2, S-EL-IV-O	2		1	
F-HTS-PMP2, F-SD1-TLA-REL2, F-SD1-TLA-REL3	3			

Table C.1 (cont.)

F-SD1-TC-D, F-SD1-TC-F, S-EL-IV-E	2		1	
F-HTS-PMP4, F-SD1-TC-D, F-SD1-TC-E	3			
F-HTS-PMP3, F-SD1-TC-D, F-SD1-TC-E	3			
F-SD1-TC-D, F-SD1-TC-F, S-EL-IV-O	2		1	
F-HTS-PMP1, F-SD1-TC-D, F-SD1-TC-E	3			
F-SD1-TC-D, F-SD1-TC-E, S-EL-IV-O	2		1	
F-HTS-PMP1, F-SD1-TC-D, F-SD1-TC-F	3			
F-SD1-TC-D, F-SD1-TC-E, S-EL-IV-E	2		1	
F-HTS-PMP2, F-SD1-TC-D, F-SD1-TC-E	3			
F-HTS-PMP4, F-SD1-TC-E, F-SD1-TC-F	3			
F-HTS-PMP3, F-SD1-TC-E, F-SD1-TC-F	3			
F-HTS-PMP2, F-SD1-TC-E, F-SD1-TC-F	3			
F-SD1-TC-E, F-SD1-TC-F, S-EL-IV-E	2		1	
F-HTS-PMP1, F-SD1-TC-E, F-SD1-TC-F	3			
F-SD1-TC-E, F-SD1-TC-F, S-EL-IV-O	2		1	
F-HTS-PMP3, F-SD1-TC-D, F-SD1-TC-F	3			
F-HTS-PMP4, F-SD1-TC-D, F-SD1-TC-F	3			
F-HTS-PMP2, F-SD1-TC-D, F-SD1-TC-F	3			

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-AA</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-HTS-PMP3, F-SD1-CR-BD-CM, S-ECC	1		2	
F-HTS-PMP2, F-SD1-CR-COIL-CM, S-ECC	1		2	
F-HTS-PMP3, F-SD1-CR-COIL-CM, S-ECC	1		2	
F-HTS-PMP4, F-SD1-CR-BD-CM, S-ECC	1		2	
F-HTS-PMP2, F-SD1-CR-BD-CM, S-ECC	1		2	
F-HTS-PMP4, F-SD1-CR-COIL-CM, S-ECC	1		2	
F-HTS-PMP1, F-SD1-CR-COIL-CM, S-ECC	1		2	
F-SD1-CR-BD-CM, S-ECC, S-EL-IV-O			3	
F-SD1-CR-COIL-CM, S-ECC, S-EL-IV-E			3	
F-SD1-CR-COIL-CM, S-ECC, S-EL-IV-O			3	
F-SD1-CR-BD-CM, S-ECC, S-EL-IV-E			3	
F-HTS-PMP1, F-SD1-CR-BD-CM, S-ECC	1		2	

Table C.1 (cont.)

Initiating Event - <i>Feeder Tube Header Break</i>		Sequence: <i>LB-AC</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-TL-G, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TL-G, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TL-H, F-SD2-TL-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TL-H, F-SD2-TL-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TL-G, F-SD2-TL-H	2		1	
F-SD1-CR-COIL-CM, F-SD2-TL-G, F-SD2-TL-H	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT5	2		1	

Table C.1 (cont.)

F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT3	2		1	

Table C.1 (cont.)

F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT5, F-SD2-ISV2-PT6	2		1	

Table C.1 (cont.)

F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT5, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-J, F-SD2-TL-H	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-H, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TL-H	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-G, F-SD2-TL-H	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-H, F-SD2-TL-G	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-H, F-SD2-TL-G	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-J, F-SD2-TL-H	2		1	

Table C.1 (cont.)

F-SD1-CR-BD-CM, F-SD2-TC-G, F-SD2-TL-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-J, F-SD2-TL-G	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-J, F-SD2-TL-G	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-H, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TC-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-G, F-SD2-TC-H	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TC-H	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-H, F-SD2-TC-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-H, F-SD2-TC-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-G, F-SD2-TC-J	2		1	

**Table C.2 LBLOCA events sequence categorization:
representative initiating event - feeder tube header break**

Specific Initiator		Feeder tube header break		Backflow into ECCS	
IE Frequency		1×10^{-4}		1×10^{-4}	
Sequence	Determinant Failures	Bin	Category	Bin	Category
LB-A	N/A	E	EC-II	I	EC-III
LB-B	2 valves, 2 heat exchangers	G	EC-III	K	EC-IV
LB-C	≥ 3 failures	H	EC-IV	L	EC-IV
LB-D	2 valves, 2 pumps, undetected low coolant tank level	G	EC-III	K	EC-IV
LB-E	≥ 3 failures	H	EC-IV	L	EC-IV
LB-F	support system, 2 signals, 2 valves, undetected low gas tank pressure, undetected low coolant tank volume	G	EC-III	K	EC-IV
LB-G	≥ 3 failures	H	EC-IV	L	EC-IV
LB-H	pump failure	F	EC-II	J	EC-III
LB-I	≥ 3 failures	H	EC-IV	L	EC-IV
LB-J	≥ 3 failures	H	EC-IV	L	EC-IV
LB-K	≥ 3 failures	H	EC-IV	L	EC-IV
LB-L	≥ 3 failures	H	EC-IV	L	EC-IV
LB-M	≥ 3 failures	H	EC-IV	L	EC-IV
LB-N	≥ 3 failures	H	EC-IV	L	EC-IV
LB-O	common mode failure, 2 relays, 2 trip computers	G	EC-III	K	EC-IV
LB-P	≥ 3 failures	H	EC-IV	L	EC-IV
LB-Q	≥ 3 failures	H	EC-IV	L	EC-IV
LB-R	≥ 3 failures	H	EC-IV	L	EC-IV
LB-S	≥ 3 failures	H	EC-IV	L	EC-IV
LB-T	≥ 3 failures	H	EC-IV	L	EC-IV
LB-U	≥ 3 failures	H	EC-IV	L	EC-IV
LB-V	≥ 3 failures	H	EC-IV	L	EC-IV
LB-W	≥ 3 failures	H	EC-IV	L	EC-IV
LB-X	≥ 3 failures	H	EC-IV	L	EC-IV
LB-Y	≥ 3 failures	H	EC-IV	L	EC-IV
LB-Z	≥ 3 failures	H	EC-IV	L	EC-IV
LB-AA	≥ 3 failures	H	EC-IV	L	EC-IV
LB-AB	≥ 3 failures	H	EC-IV	L	EC-IV
LB-AC	≥ 3 failures	H	EC-IV	L	EC-IV

Table C.3 Liquid relief valve failure sequence cut sets

Initiating Event - <i>Liquid Relief Valve Failure</i>	Sequence: <i>LRVF-A</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
NONE	NA	NA	NA	NA

Initiating Event - <i>Liquid Relief Valve Failure</i>	Sequence: <i>LRVF-B</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-AIR			1	1
S-EL-II-2-E, S-EL-II-2-O			2	
F-ASD-ASD1, F-CSD-SDV1, S-EL-II-2-E	2		1	
F-ASD-ASD2, F-CSD-SDV4, S-EL-II-2-O	2		1	
F-ASD-ASD1, F-CSD-SDV3, S-EL-II-2-E	2		1	
F-ASD-ASD2, F-CSD-SDV2, S-EL-II-2-O	2		1	

Initiating Event - <i>Liquid Relief Valve Failure</i>	Sequence: <i>LRVF-C</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1, S-AIR	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1, S-AIR	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2, S-AIR	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2, S-AIR	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1, S-AIR	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2, S-AIR	2		1	

Table C.3 (cont.)

F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1, S-AIR	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2, S-AIR	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2, S-AIR	2		1	
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2, S-AIR	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1, S-AIR	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1, S-AIR	2		1	

Initiating Event - <i>Liquid Relief Valve Failure</i>		Sequence: <i>LRVF-I</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-EL-II-1-O			1	Y
S-PCS			1	Y
F-BCS-CNV1-TK, S-EL-II-1-E	1		1	
F-BCS-CNV1, F-BCS-CNV1-TK	2			Y
F-BCS-CNV1-TK, F-BCS-CNV2	2			Y

Initiating Event - <i>Liquid Relief Valve Failure</i>		Sequence: <i>LRVF-J</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-LPI-INV1, F-LPI-INV2, S-EL-II-1-O	2		1	
F-LPI-ISV1, F-LPI-ISV2, S-EL-II-1-O	2		1	
F-LPI-PMP1, F-LPI-PMP2, S-EL-II-1-O	2		1	
F-LPI-INV2, S-EL-II-1-O, S-EL-III-2-O	1		2	
F-LPI-ISV1, S-EL-II-1-O, S-EL-III-2-E	1		2	
F-LPI-INV1, S-EL-II-1-O, S-EL-III-2-E	1		2	
F-HPI-ISV2-GI, S-EL-II-1-O, S-EL-III-2-O	1		2	
F-LPI-PMP2, S-EL-II-1-O, S-EL-III-2-O	1		2	
F-LPI-PMP1, S-EL-II-1-O, S-EL-III-2-E	1		2	
F-HPI-ISV1-GI, S-EL-II-1-O, S-EL-III-2-E	1		2	
F-LPI-ISV2, S-EL-II-1-O, S-EL-III-2-O	1		2	
F-LPI-LI-TK, F-LPI-TK, S-EL-II-1-O	2		1	
F-LPI-INV1, F-LPI-INV2, S-PCS	2		1	
F-LPI-ISV1, F-LPI-ISV2, S-PCS	2		1	

Table C.3 (cont.)

F-LPI-PMP1, F-LPI-PMP2, S-PCS	2		1	
F-LPI-INV1, S-EL-III-2-E, S-PCS	1		2	
F-LPI-INV2, S-EL-III-2-O, S-PCS	1		2	
F-LPI-ISV1, S-EL-III-2-E, S-PCS	1		2	
F-LPI-ISV2, S-EL-III-2-O, S-PCS	1		2	
F-HPI-ISV2-GI, S-EL-III-2-O, S-PCS	1		2	
F-LPI-PMP1, S-EL-III-2-E, S-PCS	1		2	
S-EL-II-1-O, S-EL-III-2-E, S-EL-III-2-O			3	
F-LPI-PMP2, S-EL-III-2-O, S-PCS	1		2	
F-LPI-LI-TK, F-LPI-TK, S-PCS	2		1	
F-HPI-ISV1-GI, S-EL-III-2-E, S-PCS	1		2	
S-EL-III-2-E, S-EL-III-2-O, S-PCS			3	

Initiating Event - <i>Liquid Relief Valve Failure</i>	Sequence: <i>LRVF-L</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-HPI-OV1A, F-HPI-OV1B, S-EL-II-1-O	2		1	
F-HPI-OV2A, F-HPI-OV2B, S-EL-II-1-O	2		1	
F-HPI-INV2A, F-HPI-INV2B, S-EL-II-1-O	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, S-EL-II-1-O	2		1	
F-HPI-INV1A, F-HPI-INV1B, S-EL-II-1-O	2		1	
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, S-EL-II-1-O	2		1	
F-HPI-INV1, F-HPI-INV2, S-EL-II-1-O	2		1	
F-HPI-ISV1-GI, F-HPI-ISV2-GI, S-EL-II-1-O	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, S-EL-II-1-O	2		1	
F-HPI-INV1, F-HPI-INV2, S-PCS	2		1	
F-HPI-LI-CITK, F-HPI-TK-CI, S-EL-II-1-O	2		1	
F-HPI-PI-GI-TK, F-HPI-TK-GI, S-EL-II-1-O	2		1	
F-HPI-OV1A, F-HPI-OV1B, S-PCS	2		1	
F-HPI-OV2A, F-HPI-OV2B, S-PCS	2		1	
F-HPI-INV2A, F-HPI-INV2B, S-PCS	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, S-PCS	2		1	
F-HPI-INV1A, F-HPI-INV1B, S-PCS	2		1	

Table C.3 (cont.)

F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, S-PCS	2		1	
F-HPI-ISV1-GI, F-HPI-ISV2-GI, S-PCS	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, S-PCS	2		1	
F-HPI-PI-GI-TK, F-HPI-TK-GI, S-PCS	2		1	
F-HPI-LI-CITK, F-HPI-TK-CI, S-PCS	2		1	

Initiating Event - <i>Liquid Relief Valve Failure</i>		Sequence: <i>LRVF-N</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-FW1-ISV1, S-PCS	1		1	
F-FW1-ISV2, S-PCS	1		1	
S-EL-IV-E, S-EL-IV-O, S-PCS			3	
F-FW1-DV2, S-EL-IV-O, S-PCS	1		2	
S-EL-II-1-E, S-EL-II-1-O, S-PCS			3	
F-FW1-CNV2, S-EL-II-1-O, S-PCS	1		2	
F-FW1-CNV1, F-FW1-CNV2, S-PCS	2		1	
F-FW1-CNV1, S-EL-II-1-E, S-PCS	1		2	
F-FW1-DV1, S-EL-IV-E, S-PCS	1		2	
F-FW1-DV1, F-FW1-PMP2, S-PCS	2		1	
F-FW1-PMP1, F-FW1-PMP2, S-PCS	2		1	
F-FW1-DV2, F-FW1-PMP1, S-PCS	2		1	
F-FW1-DV1, F-FW1-DV2, S-PCS	2		1	
F-FW1-PMP2, S-EL-IV-O, S-PCS	1		2	
F-FW1-PMP1, S-EL-IV-E, S-PCS	1		2	

Initiating Event - <i>Liquid Relief Valve Failure</i>		Sequence: <i>LRVF-O</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-FW1-HE, S-PCS, S-RCW		1	2	
F-FW1-ISV1, S-EL-III-1-O, S-PCS	1		2	
F-FW1-ISV2, S-EL-III-1-O, S-PCS	1		2	
F-FW1-ISV2, S-PCS, S-RCW	1		2	
F-FW1-ISV1, S-PCS, S-RCW	1		2	

Table C.3 (cont.)

F-FW1-ISV1, F-MCS-PMP1, S-PCS	2		1	
S-FIW, S-PCS, S-RCW			3	
F-FW1-ISV2, F-MCS-PMP1, S-PCS	2		1	
F-FW1-ISV2, F-MCS-PMP2, S-PCS	2		1	
F-FW1-ISV1, F-MCS-ISV-FC, S-PCS	2		1	
F-FW1-ISV1, F-MCS-PMP2, S-PCS	2		1	
F-FW1-ISV2, S-EL-III-1-E, S-PCS	1		2	
F-FW1-ISV2, F-MCS-ISV-FC, S-PCS	2		1	
F-FW1-ISV1, S-EL-III-1-E, S-PCS	1		2	

Initiating Event - <i>Liquid Relief Valve Failure</i>		Sequence: <i>LRVF-P</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-EL-II-1-O, S-EL-II-2-O			2	
S-ECC, S-EL-II-1-O			2	
S-AIR, S-EL-II-1-O			2	
S-EL-II-1-O, S-EL-II-2-E			2	
F-BCS-CNV1-TK, S-AIR	1		1	
S-EL-II-2-E, S-PCS			2	
S-ECC, S-PCS			2	
S-AIR, S-PCS			2	
S-EL-II-2-O, S-PCS			2	
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1, S-EL-II-1-O	2		1	
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2, S-EL-II-1-O	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1, S-EL-II-1-O	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1, S-EL-II-1-O	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1, S-EL-II-1-O	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1, S-EL-II-1-O	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2, S-EL-II-1-O	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2, S-EL-II-1-O	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2, S-EL-II-1-O	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1, S-EL-II-1-O	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2, S-EL-II-1-O	2		1	

Table C.3 (cont.)

F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2, S-EL-II-1-O	2		1	
F-BCS-CNV1, F-BCS-CNV1-TK, S-EL-II-2-E	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1, S-PCS	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2, S-PCS	2		1	
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1, S-PCS	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2, S-PCS	2		1	
F-BCS-CNV1-TK, F-BCS-CNV2, S-EL-II-2-E	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2, S-PCS	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1, S-PCS	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1, S-PCS	2		1	
F-BCS-CNV1, F-BCS-CNV1-TK, S-ECC	2		1	
F-BCS-CNV1-TK, S-EL-II-1-E, S-EL-II-2-O	1		2	
F-BCS-CNV1, F-BCS-CNV1-TK, S-EL-II-2-O	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2, S-PCS	2		1	
F-BCS-CNV1-TK, F-BCS-CNV2, S-EL-II-2-O	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2, S-PCS	2		1	
F-BCS-CNV1-TK, S-ECC, S-EL-II-1-E	1		2	
F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1, S-PCS	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1, S-PCS	2		1	
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2, S-PCS	2		1	
F-BCS-CNV1-TK, S-EL-II-1-E, S-EL-II-2-E	1		2	
F-BCS-CNV1-TK, F-BCS-CNV2, S-ECC	2		1	

Initiating Event - <i>Liquid Relief Valve Failure</i>	Sequence: <i>LRVF-Q</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-EL-II-1-O, S-EL-II-2-O, S-EL-III-1-O			3	
F-MCS-PMP1, S-EL-II-1-O, S-EL-II-2-O	1		2	
S-AIR, S-EL-II-1-O, S-RCW			3	
S-EL-II-1-O, S-EL-II-2-O, S-EL-III-1-E			3	
F-MCS-PMP2, S-EL-II-1-O, S-EL-II-2-O	1		2	
S-EL-II-1-O, S-EL-II-2-O, S-RCW			3	
S-ECC, S-EL-II-1-O, S-EL-III-1-O			3	

Table C.3 (cont.)

F-MCS-ISV-FC, S-EL-II-1-O, S-EL-II-2-O	1		2	
F-MCS-ISV-FC, S-AIR, S-EL-II-1-O	1		2	
F-MCS-PMP2, S-AIR, S-EL-II-1-O	1		2	
F-BCS-CNV1-TK, S-AIR, S-EL-III-1-E	1		2	
F-BCS-CNV1-TK, F-MCS-PMP2, S-AIR	2		1	
F-BCS-CNV1-TK, F-MCS-PMP1, S-AIR	2		1	
F-BCS-CNV1-TK, F-MCS-ISV-FC, S-AIR	2		1	
F-BCS-CNV1-TK, S-AIR, S-RCW	1		2	
F-MCS-PMP1, S-AIR, S-EL-II-1-O	1		2	
S-AIR, S-EL-II-1-O, S-EL-III-1-E			3	
S-AIR, S-EL-II-1-O, S-EL-III-1-O			3	
F-MCS-PMP1, S-ECC, S-EL-II-1-O	1		2	
F-BCS-CNV1-TK, S-AIR, S-EL-III-1-O	1		2	
S-EL-II-1-O, S-EL-II-2-E, S-EL-III-1-E			3	
F-MCS-PMP2, S-EL-II-1-O, S-EL-II-2-E	1		2	
S-ECC, S-EL-II-1-O, S-RCW			3	
S-EL-II-1-O, S-EL-II-2-E, S-EL-III-1-O			3	
F-MCS-ISV-FC, S-EL-II-1-O, S-EL-II-2-E	1		2	
F-MCS-PMP1, S-EL-II-1-O, S-EL-II-2-E	1		2	
F-MCS-ISV-FC, S-ECC, S-EL-II-1-O	1		2	
S-EL-II-1-O, S-EL-II-2-E, S-RCW			3	
S-ECC, S-EL-II-1-O, S-EL-III-1-E			3	
F-MCS-PMP2, S-ECC, S-EL-II-1-O	1		2	
S-EL-II-2-E, S-PCS, S-RCW			3	
S-AIR, S-EL-III-1-E, S-PCS			3	
F-MCS-PMP2, S-EL-II-2-E, S-PCS	1		2	
F-MCS-PMP1, S-EL-II-2-E, S-PCS	1		2	
F-MCS-PMP1, S-AIR, S-PCS	1		2	
F-MCS-ISV-FC, S-EL-II-2-E, S-PCS	1		2	
S-AIR, S-EL-III-1-O, S-PCS			3	
F-MCS-PMP2, S-AIR, S-PCS	1		2	
S-EL-II-2-E, S-EL-III-1-E, S-PCS			3	
S-AIR, S-PCS, S-RCW			3	
F-MCS-PMP2, S-ECC, S-PCS	1		2	

Table C.3 (cont.)

F-MCS-PMP2, S-EL-II-2-O, S-PCS	1		2	
F-MCS-ISV-FC, S-EL-II-2-O, S-PCS	1		2	
S-EL-II-2-O, S-PCS, S-RCW			3	
S-ECC, S-EL-III-1-O, S-PCS			3	
S-ECC, S-EL-III-1-E, S-PCS			3	
S-EL-II-2-O, S-EL-III-1-E, S-PCS			3	
F-MCS-ISV-FC, S-ECC, S-PCS	1		2	
F-MCS-PMP1, S-ECC, S-PCS	1		2	
F-MCS-ISV-FC, S-AIR, S-PCS	1		2	
S-ECC, S-PCS, S-RCW			3	
S-EL-II-2-O, S-EL-III-1-O, S-PCS			3	
S-EL-II-2-E, S-EL-III-1-O, S-PCS			3	
F-MCS-PMP1, S-EL-II-2-O, S-PCS	1		2	

Initiating Event - <i>Liquid Relief Valve Failure</i>		Sequence: <i>LRVF-R</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-SD1-CR-BD-CM			1	Y
F-SD1-CR-COIL-CM			1	Y
F-SD1-TLB-REL2, F-SD1-TLB-REL3	2			Y
F-SD1-TLB-REL1, F-SD1-TLB-REL2	2			Y
F-SD1-TLA-REL1, F-SD1-TLA-REL2	2			Y
F-SD1-TLB-REL1, F-SD1-TLB-REL3	2			Y
F-SD1-TLA-REL2, F-SD1-TLA-REL3	2			Y
F-SD1-TLA-REL1, F-SD1-TLA-REL3	2			Y
F-SD1-TC-D, F-SD1-TC-E	2			Y
F-SD1-TC-D, F-SD1-TC-F	2			Y
F-SD1-TC-E, F-SD1-TC-F	2			Y

Table C.3 (cont.)

Initiating Event - <i>Liquid Relief Valve Failure</i>		Sequence: <i>LRVF-S</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-SD1-CR-BD-CM, S-AIR			2	
F-SD1-CR-COIL-CM, S-AIR			2	
F-SD1-TLB-REL2, F-SD1-TLB-REL3, S-AIR	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL3, S-AIR	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL2, S-AIR	2		1	
F-SD1-TLA-REL2, F-SD1-TLA-REL3, S-AIR	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL2, S-AIR	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL3, S-AIR	2		1	
F-SD1-CR-COIL-CM, S-EL-II-2-E, S-EL-II-2-O			3	
F-SD1-CR-BD-CM, S-EL-II-2-E, S-EL-II-2-O			3	
F-SD1-TC-E, F-SD1-TC-F, S-AIR	2		1	
F-SD1-TC-D, F-SD1-TC-F, S-AIR	2		1	
F-SD1-TC-D, F-SD1-TC-E, S-AIR	2		1	

Initiating Event - <i>Liquid Relief Valve Failure</i>		Sequence: <i>LRVF-Z</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-SD1-CR-BD-CM, S-EL-II-1-O			2	
F-SD1-CR-COIL-CM, S-EL-II-1-O			2	
F-SD1-CR-COIL-CM, S-PCS			2	
F-SD1-CR-BD-CM, S-PCS			2	
F-SD1-TLA-REL1, F-SD1-TLA-REL2, S-EL-II-1-O	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL3, S-EL-II-1-O	2		1	
F-SD1-TLA-REL2, F-SD1-TLA-REL3, S-EL-II-1-O	2		1	
F-SD1-TLB-REL2, F-SD1-TLB-REL3, S-EL-II-1-O	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL3, S-EL-II-1-O	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL2, S-EL-II-1-O	2		1	
F-BCS-CNV1-TK, F-BCS-CNV2, F-SD1-CR-COIL-CM	2		1	
F-BCS-CNV1-TK, F-SD1-CR-BD-CM, S-EL-II-1-E	2		1	
F-BCS-CNV1, F-BCS-CNV1-TK, F-SD1-CR-BD-CM	2		1	

Table C.3 (cont.)

F-BCS-CNV1, F-BCS-CNV1-TK, F-SD1-CR-COIL-CM	2		1	
F-BCS-CNV1-TK, F-SD1-CR-COIL-CM, S-EL-II-1-E	1		2	
F-SD1-TLA-REL2, F-SD1-TLA-REL3, S-PCS	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL2, S-PCS	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL3, S-PCS	2		1	
F-SD1-TLB-REL2, F-SD1-TLB-REL3, S-PCS	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL3, S-PCS	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL2, S-PCS	2		1	
F-BCS-CNV1-TK, F-BCS-CNV2, F-SD1-CR-BD-CM	2		1	
F-SD1-TC-D, F-SD1-TC-F, S-EL-II-1-O	2		1	
F-SD1-TC-E, F-SD1-TC-F, S-EL-II-1-O	2		1	
F-SD1-TC-D, F-SD1-TC-E, S-EL-II-1-O	2		1	
F-SD1-TC-D, F-SD1-TC-E, S-PCS	2		1	
F-SD1-TC-E, F-SD1-TC-F, S-PCS	2		1	
F-SD1-TC-D, F-SD1-TC-F, S-PCS	2		1	

Initiating Event - <i>Liquid Relief Valve Failure</i>		Sequence: <i>LRVF-AE</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-FW1-ISV2, F-SD1-CR-COIL-CM, S-PCS	1		2	
F-FW1-ISV1, F-SD1-CR-COIL-CM, S-PCS	1		2	
F-FW1-ISV1, F-SD1-CR-BD-CM, S-PCS	1		2	
F-FW1-ISV2, F-SD1-CR-BD-CM, S-PCS	1		2	

Initiating Event - <i>Liquid Relief Valve Failure</i>		Sequence: <i>LRVF-AG</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-SD1-CR-COIL-CM, S-EL-II-1-O, S-EL-II-2-O			3	
F-SD1-CR-BD-CM, S-EL-II-1-O, S-EL-II-2-O			3	
F-SD1-CR-BD-CM, S-AIR, S-EL-II-1-O			3	
F-SD1-CR-COIL-CM, S-AIR, S-EL-II-1-O			3	
F-SD1-CR-COIL-CM, S-ECC, S-EL-II-1-O			3	
F-BCS-CNV1-TK, F-SD1-CR-BD-CM, S-AIR	1		2	

Table C.3 (cont.)

F-BCS-CNV1-TK, F-SD1-CR-COIL-CM, S-AIR	1		2	
F-SD1-CR-BD-CM, S-EL-II-1-O, S-EL-II-2-E			3	
F-SD1-CR-COIL-CM, S-EL-II-1-O, S-EL-II-2-E			3	
F-SD1-CR-BD-CM, S-ECC, S-EL-II-1-O			3	
F-SD1-CR-COIL-CM, S-AIR, S-PCS			3	
F-SD1-CR-BD-CM, S-EL-II-2-E, S-PCS			3	
F-SD1-CR-COIL-CM, S-EL-II-2-E, S-PCS			3	
F-SD1-CR-BD-CM, S-AIR, S-PCS			3	
F-SD1-CR-COIL-CM, S-EL-II-2-O, S-PCS			3	
F-SD1-CR-BD-CM, S-EL-II-2-O, S-PCS			3	
F-SD1-CR-COIL-CM, S-ECC, S-PCS			3	
F-SD1-CR-BD-CM, S-ECC, S-PCS			3	

Initiating Event - <i>Liquid Relief Valve Failure</i>		Sequence: <i>LRVF-FTSD-A</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-TL-G, F-SD2-TL-J	2		1	

Table C.3 (cont.)

F-SD1-CR-COIL-CM, F-SD2-TL-G, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TL-H, F-SD2-TL-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TL-H, F-SD2-TL-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TL-G, F-SD2-TL-H	2		1	
F-SD1-CR-COIL-CM, F-SD2-TL-G, F-SD2-TL-H	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT5	2		1	

Table C.3 (cont.)

F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT2	2		1	

Table C.3 (cont.)

F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT5, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT5, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT5	2		1	

Table C.3 (cont.)

F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-J, F-SD2-TL-H	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-H, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TL-H	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-G, F-SD2-TL-H	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-H, F-SD2-TL-G	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-H, F-SD2-TL-G	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-J, F-SD2-TL-H	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-G, F-SD2-TL-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-J, F-SD2-TL-G	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-J, F-SD2-TL-G	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-H, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TC-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-G, F-SD2-TC-H	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TC-H	2		1	

**Table C.4 Small-break loss-of-coolant events sequence categorization:
representative initiating event - liquid relief valve failure**

Specific Initiator		Liquid relief valve failure		Failure of pressure and inventory control system	
IE Frequency		1×10^{-1}		1×10^{-2}	
Sequence	Determinant Failures	Bin	Category	Bin	Category
LRVF-A	NA	A	EC-I	A	EC-I
LRVF-B	support system	C	EC-III	C	EC-III
LRVF-C	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-D	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-E	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-F	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-G	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-H	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-I	support systems, 2 valves	C	EC-III	C	EC-III
LRVF-J	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-K	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-L	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-M	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-N	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-O	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-P	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-Q	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-R	common mode failure, 2 relays, 2 trip computers	C	EC-III	C	EC-III
LRVF-S	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-T	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-U	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-V	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-W	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-X	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-Y	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-Z	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-AA	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-AB	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-AC	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-AD	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-AE	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-AF	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-AG	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-AH	≥ 3 failures	D	EC-IV	D	EC-IV

Table C.4 (cont.)

Specific Initiator		<i>Liquid relief valve failure</i>		Failure of pressure and inventory control system	
IE Frequency		1×10^{-1}		1×10^{-2}	
Sequence	Determinant Failures	Bin	Category	Bin	Category
LRVF-FTSD-A	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-FTSD-B	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-FTSD-C	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-FTSD-D	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-FTSD-E	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-FTSD-F	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-FTSD-G	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-FTSD-H	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-FTSD-I	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-FTSD-J	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-FTSD-K	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-FTSD-L	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-FTSD-M	≥ 3 failures	D	EC-IV	D	EC-IV
LRVF-FTSD-N	≥ 3 failures	D	EC-IV	D	EC-IV

Table C.5 Feeder tube break sequence cut sets

Initiating Event - Feeder Tube Break	Sequence: <i>SBLFB-A</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
NONE	NA	NA	NA	NA

Initiating Event - Feeder Tube Break	Sequence: <i>SBLFB-B</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-LPI-ISV1, F-LPI-ISV2	2			Y
F-LPI-PMP1, F-LPI-PMP2	2			Y
F-LPI-INV1, F-LPI-INV2	2			Y
F-LPI-PMP1, S-EL-III-2-E	1		1	
F-LPI-PMP2, S-EL-III-2-O	1		1	
F-LPI-ISV2, S-EL-III-2-O	1		1	
F-HPI-ISV1-GI, S-EL-III-2-E	1		1	
F-LPI-LI-TK, F-LPI-TK	2			Y
F-HPI-ISV2-GI, S-EL-III-2-O	1		1	
F-LPI-INV2, S-EL-III-2-O	1		1	
F-LPI-ISV1, S-EL-III-2-E	1		1	
F-LPI-INV1, S-EL-III-2-E	1		1	
S-EL-III-2-E, S-EL-III-2-O			2	

Initiating Event - Feeder Tube Break	Sequence: <i>SBLFB-C</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-LPI-INV1, F-LPI-INV2, F-MCS-ISV-FC	3			
F-LPI-ISV1, F-LPI-ISV2, S-RCW	2		1	
F-LPI-INV1, F-LPI-INV2, F-MCS-PMP2	3			
F-LPI-ISV1, F-LPI-ISV2, S-EL-III-1-O	2		1	
F-LPI-ISV1, F-LPI-ISV2, F-MCS-PMP1	3			
F-LPI-ISV1, F-LPI-ISV2, F-MCS-PMP2	3			

Table C.5 (cont.)

F-LPI-ISV1, F-LPI-ISV2, S-EL-III-1-E	2		1	
F-LPI-INV1, F-LPI-INV2, F-MCS-PMP1	3			
F-LPI-INV1, F-LPI-INV2, S-EL-III-1-O	2		1	
F-LPI-PMP1, F-LPI-PMP2, S-EL-III-1-O	2		1	
F-LPI-PMP1, F-LPI-PMP2, F-MCS-PMP1	3			
F-LPI-PMP1, F-LPI-PMP2, S-RCW	2		1	
F-LPI-PMP1, F-LPI-PMP2, S-EL-III-1-E	2		1	
F-LPI-PMP1, F-LPI-PMP2, F-MCS-PMP2	3			
F-LPI-INV1, F-LPI-INV2, S-RCW	2		1	
F-LPI-PMP1, F-LPI-PMP2, F-MCS-ISV-FC	3			
F-LPI-ISV1, F-LPI-ISV2, F-MCS-ISV-FC	3			
F-LPI-INV1, F-LPI-INV2, S-EL-III-1-E	2		1	
F-LPI-PMP2, F-MCS-PMP2, S-EL-III-2-O	2		1	
F-LPI-PMP2, F-MCS-ISV-FC, S-EL-III-2-O	2		1	
F-LPI-PMP2, S-EL-III-1-E, S-EL-III-2-O	1		2	
F-LPI-PMP2, F-MCS-PMP1, S-EL-III-2-O	2		1	
F-HPI-ISV1-GI, S-EL-III-2-E, S-RCW	1		2	
F-LPI-PMP2, S-EL-III-1-O, S-EL-III-2-O	1		2	
F-HPI-ISV1-GI, S-EL-III-1-O, S-EL-III-2-E	1		2	
F-HPI-ISV1-GI, F-MCS-ISV-FC, S-EL-III-2-E	2		1	
F-LPI-ISV1, S-EL-III-2-E, S-RCW	1		2	
F-HPI-ISV1-GI, F-MCS-PMP2, S-EL-III-2-E	2		1	
F-HPI-ISV1-GI, S-EL-III-1-E, S-EL-III-2-E	1		2	
F-LPI-PMP2, S-EL-III-2-O, S-RCW	1		2	
F-HPI-ISV1-GI, F-MCS-PMP1, S-EL-III-2-E	2		1	
F-LPI-PMP1, F-MCS-ISV-FC, S-EL-III-2-E	2		1	
F-LPI-LI-TK, F-LPI-TK, S-EL-III-1-E	2		1	
F-LPI-LI-TK, F-LPI-TK, F-MCS-PMP2	3			
F-LPI-LI-TK, F-LPI-TK, F-MCS-PMP1	3			
F-LPI-LI-TK, F-LPI-TK, S-EL-III-1-O	2		1	
F-LPI-LI-TK, F-LPI-TK, F-MCS-ISV-FC	3			
F-LPI-LI-TK, F-LPI-TK, S-RCW	2		1	
F-LPI-ISV2, F-MCS-ISV-FC, S-EL-III-2-O	2		1	
F-LPI-PMP1, S-EL-III-1-E, S-EL-III-2-E	1		2	

Table C.5 (cont.)

F-LPI-PMP1, F-MCS-PMP2, S-EL-III-2-E	2		1	
F-LPI-PMP1, F-MCS-PMP1, S-EL-III-2-E	2		1	
F-LPI-PMP1, S-EL-III-1-O, S-EL-III-2-E	1		2	
F-HPI-ISV2-GI, S-EL-III-1-O, S-EL-III-2-O	1		2	
F-LPI-PMP1, S-EL-III-2-E, S-RCW	1		2	
F-HPI-ISV2-GI, S-EL-III-2-O, S-RCW	1		2	
F-LPI-INV1, F-MCS-PMP1, S-EL-III-2-E	2		1	
F-LPI-INV1, S-EL-III-1-E, S-EL-III-2-E	1		2	
F-LPI-INV1, S-EL-III-1-O, S-EL-III-2-E	1		2	
F-LPI-INV1, S-EL-III-2-E, S-RCW	1		2	
F-LPI-INV1, F-MCS-PMP2, S-EL-III-2-E	2		1	
F-HPI-ISV2-GI, F-MCS-PMP1, S-EL-III-2-O	2		1	
F-LPI-INV1, F-MCS-ISV-FC, S-EL-III-2-E	2		1	
F-LPI-ISV1, F-MCS-PMP1, S-EL-III-2-E	2		1	
F-LPI-ISV1, S-EL-III-1-O, S-EL-III-2-E	1		2	
F-LPI-ISV1, S-EL-III-1-E, S-EL-III-2-E	1		2	
F-LPI-ISV1, F-MCS-PMP2, S-EL-III-2-E	2		1	
F-LPI-INV2, F-MCS-PMP2, S-EL-III-2-O	2		1	
F-LPI-ISV1, F-MCS-ISV-FC, S-EL-III-2-E	2		1	
F-LPI-INV2, F-MCS-ISV-FC, S-EL-III-2-O	2		1	
F-LPI-ISV2, F-MCS-PMP2, S-EL-III-2-O	2		1	
F-LPI-ISV2, S-EL-III-1-E, S-EL-III-2-O	1		2	
F-HPI-ISV2-GI, F-MCS-ISV-FC, S-EL-III-2-O	2		1	
F-HPI-ISV2-GI, F-MCS-PMP2, S-EL-III-2-O	2		1	
F-LPI-ISV2, F-MCS-PMP1, S-EL-III-2-O	2		1	
F-LPI-INV2, S-EL-III-1-E, S-EL-III-2-O	1		2	
F-HPI-ISV2-GI, S-EL-III-1-E, S-EL-III-2-O	1		2	
F-LPI-INV2, S-EL-III-2-O, S-RCW	1		2	
F-LPI-ISV2, S-EL-III-2-O, S-RCW	1		2	
F-LPI-INV2, S-EL-III-1-O, S-EL-III-2-O	1		2	
F-LPI-ISV2, S-EL-III-1-O, S-EL-III-2-O	1		2	
F-LPI-INV2, F-MCS-PMP1, S-EL-III-2-O	2		1	
S-EL-III-1-O, S-EL-III-2-E, S-EL-III-2-O			3	
S-EL-III-2-E, S-EL-III-2-O, S-RCW			3	

Table C.5 (cont.)

F-MCS-PMP1, S-EL-III-2-E, S-EL-III-2-O	1		2	
S-EL-III-1-E, S-EL-III-2-E, S-EL-III-2-O			3	
F-MCS-ISV-FC, S-EL-III-2-E, S-EL-III-2-O	1		2	
F-MCS-PMP2, S-EL-III-2-E, S-EL-III-2-O	1		2	

Initiating Event - <i>Feeder Tube Break</i>		Sequence: <i>SBLFB-D</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS	2			Y
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS	2			Y
F-HPI-ISV1-GI, F-HPI-ISV2-GI	2			Y
F-HPI-INV1, F-HPI-INV2	2			Y
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS	2			Y
F-HPI-OV2A, F-HPI-OV2B	2			Y
F-HPI-INV1A, F-HPI-INV1B	2			Y
F-HPI-INV2A, F-HPI-INV2B	2			Y
F-HPI-OV1A, F-HPI-OV1B	2			Y
F-HPI-PI-GI-TK, F-HPI-TK-GI	2			Y
F-HPI-LI-CITK, F-HPI-TK-CI	2			Y

Initiating Event - <i>Feeder Tube Break</i>		Sequence: <i>SBLFB-E</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, F-MCS-ISV-FC	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, S-RCW	2		1	
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, F-MCS-PMP2	3			
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, S-EL-III-1-E	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, S-EL-III-1-O	2		1	
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, F-MCS-PMP1	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, F-MCS-PMP1	3			
F-HPI-OV2A, F-HPI-OV2B, S-RCW	2		1	
F-HPI-OV2A, F-HPI-OV2B, S-EL-III-1-O	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, F-MCS-ISV-FC	3			

Table C.5 (cont.)

F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, F-MCS-PMP2	3			
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, S-EL-III-1-O	2		1	
F-HPI-INV1, F-HPI-INV2, F-MCS-ISV-FC	3			
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, S-RCW	2		1	
F-HPI-ISV1-GI, F-HPI-ISV2-GI, S-EL-III-1-E	2		1	
F-HPI-ISV1-GI, F-HPI-ISV2-GI, F-MCS-PMP2	3			
F-HPI-ISV1-GI, F-HPI-ISV2-GI, F-MCS-PMP1	3			
F-HPI-ISV1-GI, F-HPI-ISV2-GI, S-EL-III-1-O	2		1	
F-HPI-ISV1-GI, F-HPI-ISV2-GI, F-MCS-ISV-FC	3			
F-HPI-ISV1-GI, F-HPI-ISV2-GI, S-RCW	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, S-RCW	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, F-MCS-PMP2	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, F-MCS-ISV-FC	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, S-EL-III-1-E	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, F-MCS-PMP1	3			
F-HPI-OV2A, F-HPI-OV2B, F-MCS-PMP1	3			
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, S-EL-III-1-O	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, S-EL-III-1-E	2		1	
F-HPI-INV1A, F-HPI-INV1B, F-MCS-PMP1	3			
F-HPI-OV2A, F-HPI-OV2B, S-EL-III-1-E	2		1	
F-HPI-INV1A, F-HPI-INV1B, S-EL-III-1-O	2		1	
F-HPI-INV1A, F-HPI-INV1B, S-RCW	2		1	
F-HPI-INV1A, F-HPI-INV1B, F-MCS-PMP2	3			
F-HPI-INV2A, F-HPI-INV2B, F-MCS-ISV-FC	3			
F-HPI-INV1A, F-HPI-INV1B, F-MCS-ISV-FC	3			
F-HPI-INV1, F-HPI-INV2, S-EL-III-1-E	2		1	
F-HPI-INV1, F-HPI-INV2, F-MCS-PMP2	3			
F-HPI-INV1, F-HPI-INV2, F-MCS-PMP1	3			
F-HPI-INV1, F-HPI-INV2, S-EL-III-1-O	2		1	
F-HPI-INV2A, F-HPI-INV2B, F-MCS-PMP2	3			
F-HPI-INV1, F-HPI-INV2, S-RCW	2		1	
F-HPI-INV1A, F-HPI-INV1B, S-EL-III-1-E	2		1	
F-HPI-OV1A, F-HPI-OV1B, S-EL-III-1-O	2		1	
F-HPI-OV1A, F-HPI-OV1B, F-MCS-PMP1	3			

Table C.5 (cont.)

F-HPI-OV1A, F-HPI-OV1B, S-RCW	2		1	
F-HPI-OV2A, F-HPI-OV2B, F-MCS-ISV-FC	3			
F-HPI-OV1A, F-HPI-OV1B, S-EL-III-1-E	2		1	
F-HPI-INV2A, F-HPI-INV2B, S-EL-III-1-E	2		1	
F-HPI-OV2A, F-HPI-OV2B, F-MCS-PMP2	3			
F-HPI-OV1A, F-HPI-OV1B, F-MCS-PMP2	3			
F-HPI-INV2A, F-HPI-INV2B, F-MCS-PMP1	3			
F-HPI-INV2A, F-HPI-INV2B, S-EL-III-1-O	2		1	
F-HPI-INV2A, F-HPI-INV2B, S-RCW	2		1	
F-HPI-OV1A, F-HPI-OV1B, F-MCS-ISV-FC	3			
F-HPI-PI-GI-TK, F-HPI-TK-GI, F-MCS-PMP2	3			
F-HPI-PI-GI-TK, F-HPI-TK-GI, S-EL-III-1-E	2		1	
F-HPI-PI-GI-TK, F-HPI-TK-GI, S-RCW	2		1	
F-HPI-PI-GI-TK, F-HPI-TK-GI, F-MCS-ISV-FC	3			
F-HPI-PI-GI-TK, F-HPI-TK-GI, S-EL-III-1-O	2		1	
F-HPI-PI-GI-TK, F-HPI-TK-GI, F-MCS-PMP1	3			
F-HPI-LI-CITK, F-HPI-TK-CI, F-MCS-PMP1	3			
F-HPI-LI-CITK, F-HPI-TK-CI, F-MCS-PMP2	3			
F-HPI-LI-CITK, F-HPI-TK-CI, F-MCS-ISV-FC	3			
F-HPI-LI-CITK, F-HPI-TK-CI, S-EL-III-1-E	2		1	
F-HPI-LI-CITK, F-HPI-TK-CI, S-RCW	2		1	
F-HPI-LI-CITK, F-HPI-TK-CI, S-EL-III-1-O	2		1	

Initiating Event - <i>Feeder Tube Break</i>	Sequence: <i>SBLFB-F</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-FW1-ISV1, S-PCS	1		1	
F-FW1-ISV2, S-PCS	1		1	
S-EL-IV-E, S-EL-IV-O, S-PCS			3	
F-FW1-DV2, S-EL-IV-O, S-PCS	1		2	
S-EL-II-1-E, S-EL-II-1-O, S-PCS			3	
F-FW1-CNV2, S-EL-II-1-O, S-PCS	1		2	
F-FW1-CNV1, F-FW1-CNV2, S-PCS	2		1	

Table C.5 (cont.)

F-FW1-CNV1, S-EL-II-1-E, S-PCS	1		2	
F-FW1-DV1, S-EL-IV-E, S-PCS	1		2	
F-FW1-DV1, F-FW1-PMP2, S-PCS	2		1	
F-FW1-PMP1, F-FW1-PMP2, S-PCS	2		1	
F-FW1-DV2, F-FW1-PMP1, S-PCS	2		1	
F-FW1-DV1, F-FW1-DV2, S-PCS	2		1	
F-FW1-PMP2, S-EL-IV-O, S-PCS	1		2	
F-FW1-PMP1, S-EL-IV-E, S-PCS	1		2	

Initiating Event - <i>Feeder Tube Break</i>		Sequence: <i>SBLFB-G</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-FW1-HE, S-PCS, S-RCW		1	2	
F-FW1-ISV1, S-EL-III-1-O, S-PCS	1		2	
F-FW1-ISV2, S-EL-III-1-O, S-PCS	1		2	
F-FW1-ISV2, S-PCS, S-RCW	1		2	
F-FW1-ISV1, S-PCS, S-RCW	1		2	
F-FW1-ISV1, F-MCS-PMP1, S-PCS	2		1	
S-FIW, S-PCS, S-RCW			3	
F-FW1-ISV2, F-MCS-PMP1, S-PCS	2		1	
F-FW1-ISV2, F-MCS-PMP2, S-PCS	2		1	
F-FW1-ISV1, F-MCS-ISV-FC, S-PCS	2		1	
F-FW1-ISV1, F-MCS-PMP2, S-PCS	2		1	
F-FW1-ISV2, S-EL-III-1-E, S-PCS	1		2	
F-FW1-ISV2, F-MCS-ISV-FC, S-PCS	2		1	
F-FW1-ISV1, S-EL-III-1-E, S-PCS	1		2	

Table C.5 (cont.)

Initiating Event - Feeder Tube Break		Sequence: <i>SBLFB-H</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-ECC			1	Y
S-EL-II-2-O			1	Y
S-AIR			1	Y
S-EL-II-2-E			1	Y
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2	2			Y
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1	2			Y
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2	2			Y
F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2	2			Y
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1	2			Y
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1	2			Y
F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2	2			Y
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1	2			Y
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2	2			Y
F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1	2			Y
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2	2			Y
F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1	2			Y

Initiating Event - Feeder Tube Break		Sequence: <i>SBLFB-I</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-EL-II-2-O, S-RCW			2	
S-ECC, S-EL-III-1-O			2	
F-MCS-ISV-FC, S-EL-II-2-O	1		1	
F-MCS-PMP1, S-ECC	1		1	
S-ECC, S-EL-III-1-E			2	
F-MCS-ISV-FC, S-ECC	1		1	
F-MCS-PMP2, S-ECC	1		1	
F-MCS-PMP2, S-EL-II-2-O	1		1	
S-EL-II-2-O, S-EL-III-1-E			2	
S-AIR, S-EL-III-1-E			2	

Table C.5 (cont.)

F-MCS-PMP2, S-AIR	1		1	
F-MCS-PMP1, S-AIR	1		1	
F-MCS-ISV-FC, S-AIR	1		1	
S-AIR, S-RCW			2	
F-MCS-PMP1, S-EL-II-2-O	1		1	
S-EL-II-2-O, S-EL-III-1-O			2	
S-ECC, S-RCW			2	
S-AIR, S-EL-III-1-O			2	
F-MCS-PMP2, S-EL-II-2-E	1		1	
F-MCS-PMP1, S-EL-II-2-E	1		1	
F-MCS-ISV-FC, S-EL-II-2-E	1		1	
S-EL-II-2-E, S-EL-III-1-O			2	
S-EL-II-2-E, S-RCW			2	
S-EL-II-2-E, S-EL-III-1-E			2	
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1, S-EL-III-1-O	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2, S-RCW	2		1	
F-MCS-PMP1, F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1	3			
F-MCS-ISV-FC, F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2	3			
F-MCS-PMP2, F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2	3			
F-MCS-PMP1, F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2	3			
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2, S-EL-III-1-O	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2, S-EL-III-1-E	2		1	
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1, S-EL-III-1-E	2		1	
F-MCS-PMP2, F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1	3			
F-MCS-PMP2, F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1	3			
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1, S-EL-III-1-E	2		1	
F-MCS-ISV-FC, F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1	3			
F-MCS-PMP1, F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1	3			
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1, S-EL-III-1-O	2		1	
F-MCS-ISV-FC, F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1	3			
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1, S-RCW	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2, S-RCW	2		1	
F-MCS-ISV-FC, F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2	3			
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1, S-EL-III-1-O	2		1	

Table C.5 (cont.)

F-MCS-PMP1, F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1	3			
F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2, S-EL-III-1-O	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1, S-EL-III-1-E	2		1	
F-MCS-PMP2, F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1	3			
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1, S-RCW	2		1	
F-MCS-ISV-FC, F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1	3			
F-MCS-PMP1, F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2	3			
F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2, S-EL-III-1-E	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2, S-EL-III-1-E	2		1	
F-MCS-PMP1, F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2	3			
F-MCS-PMP2, F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2	3			
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2, S-EL-III-1-O	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2, S-RCW	3			
F-MCS-PMP2, F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2	3			
F-MCS-ISV-FC, F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2	3			
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1, S-RCW	2		1	
F-MCS-ISV-FC, F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2	3			
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2, S-EL-III-1-O	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1, S-RCW	2		1	
F-MCS-PMP1, F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2	3			
F-MCS-ISV-FC, F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1	3			
F-MCS-PMP2, F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1	3			
F-MCS-PMP1, F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1	3			
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1, S-EL-III-1-E	2		1	
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2, S-EL-III-1-E	2		1	
F-MCS-PMP2, F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2	3			
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2, S-EL-III-1-E	2		1	
F-MCS-PMP2, F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2	3			
F-MCS-PMP1, F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2	3			
F-MCS-ISV-FC, F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2	3			
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2, S-RCW	2		1	
F-MCS-ISV-FC, F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2	3			
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2, S-RCW	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1, S-EL-III-1-O	2		1	

Table C.5 (cont.)

F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1, S-RCW	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1, S-EL-III-1-O	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2, S-EL-III-1-O	2		1	
F-MCS-PMP1, F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1	3			
F-MCS-PMP1, F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2	3			
F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2, S-RCW	2		1	
F-MCS-PMP2, F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2	3			
F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2, S-EL-III-1-E	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1, S-EL-III-1-E	2		1	
F-MCS-PMP2, F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1	3			
F-MCS-PMP2, F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1	3			
F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1, S-EL-III-1-E	2		1	
F-MCS-ISV-FC, F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1	3			
F-MCS-PMP1, F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1	3			
F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1, S-EL-III-1-O	2		1	
F-MCS-ISV-FC, F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1	3			
F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1, S-RCW	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2, S-EL-III-1-O	2		1	

Initiating Event - <i>Feeder Tube Break</i>	Sequence: <i>SBLFB-J</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-SD1-CR-BD-CM			1	Y
F-SD1-CR-COIL-CM			1	Y
F-SD1-TLB-REL2, F-SD1-TLB-REL3	2			Y
F-SD1-TLB-REL1, F-SD1-TLB-REL2	2			Y
F-SD1-TLA-REL1, F-SD1-TLA-REL2	2			Y
F-SD1-TLB-REL1, F-SD1-TLB-REL3	2			Y
F-SD1-TLA-REL2, F-SD1-TLA-REL3	2			Y
F-SD1-TLA-REL1, F-SD1-TLA-REL3	2			Y
F-SD1-TC-D, F-SD1-TC-E	2			Y
F-SD1-TC-D, F-SD1-TC-F	2			Y
F-SD1-TC-E, F-SD1-TC-F	2			Y

Table C.5 (cont.)

Initiating Event - Feeder Tube Break		Sequence: SBLFB-K		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-LPI-INV1, F-LPI-INV2, F-SD1-CR-COIL-CM	2		1	
F-LPI-ISV1, F-LPI-ISV2, F-SD1-CR-COIL-CM	2		1	
F-LPI-PMP1, F-LPI-PMP2, F-SD1-CR-BD-CM	2		1	
F-LPI-ISV1, F-LPI-ISV2, F-SD1-CR-BD-CM	2		1	
F-LPI-PMP1, F-LPI-PMP2, F-SD1-CR-COIL-CM	2		1	
F-LPI-INV1, F-LPI-INV2, F-SD1-CR-BD-CM	2		1	
F-LPI-PMP2, F-SD1-CR-BD-CM, S-EL-III-2-O	1		2	
F-LPI-PMP2, F-SD1-CR-COIL-CM, S-EL-III-2-O	1		2	
F-HPI-ISV1-GI, F-SD1-CR-COIL-CM, S-EL-III-2-E	1		2	
F-LPI-PMP1, F-SD1-CR-BD-CM, S-EL-III-2-E	1		2	
F-LPI-PMP1, F-SD1-CR-COIL-CM, S-EL-III-2-E	1		2	
F-LPI-LI-TK, F-LPI-TK, F-SD1-CR-BD-CM	2		1	
F-LPI-LI-TK, F-LPI-TK, F-SD1-CR-COIL-CM	2		1	
F-LPI-ISV2, F-SD1-CR-BD-CM, S-EL-III-2-O	1		2	
F-HPI-ISV1-GI, F-SD1-CR-BD-CM, S-EL-III-2-E	1		2	
F-HPI-ISV2-GI, F-SD1-CR-COIL-CM, S-EL-III-2-O	1		2	
F-LPI-INV1, F-SD1-CR-BD-CM, S-EL-III-2-E	1		2	
F-LPI-INV1, F-SD1-CR-COIL-CM, S-EL-III-2-E	1		2	
F-LPI-ISV1, F-SD1-CR-BD-CM, S-EL-III-2-E	1		2	
F-LPI-INV2, F-SD1-CR-BD-CM, S-EL-III-2-O	1		2	
F-LPI-INV2, F-SD1-CR-COIL-CM, S-EL-III-2-O	1		2	
F-LPI-ISV2, F-SD1-CR-COIL-CM, S-EL-III-2-O	1		2	
F-LPI-ISV1, F-SD1-CR-COIL-CM, S-EL-III-2-E	1		2	
F-HPI-ISV2-GI, F-SD1-CR-BD-CM, S-EL-III-2-O	1		2	
F-SD1-CR-COIL-CM, S-EL-III-2-E, S-EL-III-2-O			3	
F-SD1-CR-BD-CM, S-EL-III-2-E, S-EL-III-2-O			3	

Table C.5 (cont.)

Initiating Event - Feeder Tube Break		Sequence: SBLFB-M		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, F-SD1-CR-COIL-CM	2		1	
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, F-SD1-CR-BD-CM	2		1	
F-HPI-INV1, F-HPI-INV2, F-SD1-CR-BD-CM	2		1	
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, F-SD1-CR-COIL-CM	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, F-SD1-CR-BD-CM	2		1	
F-HPI-ISV1-GI, F-HPI-ISV2-GI, F-SD1-CR-BD-CM	2		1	
F-HPI-ISV1-GI, F-HPI-ISV2-GI, F-SD1-CR-COIL-CM	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, F-SD1-CR-COIL-CM	2		1	
F-HPI-OV2A, F-HPI-OV2B, F-SD1-CR-COIL-CM	2		1	
F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, F-SD1-CR-BD-CM	2		1	
F-HPI-INV1A, F-HPI-INV1B, F-SD1-CR-BD-CM	2		1	
F-HPI-OV2A, F-HPI-OV2B, F-SD1-CR-BD-CM	2		1	
F-HPI-INV1, F-HPI-INV2, F-SD1-CR-COIL-CM	2		1	
F-HPI-INV2A, F-HPI-INV2B, F-SD1-CR-BD-CM	2		1	
F-HPI-INV1A, F-HPI-INV1B, F-SD1-CR-COIL-CM	2		1	
F-HPI-INV2A, F-HPI-INV2B, F-SD1-CR-COIL-CM	2		1	
F-HPI-OV1A, F-HPI-OV1B, F-SD1-CR-COIL-CM	2		1	
F-HPI-OV1A, F-HPI-OV1B, F-SD1-CR-BD-CM	2		1	
F-HPI-PI-GI-TK, F-HPI-TK-GI, F-SD1-CR-BD-CM	2		1	
F-HPI-PI-GI-TK, F-HPI-TK-GI, F-SD1-CR-COIL-CM	2		1	
F-HPI-LI-CITK, F-HPI-TK-CI, F-SD1-CR-BD-CM	2		1	
F-HPI-LI-CITK, F-HPI-TK-CI, F-SD1-CR-COIL-CM	2		1	

Initiating Event - Feeder Tube Break		Sequence: SBLFB-O		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-FW1-ISV2, F-SD1-CR-COIL-CM, S-PCS	1		2	
F-FW1-ISV1, F-SD1-CR-COIL-CM, S-PCS	1		2	
F-FW1-ISV1, F-SD1-CR-BD-CM, S-PCS	1		2	
F-FW1-ISV2, F-SD1-CR-BD-CM, S-PCS	1		2	

Table C.5 (cont.)

Initiating Event - <i>Feeder Tube Break</i>		Sequence: <i>SBLFB-Q</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant at Failure ?
F-SD1-CR-BD-CM, S-ECC			2	
F-SD1-CR-COIL-CM, S-EL-II-2-E			2	
F-SD1-CR-COIL-CM, S-ECC			2	
F-SD1-CR-BD-CM, S-EL-II-2-O			2	
F-SD1-CR-BD-CM, S-AIR			2	
F-SD1-CR-COIL-CM, S-EL-II-2-O			2	
F-SD1-CR-BD-CM, S-EL-II-2-E			2	
F-SD1-CR-COIL-CM, S-AIR			2	
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1, F-SD1-CR-COIL-CM	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1, F-SD1-CR-BD-CM	2		1	
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1, F-SD1-CR-BD-CM	2		1	
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1, F-SD1-CR-COIL-CM	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL2, S-EL-II-2-O	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2, F-SD1-CR-BD-CM	2		1	
F-SD1-TLB-REL2, F-SD1-TLB-REL3, S-EL-II-2-O	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL3, S-EL-II-2-O	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1, F-SD1-CR-COIL-CM	2		1	
F-SD1-TLA-REL2, F-SD1-TLA-REL3, S-EL-II-2-O	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL2, S-EL-II-2-O	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2, F-SD1-CR-COIL-CM	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL3, S-EL-II-2-O	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2, F-SD1-CR-BD-CM	2		1	
F-SD1-TLB-REL2, F-SD1-TLB-REL3, S-AIR	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL3, S-AIR	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL2, S-AIR	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1, F-SD1-CR-COIL-CM	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL2, S-AIR	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL3, S-EL-II-2-E	2		1	
F-SD1-TLA-REL2, F-SD1-TLA-REL3, S-AIR	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2, F-SD1-CR-BD-CM	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2, F-SD1-CR-COIL-CM	2		1	

Table C.5 (cont.)

F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2, F-SD1-CR-COIL-CM	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1, F-SD1-CR-BD-CM	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL3, S-AIR	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1, F-SD1-CR-BD-CM	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL3, S-ECC	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2, F-SD1-CR-COIL-CM	2		1	
F-SD1-TLA-REL2, F-SD1-TLA-REL3, S-ECC	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1, F-SD1-CR-COIL-CM	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2, F-SD1-CR-BD-CM	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL3, S-ECC	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2, F-SD1-CR-COIL-CM	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL2, S-EL-II-2-E	2		1	
F-SD1-TLB-REL2, F-SD1-TLB-REL3, S-EL-II-2-E	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL2, S-EL-II-2-E	2		1	
F-SD1-TLA-REL2, F-SD1-TLA-REL3, S-EL-II-2-E	2		1	
F-SD1-TLB-REL2, F-SD1-TLB-REL3, S-ECC	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2, F-SD1-CR-BD-CM	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL2, S-ECC	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1, F-SD1-CR-BD-CM	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1, F-SD1-CR-COIL-CM	2		1	
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2, F-SD1-CR-COIL-CM	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1, F-SD1-CR-BD-CM	2		1	
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2, F-SD1-CR-BD-CM	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL2, S-ECC	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL3, S-EL-II-2-E	2		1	
F-SD1-TC-E, F-SD1-TC-F, S-EL-II-2-O	2		1	
F-SD1-TC-D, F-SD1-TC-E, S-EL-II-2-O	2		1	
F-SD1-TC-D, F-SD1-TC-F, S-EL-II-2-O	2		1	
F-SD1-TC-D, F-SD1-TC-F, S-AIR	2		1	
F-SD1-TC-D, F-SD1-TC-F, S-EL-II-2-E	2		1	
F-SD1-TC-E, F-SD1-TC-F, S-EL-II-2-E	2		1	
F-SD1-TC-D, F-SD1-TC-E, S-EL-II-2-E	2		1	
F-SD1-TC-E, F-SD1-TC-F, S-ECC	2		1	
F-SD1-TC-D, F-SD1-TC-F, S-ECC	2		1	

Table C.5 (cont.)

F-SD1-TC-D, F-SD1-TC-E, S-AIR	2		1	
F-SD1-TC-D, F-SD1-TC-E, S-ECC	2		1	
F-SD1-TC-E, F-SD1-TC-F, S-AIR	2		1	

Initiating Event - Feeder Tube Break		Sequence: SBLFB-R		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-MCS-PMP1, F-SD1-CR-BD-CM, S-EL-II-2-O	1		2	
F-SD1-CR-COIL-CM, S-EL-II-2-O, S-EL-III-1-E			3	
F-MCS-PMP1, F-SD1-CR-COIL-CM, S-EL-II-2-O	1		2	
F-SD1-CR-BD-CM, S-EL-II-2-O, S-EL-III-1-O			3	
F-SD1-CR-BD-CM, S-EL-II-2-O, S-EL-III-1-E			3	
F-SD1-CR-COIL-CM, S-EL-II-2-O, S-EL-III-1-O			3	
F-MCS-PMP2, F-SD1-CR-COIL-CM, S-EL-II-2-O	1		2	
F-MCS-ISV-FC, F-SD1-CR-BD-CM, S-EL-II-2-O	1		2	
F-SD1-CR-COIL-CM, S-EL-II-2-O, S-RCW			3	
F-MCS-ISV-FC, F-SD1-CR-COIL-CM, S-EL-II-2-O	1		2	
F-SD1-CR-BD-CM, S-AIR, S-RCW			3	
F-MCS-PMP2, F-SD1-CR-BD-CM, S-EL-II-2-O	1		2	
F-SD1-CR-COIL-CM, S-AIR, S-RCW			3	
F-MCS-PMP1, F-SD1-CR-COIL-CM, S-AIR	1		2	
F-MCS-PMP1, F-SD1-CR-BD-CM, S-AIR	1		2	
F-SD1-CR-BD-CM, S-AIR, S-EL-III-1-O			3	
F-SD1-CR-COIL-CM, S-AIR, S-EL-III-1-E			3	
F-SD1-CR-COIL-CM, S-AIR, S-EL-III-1-O			3	
F-SD1-CR-BD-CM, S-AIR, S-EL-III-1-E			3	
F-MCS-ISV-FC, F-SD1-CR-COIL-CM, S-AIR	1		2	
F-MCS-ISV-FC, F-SD1-CR-BD-CM, S-AIR	1		2	
F-MCS-PMP2, F-SD1-CR-BD-CM, S-AIR	1		2	
F-SD1-CR-BD-CM, S-EL-II-2-O, S-RCW			3	
F-MCS-PMP2, F-SD1-CR-COIL-CM, S-AIR	1		2	
F-SD1-CR-COIL-CM, S-ECC, S-EL-III-1-O			3	
F-MCS-PMP1, F-SD1-CR-BD-CM, S-EL-II-2-E	1		2	

Table C.5 (cont.)

F-SD1-CR-COIL-CM, S-EL-II-2-E, S-EL-III-1-E			3	
F-MCS-PMP1, F-SD1-CR-COIL-CM, S-EL-II-2-E	1		2	
F-SD1-CR-BD-CM, S-EL-II-2-E, S-EL-III-1-E			3	
F-SD1-CR-BD-CM, S-EL-II-2-E, S-EL-III-1-O			3	
F-MCS-PMP2, F-SD1-CR-COIL-CM, S-EL-II-2-E	1		2	
F-MCS-ISV-FC, F-SD1-CR-BD-CM, S-EL-II-2-E	1		2	
F-SD1-CR-COIL-CM, S-EL-II-2-E, S-RCW			3	
F-MCS-ISV-FC, F-SD1-CR-COIL-CM, S-EL-II-2-E	1		2	
F-SD1-CR-COIL-CM, S-EL-II-2-E, S-EL-III-1-O			3	
F-MCS-PMP2, F-SD1-CR-BD-CM, S-EL-II-2-E	1		2	
F-SD1-CR-BD-CM, S-ECC, S-RCW			3	
F-MCS-PMP1, F-SD1-CR-BD-CM, S-ECC	1		2	
F-SD1-CR-COIL-CM, S-ECC, S-EL-III-1-E			3	
F-MCS-PMP1, F-SD1-CR-COIL-CM, S-ECC	1		2	
F-SD1-CR-BD-CM, S-ECC, S-EL-III-1-E			3	
F-SD1-CR-BD-CM, S-ECC, S-EL-III-1-O			3	
F-MCS-PMP2, F-SD1-CR-COIL-CM, S-ECC	1		2	
F-MCS-ISV-FC, F-SD1-CR-BD-CM, S-ECC	1		2	
F-SD1-CR-COIL-CM, S-ECC, S-RCW			3	
F-MCS-ISV-FC, F-SD1-CR-COIL-CM, S-ECC	1		2	
F-SD1-CR-BD-CM, S-EL-II-2-E, S-RCW			3	
F-MCS-PMP2, F-SD1-CR-BD-CM, S-ECC	1		2	

Table C.5 (cont.)

Initiating Event - <i>Feeder Tube Break</i>		Sequence: <i>SBLFB-FTSD-A</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-TL-G, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TL-G, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TL-H, F-SD2-TL-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TL-H, F-SD2-TL-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TL-G, F-SD2-TL-H	2		1	
F-SD1-CR-COIL-CM, F-SD2-TL-G, F-SD2-TL-H	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT5	2		1	

Table C.5 (cont.)

F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT6	2	*	1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT3	2		1	

Table C.5 (cont.)

F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT5, F-SD2-ISV2-PT6	2		1	

Table C.5 (cont.)

F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT5, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-J, F-SD2-TL-H	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-H, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TL-H	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-G, F-SD2-TL-H	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-H, F-SD2-TL-G	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-H, F-SD2-TL-G	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-J, F-SD2-TL-H	2		1	

Table C.5 (cont.)

F-SD1-CR-BD-CM, F-SD2-TC-G, F-SD2-TL-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-J, F-SD2-TL-G	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-J, F-SD2-TL-G	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-H, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TC-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-G, F-SD2-TC-H	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TC-H	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-H, F-SD2-TC-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-H, F-SD2-TC-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-G, F-SD2-TC-J	2		1	

**Table C.6 Small-break loss-of-coolant events sequence categorization:
representative initiating event - *feeder tube break***

Specific Initiator		Feeder tube break		Pressure tube leak/rupture		Fuel handling machine breaks end fitting	
IE Frequency		1×10^{-2}		1×10^{-2}		1×10^{-2}	
Sequence	Determinant Failures	Bin	Category	Bin	Category	Bin	Category
SBLFB-A	NA	A	EC-I	A	EC-I	A	EC-I
SBLFB-B	2 valves, 2 pumps, undetected low grade level tank level	C	EC-III	C	EC-III	C	EC-III
SBLFB-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-D	2 signals, 2 valves, undetected low gas tank pressure, undetected low coolant tank volume	C	EC-III	C	EC-III	C	EC-III
SBLFB-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-F	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-H	support systems, 2 main steam safety valves	C	EC-III	C	EC-III	C	EC-III
SBLFB-I	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-J	common mode failure, 2 relays, 2 trip computers	C	EC-III	C	EC-III	C	EC-III
SBLFB-K	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-L	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-M	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-N	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-O	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-P	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-Q	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-R	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-A	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-B	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-F	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-I	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-J	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-K	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-L	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-M	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-N	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV

Table C.6 (cont.)

Specific Initiator		Leakage from fuel handling machine/cooling system		Vent line and sample line leaks/breaks or leakage from primary system		Heat transport pump seals fail	
IE Frequency		1×10^{-2}		1×10^{-1}		1×10^{-2}	
Sequence	Determinant Failures	Bin	Category	Bin	Category	Bin	Category
SBLFB-A	NA	A	EC-I	A	EC-I	A	EC-I
SBLFB-B	2 valves, 2 pumps, undetected low grade level tank level	C	EC-III	C	EC-III	C	EC-III
SBLFB-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-D	2 signals, 2 valves, undetected low gas tank pressure, undetected low coolant tank volume	C	EC-III	C	EC-III	C	EC-III
SBLFB-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-F	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-H	support systems, 2 main steam safety valves	C	EC-III	C	EC-III	C	EC-III
SBLFB-I	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-J	common mode failure, 2 relays, 2 trip computers	C	EC-III	C	EC-III	C	EC-III
SBLFB-K	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-L	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-M	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-N	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-O	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-P	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-Q	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-R	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-A	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-B	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-F	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-I	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-J	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-K	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-L	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-M	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SBLFB-FTSD-N	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV

Table C.7 Loss of Class IV power sequence cut sets

Initiating Event - <i>Loss of Class IV Power</i>	Sequence: <i>LOP-A</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
NONE	NA	NA	NA	NA

Initiating Event - <i>Loss of Class IV Power</i>	Sequence: <i>LOP-B</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-ASD-ASD1, F-ASD-ASD2	2			Y
F-ASD-ASD2, S-EL-II-2-O	1		1	
F-ASD-ASD1, S-EL-II-2-E	1		1	

Initiating Event - <i>Loss of Class IV Power</i>	Sequence: <i>LOP-F</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-FW2-HE, F-FW2-LI-TK	1	1		Y
F-FW2-IV1, F-FW2-IV2	2			Y
F-FW2-PMP1, F-FW2-PMP2	2			Y
F-FW2-IV1, F-FW2-PMP2	2			Y
F-FW2-OV2, F-FW2-PMP1	2			Y
F-FW2-IV2, F-FW2-OV1	2			Y
F-FW2-IV2, F-FW2-PMP1	2			Y
F-FW2-OV1, F-FW2-PMP2	2			Y
F-FW2-OV1, F-FW2-OV2	2			Y
F-FW2-IV1, F-FW2-OV2	2			Y
F-FW2-PMP1, S-EL-III-2-E	1		1	

Table C.7 (cont.)

F-FW2-IV2, S-EL-III-2-O	1		1	
F-FW2-OV2, S-EL-III-2-O	1		1	
F-FW2-IV1, S-EL-III-2-E	1		1	
F-FW2-OV1, S-EL-III-2-E	1		1	
F-FW2-PMP2, S-EL-III-2-O	1		1	
S-EL-III-2-E, S-EL-III-2-O			2	
F-FW2-ISV1-SG1, F-FW2-ISV1-SG2, S-EL-II-2-E	2		1	
F-FW2-ISV2-SG1, F-FW2-ISV2-SG2, S-EL-II-2-O	2		1	

Initiating Event - <i>Loss of Class IV Power</i>		Sequence: <i>LOP-G</i>		
Sequence Level Cut Sets		Component Failures	Human Errors	Support System Failures
S-EL-II-2-E, S-EL-III-2-O				2

Initiating Event - <i>Loss of Class IV Power</i>		Sequence: <i>LOP-K</i>		
Sequence Level Cut Sets		Component Failures	Human Errors	Support System Failures
F-AFW-PMP, F-FW2-HE, F-FW2-LI-TK		2	1	
F-AFW-DIESEL, F-FW2-HE, F-FW2-LI-TK		2	1	
F-AFW-DV, F-FW2-HE, F-FW2-LI-TK		2	1	
F-AFW-DV, F-FW2-IV1, F-FW2-PMP2		3		
F-AFW-DV, F-FW2-IV1, F-FW2-OV2		3		
F-AFW-DV, F-FW2-IV2, F-FW2-OV1		3		
F-AFW-DV, F-FW2-OV1, F-FW2-OV2		3		
F-AFW-DV, F-FW2-IV1, F-FW2-IV2		3		
F-AFW-DV, F-FW2-OV1, F-FW2-PMP2		3		
F-AFW-DV, F-FW2-PMP1, F-FW2-PMP2		3		
F-AFW-PMP, F-FW2-OV1, F-FW2-OV2		3		
F-AFW-PMP, F-FW2-OV1, F-FW2-PMP2		3		
F-AFW-PMP, F-FW2-IV2, F-FW2-OV1		3		
F-AFW-DV, F-FW2-IV2, F-FW2-PMP1		3		
F-AFW-DIESEL, F-FW2-IV2, F-FW2-PMP1		3		
F-AFW-PMP, F-FW2-IV1, F-FW2-PMP2		3		

Table C.7 (cont.)

F-AFW-DV, F-FW2-OV2, F-FW2-PMP1	3			
F-AFW-PMP, F-FW2-OV2, F-FW2-PMP1	3			
F-AFW-PMP, F-FW2-IV2, F-FW2-PMP1	3			
F-AFW-PMP, F-FW2-PMP1, F-FW2-PMP2	3			
F-AFW-PMP, F-FW2-IV1, F-FW2-IV2	3			
F-AFW-DIESEL, F-FW2-OV1, F-FW2-PMP2	3			
F-AFW-DIESEL, F-FW2-OV2, F-FW2-PMP1	3			
F-AFW-PMP, F-FW2-IV1, F-FW2-OV2	3			
F-AFW-DIESEL, F-FW2-IV1, F-FW2-IV2	3			
F-AFW-DIESEL, F-FW2-OV1, F-FW2-OV2	3			
F-AFW-DIESEL, F-FW2-IV1, F-FW2-OV2	3			
F-AFW-DIESEL, F-FW2-PMP1, F-FW2-PMP2	3			
F-AFW-DIESEL, F-FW2-IV1, F-FW2-PMP2	3			
F-AFW-DIESEL, F-FW2-IV2, F-FW2-OV1	3			
F-AFW-DIESEL, F-FW2-IV2, S-EL-III-2-O	2		1	
F-AFW-DV, F-FW2-PMP2, S-EL-III-2-O	2		1	
F-AFW-DIESEL, F-FW2-OV2, S-EL-III-2-O	2		1	
F-AFW-DV, F-FW2-OV2, S-EL-III-2-O	2		1	
F-AFW-DV, F-FW2-IV2, S-EL-III-2-O	2		1	
F-AFW-PMP, F-FW2-PMP1, S-EL-III-2-E	2		1	
F-AFW-PMP, F-FW2-IV1, S-EL-III-2-E	2		1	
F-AFW-PMP, F-FW2-OV1, S-EL-III-2-E	2		1	
F-AFW-DIESEL, F-FW2-PMP2, S-EL-III-2-O	2		1	
F-AFW-PMP, F-FW2-IV2, S-EL-III-2-O	2		1	
F-AFW-DIESEL, F-FW2-PMP1, S-EL-III-2-E	2		1	
F-AFW-DV, F-FW2-OV1, S-EL-III-2-E	2		1	
F-AFW-DIESEL, F-FW2-IV1, S-EL-III-2-E	2		1	
F-AFW-DV, F-FW2-IV1, S-EL-III-2-E	2		1	
F-AFW-DV, F-FW2-PMP1, S-EL-III-2-E	2		1	
F-AFW-PMP, F-FW2-OV2, S-EL-III-2-O	2		1	
F-AFW-PMP, F-FW2-PMP2, S-EL-III-2-O	2		1	
F-AFW-DIESEL, F-FW2-OV1, S-EL-III-2-E	2		1	

Table C.7 (cont.)

Initiating Event - <i>Loss of Class IV Power</i>	Sequence: <i>LOP-L</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-AFW-DIESEL, S-EL-III-2-E, S-EL-III-2-O	1		2	
F-AFW-DV, S-EL-III-2-E, S-EL-III-2-O	1		2	
F-AFW-PMP, S-EL-III-2-E, S-EL-III-2-O	1		2	
F-AFW-DV, S-EL-II-2-E, S-EL-II-2-O	1		2	
F-AFW-PMP, S-EL-II-2-E, S-EL-II-2-O	1		2	
F-AFW-DIESEL, S-EL-II-2-E, S-EL-II-2-O	1		2	

Initiating Event - <i>Loss of Class IV Power</i>	Sequence: <i>LOP-N</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-EL-II-1-E			1	
F-LRC-VLV2	1			Y
F-LRC-VLV1	1			Y

Initiating Event - <i>Loss of Class IV Power</i>	Sequence: <i>LOP-O</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-AIR			1	
F-ASD-ASD1, F-ASD-ASD2, F-LRC-VLV2	3			
F-ASD-ASD1, F-ASD-ASD2, F-LRC-VLV1	3			
F-ASD-ASD1, F-ASD-ASD2, S-EL-II-1-E	2		1	
F-ASD-ASD2, S-EL-II-1-E, S-EL-II-2-O	1		2	
F-ASD-ASD1, F-LRC-VLV1, S-EL-II-2-E	2		1	
F-ASD-ASD2, F-LRC-VLV2, S-EL-II-2-O	2		1	
F-ASD-ASD2, F-LRC-VLV1, S-EL-II-2-O	2		1	
F-ASD-ASD1, F-LRC-VLV2, S-EL-II-2-E	2		1	
F-ASD-ASD1, S-EL-II-1-E, S-EL-II-2-E	1		2	

Table C.7 (cont.)

Initiating Event - <i>Loss of Class IV Power</i>	Sequence: <i>LOP-P</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1, S-AIR	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1, S-AIR	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2, S-AIR	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2, S-AIR	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1, S-AIR	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2, S-AIR	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1, S-AIR	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2, S-AIR	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2, S-AIR	2		1	
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2, S-AIR	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1, S-AIR	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1, S-AIR	2		1	

Initiating Event - <i>Loss of Class IV Power</i>	Sequence: <i>LOP-S</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-FW2-HE, F-FW2-LI-TK, F-LRC-VLV1	2	1		
F-FW2-HE, F-FW2-LI-TK, F-LRC-VLV2	2	1		
F-FW2-HE, F-FW2-LI-TK, S-EL-II-1-E	1	1	1	
F-FW2-OV1, F-FW2-PMP2, S-EL-II-1-E	2		1	
F-FW2-IV2, F-FW2-PMP1, F-LRC-VLV2	3			
F-FW2-OV1, F-FW2-OV2, S-EL-II-1-E	2		1	
F-FW2-OV2, F-FW2-PMP1, F-LRC-VLV2	3			
F-FW2-PMP1, F-FW2-PMP2, F-LRC-VLV2	3			
F-FW2-IV2, F-FW2-OV1, F-LRC-VLV1	3			
F-FW2-IV1, F-FW2-IV2, F-LRC-VLV2	3			
F-FW2-IV2, F-FW2-OV1, S-EL-II-1-E	2		1	
F-FW2-IV1, F-FW2-PMP2, S-EL-II-1-E	2		1	
F-FW2-OV1, F-FW2-OV2, F-LRC-VLV1	3			
F-FW2-IV2, F-FW2-PMP1, S-EL-II-1-E	2		1	

Table C.7 (cont.)

F-FW2-OV1, F-FW2-PMP2, F-LRC-VLV1	3			
F-FW2-OV2, F-FW2-PMP1, S-EL-II-1-E	2		1	
F-FW2-PMP1, F-FW2-PMP2, S-EL-II-1-E	2		1	
F-FW2-IV1, F-FW2-OV2, S-EL-II-1-E	2		1	
F-FW2-IV1, F-FW2-IV2, S-EL-II-1-E	2		1	
F-FW2-IV1, F-FW2-PMP2, F-LRC-VLV2	3			
F-FW2-IV1, F-FW2-OV2, F-LRC-VLV2	3			
F-FW2-OV2, F-FW2-PMP1, F-LRC-VLV1	3			
F-FW2-IV2, F-FW2-PMP1, F-LRC-VLV1	3			
F-FW2-IV1, F-FW2-IV2, F-LRC-VLV1	3			
F-FW2-IV1, F-FW2-OV2, F-LRC-VLV1	3			
F-FW2-OV1, F-FW2-PMP2, F-LRC-VLV2	3			
F-FW2-IV1, F-FW2-PMP2, F-LRC-VLV1	3			
F-FW2-PMP1, F-FW2-PMP2, F-LRC-VLV1	3			
F-FW2-OV1, F-FW2-OV2, F-LRC-VLV2	3			
F-FW2-IV2, F-FW2-OV1, F-LRC-VLV2	3			
F-FW2-IV1, F-LRC-VLV1, S-EL-III-2-E	2		1	
F-FW2-OV2, F-LRC-VLV2, S-EL-III-2-O	2		1	
F-FW2-IV2, F-LRC-VLV2, S-EL-III-2-O	2		1	
F-FW2-IV1, S-EL-II-1-E, S-EL-III-2-E	1		2	
F-FW2-PMP1, S-EL-II-1-E, S-EL-III-2-E	1		2	
F-FW2-OV2, F-LRC-VLV1, S-EL-III-2-O	2		1	
F-FW2-OV1, F-LRC-VLV1, S-EL-III-2-E	2		1	
F-FW2-PMP2, F-LRC-VLV1, S-EL-III-2-O	2		1	
F-FW2-PMP2, F-LRC-VLV2, S-EL-III-2-O	2		1	
F-FW2-IV2, F-LRC-VLV1, S-EL-III-2-O	2		1	
F-FW2-IV2, S-EL-II-1-E, S-EL-III-2-O	1		2	
F-FW2-IV1, F-LRC-VLV2, S-EL-III-2-E	2		1	
F-FW2-OV1, S-EL-II-1-E, S-EL-III-2-E	1		2	
F-FW2-OV1, F-LRC-VLV2, S-EL-III-2-E	2		1	
F-FW2-PMP1, F-LRC-VLV1, S-EL-III-2-E	2		1	
F-FW2-PMP1, F-LRC-VLV2, S-EL-III-2-E	2		1	
F-FW2-PMP2, S-EL-II-1-E, S-EL-III-2-O	1		2	
F-FW2-OV2, S-EL-II-1-E, S-EL-III-2-O	1		2	

Table C.7 (cont.)

F-LRC-VLV2, S-EL-III-2-E, S-EL-III-2-O	1		2	
S-EL-II-1-E, S-EL-III-2-E, S-EL-III-2-O			3	
F-LRC-VLV1, S-EL-III-2-E, S-EL-III-2-O	1		2	

Initiating Event - <i>Loss of Class IV Power</i>		Sequence: <i>LOP-T</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-FW2-HE, F-FW2-LI-TK, S-AIR	1	1	1	
F-FW2-IV1, F-FW2-IV2, S-AIR	2		1	
F-FW2-PMP1, F-FW2-PMP2, S-AIR	2		1	
F-FW2-IV1, F-FW2-OV2, S-AIR	2		1	
F-FW2-IV2, F-FW2-OV1, S-AIR	2		1	
F-FW2-IV1, F-FW2-PMP2, S-AIR	2		1	
F-FW2-OV1, F-FW2-OV2, S-AIR	2		1	
F-FW2-OV1, F-FW2-PMP2, S-AIR	2		1	
F-FW2-IV2, F-FW2-PMP1, S-AIR	2		1	
F-FW2-OV2, F-FW2-PMP1, S-AIR	2		1	
F-LRC-VLV1, S-EL-II-2-E, S-EL-II-2-O	1		2	
F-FW2-PMP1, S-AIR, S-EL-III-2-E	1		2	
F-FW2-IV1, S-AIR, S-EL-III-2-E	1		2	
F-FW2-OV2, S-AIR, S-EL-III-2-O	1		2	
F-FW2-OV1, S-AIR, S-EL-III-2-E	1		2	
S-EL-II-1-E, S-EL-II-2-E, S-EL-II-2-O			3	
F-FW2-IV2, S-AIR, S-EL-III-2-O	1		2	
F-FW2-PMP2, S-AIR, S-EL-III-2-O	1		2	
F-LRC-VLV2, S-EL-II-2-E, S-EL-II-2-O	1		2	
S-AIR, S-EL-III-2-E, S-EL-III-2-O			3	
S-AIR, S-EL-II-2-E, S-EL-II-2-O			3	

Table C.7 (cont.)

Initiating Event - <i>Loss of Class IV Power</i>	Sequence: <i>LOP-AA</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-EL-II-1-O			1	Y
F-BCS-CNV1-TK, S-EL-II-1-E	1		1	
F-BCS-CNV1-TK, F-BCS-CNV2, F-LRC-VLV2	3			
F-BCS-CNV1-TK, F-BCS-CNV2, F-LRC-VLV1	3			
F-BCS-CNV1, F-BCS-CNV1-TK, F-LRC-VLV2	3			
F-BCS-CNV1, F-BCS-CNV1-TK, F-LRC-VLV1	3			

Initiating Event - <i>Loss of Class IV Power</i>	Sequence: <i>LOP-AB</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-LPI-ISV1, F-LPI-ISV2, S-EL-II-1-O	2		1	
F-LPI-PMP1, F-LPI-PMP2, S-EL-II-1-O	2		1	
F-LPI-INV1, F-LPI-INV2, S-EL-II-1-O	2		1	
F-LPI-ISV1, S-EL-II-1-O, S-EL-III-2-E	1		2	
F-LPI-PMP1, S-EL-II-1-O, S-EL-III-2-E	1		2	
F-LPI-LI-TK, F-LPI-TK, S-EL-II-1-O	2		1	
F-LPI-PMP2, S-EL-II-1-O, S-EL-III-2-O	1		2	
F-HPI-ISV1-GI, S-EL-II-1-O, S-EL-III-2-E	1		2	
F-LPI-ISV2, S-EL-II-1-O, S-EL-III-2-O	1		2	
F-LPI-INV2, S-EL-II-1-O, S-EL-III-2-O	1		2	
F-HPI-ISV2-GI, S-EL-II-1-O, S-EL-III-2-O	1		2	
F-LPI-INV1, S-EL-II-1-O, S-EL-III-2-E	1		2	

Initiating Event - <i>Loss of Class IV Power</i>	Sequence: <i>LOP-AD</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-HPI-SIG1-LPHTS, F-HPI-SIG2-LPHTS, S-EL-II-1-O	2		1	
F-HPI-SIG2-LPHTS, F-HPI-SIG3-LPHTS, S-EL-II-1-O	2		1	
F-HPI-ISV1-GI, F-HPI-ISV2-GI, S-EL-II-1-O	2		1	
F-HPI-INV1, F-HPI-INV2, S-EL-II-1-O	2		1	

Table C.7 (cont.)

F-HPI-SIG1-LPHTS, F-HPI-SIG3-LPHTS, S-EL-II-1-O	2		1	
F-HPI-OV2A, F-HPI-OV2B, S-EL-II-1-O	2		1	
F-HPI-INV1A, F-HPI-INV1B, S-EL-II-1-O	2		1	
F-HPI-INV2A, F-HPI-INV2B, S-EL-II-1-O	2		1	
F-HPI-OV1A, F-HPI-OV1B, S-EL-II-1-O	2		1	
F-HPI-PI-GI-TK, F-HPI-TK-GI, S-EL-II-1-O	2		1	
F-HPI-LI-CITK, F-HPI-TK-CI, S-EL-II-1-O	2		1	

Initiating Event - <i>Loss of Class IV Power</i>		Sequence: <i>LOP-AF</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-FW2-HE, F-FW2-LI-TK, S-EL-II-1-O	1	1	1	
F-FW2-OV1, F-FW2-OV2, S-EL-II-1-O	2		1	
F-FW2-OV2, F-FW2-PMP1, S-EL-II-1-O	2		1	
F-FW2-OV1, F-FW2-PMP2, S-EL-II-1-O	2		1	
F-FW2-PMP1, F-FW2-PMP2, S-EL-II-1-O	2		1	
F-FW2-IV2, F-FW2-PMP1, S-EL-II-1-O	2		1	
F-FW2-IV1, F-FW2-PMP2, S-EL-II-1-O	2		1	
F-FW2-IV1, F-FW2-IV2, S-EL-II-1-O	2		1	
F-FW2-IV2, F-FW2-OV1, S-EL-II-1-O	2		1	
F-FW2-IV1, F-FW2-OV2, S-EL-II-1-O	2		1	
F-FW2-IV2, S-EL-II-1-O, S-EL-III-2-O	1		2	
F-FW2-OV1, S-EL-II-1-O, S-EL-III-2-E	1		2	
F-FW2-OV2, S-EL-II-1-O, S-EL-III-2-O	1		2	
F-FW2-PMP2, S-EL-II-1-O, S-EL-III-2-O	1		2	
F-FW2-IV1, S-EL-II-1-O, S-EL-III-2-E	1		2	
F-FW2-PMP1, S-EL-II-1-O, S-EL-III-2-E	1		2	

Initiating Event - <i>Loss of Class IV Power</i>		Sequence: <i>LOP-AG</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-EL-II-1-O, S-EL-III-2-E, S-EL-III-2-O			3	

Table C.7 (cont.)

Initiating Event - <i>Loss of Class IV Power</i>	Sequence: <i>LOP-AK</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-PCS			1	Y

Initiating Event - <i>Loss of Class IV Power</i>	Sequence: <i>LOP-AL</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-MCS-PMP1, S-PCS	1		1	
S-EL-III-1-O, S-PCS			2	
S-EL-III-1-E, S-PCS			2	
F-MCS-PMP2, S-PCS	1		1	
S-PCS, S-RCW			2	
F-MCS-ISV-FC, S-PCS	1		1	

Initiating Event - <i>Loss of Class IV Power</i>	Sequence: <i>LOP-AM</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-AIR, S-EL-II-1-O			2	
S-ECC, S-EL-II-1-O			2	
S-EL-II-1-O, S-EL-II-2-E			2	
S-EL-II-1-O, S-EL-II-2-O			2	
F-BCS-CNV1-TK, S-AIR	1		1	
S-ECC, S-PCS			2	
S-EL-II-2-O, S-PCS			2	
S-AIR, S-PCS			2	
S-EL-II-2-E, S-PCS			2	
F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1, S-EL-II-1-O	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1, S-EL-II-1-O	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2, S-EL-II-1-O	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2, S-EL-II-1-O	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2, S-EL-II-1-O	2		1	
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1, S-EL-II-1-O	2		1	

Table C.7 (cont.)

F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1, S-EL-II-1-O	2		1	
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2, S-EL-II-1-O	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2, S-EL-II-1-O	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2, S-EL-II-1-O	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1, S-EL-II-1-O	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1, S-EL-II-1-O	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2, S-PCS	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2, S-PCS	2		1	
F-BCS-CNV1-TK, S-EL-II-1-E, S-EL-II-2-O	1		2	
F-BCS-CNV1-TK, S-ECC, S-EL-II-1-E	1		2	
F-BCS-CNV1-TK, S-EL-II-1-E, S-EL-II-2-E	1		2	
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2, S-PCS	2		1	
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2, S-PCS	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1, S-PCS	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1, S-PCS	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1, S-PCS	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1, S-PCS	2		1	
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1, S-PCS	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1, S-PCS	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2, S-PCS	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2, S-PCS	2		1	

Initiating Event - <i>Loss of Class IV Power</i>	Sequence: <i>LOP-AN</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-EL-II-1-O, S-EL-II-2-O, S-EL-III-1-O			3	
F-MCS-PMP1, S-EL-II-1-O, S-EL-II-2-O	1		2	
S-AIR, S-EL-II-1-O, S-RCW			3	
S-EL-II-1-O, S-EL-II-2-O, S-EL-III-1-E			3	
F-MCS-PMP2, S-EL-II-1-O, S-EL-II-2-O	1		2	
S-EL-II-1-O, S-EL-II-2-O, S-RCW			3	
S-ECC, S-EL-II-1-O, S-EL-III-1-O			3	
F-MCS-ISV-FC, S-EL-II-1-O, S-EL-II-2-O	1		2	

Table C.7 (cont.)

F-MCS-ISV-FC, S-AIR, S-EL-II-1-O	1		2	
F-MCS-PMP2, S-AIR, S-EL-II-1-O	1		2	
F-BCS-CNV1-TK, S-AIR, S-EL-III-1-E	1		2	
F-BCS-CNV1-TK, F-MCS-PMP2, S-AIR	2		1	
F-BCS-CNV1-TK, F-MCS-PMP1, S-AIR	2		1	
F-BCS-CNV1-TK, F-MCS-ISV-FC, S-AIR	2		1	
F-BCS-CNV1-TK, S-AIR, S-RCW	1		2	
F-MCS-PMP1, S-AIR, S-EL-II-1-O	1		2	
S-AIR, S-EL-II-1-O, S-EL-III-1-E			3	
S-AIR, S-EL-II-1-O, S-EL-III-1-O			3	
F-MCS-PMP1, S-ECC, S-EL-II-1-O	1		2	
F-BCS-CNV1-TK, S-AIR, S-EL-III-1-O	1		2	
S-EL-II-1-O, S-EL-II-2-E, S-EL-III-1-E			3	
F-MCS-PMP2, S-EL-II-1-O, S-EL-II-2-E	1		2	
S-ECC, S-EL-II-1-O, S-RCW			3	
S-EL-II-1-O, S-EL-II-2-E, S-EL-III-1-O			3	
F-MCS-ISV-FC, S-EL-II-1-O, S-EL-II-2-E	1		2	
F-MCS-PMP1, S-EL-II-1-O, S-EL-II-2-E	1		2	
F-MCS-ISV-FC, S-ECC, S-EL-II-1-O	1		2	
S-EL-II-1-O, S-EL-II-2-E, S-RCW			3	
S-ECC, S-EL-II-1-O, S-EL-III-1-E			3	
F-MCS-PMP2, S-ECC, S-EL-II-1-O	1		2	
S-EL-II-2-E, S-PCS, S-RCW			3	
S-AIR, S-EL-III-1-E, S-PCS			3	
F-MCS-PMP2, S-EL-II-2-E, S-PCS	1		2	
F-MCS-PMP1, S-EL-II-2-E, S-PCS	1		2	
F-MCS-PMP1, S-AIR, S-PCS	1		2	
F-MCS-ISV-FC, S-EL-II-2-E, S-PCS	1		2	
S-AIR, S-EL-III-1-O, S-PCS			3	
F-MCS-PMP2, S-AIR, S-PCS	1		2	
S-EL-II-2-E, S-EL-III-1-E, S-PCS			3	
S-AIR, S-PCS, S-RCW			3	
F-MCS-PMP2, S-ECC, S-PCS	1		2	
F-MCS-PMP2, S-EL-II-2-O, S-PCS	1		2	

Table C.7 (cont.)

F-MCS-ISV-FC, S-EL-II-2-O, S-PCS	1		2	
S-EL-II-2-O, S-PCS, S-RCW			3	
S-ECC, S-EL-III-1-O, S-PCS			3	
S-ECC, S-EL-III-1-E, S-PCS			3	
S-EL-II-2-O, S-EL-III-1-E, S-PCS			3	
F-MCS-ISV-FC, S-ECC, S-PCS	1		2	
F-MCS-PMP1, S-ECC, S-PCS	1		2	
F-MCS-ISV-FC, S-AIR, S-PCS	1		2	
S-ECC, S-PCS, S-RCW			3	
S-EL-II-2-O, S-EL-III-1-O, S-PCS			3	
S-EL-II-2-E, S-EL-III-1-O, S-PCS			3	
F-MCS-PMP1, S-EL-II-2-O, S-PCS	1		2	

Initiating Event - <i>Loss of Class IV Power</i>		Sequence: <i>LOP-AO</i>			
Sequence Level Cut Sets		Component Failures	Human Errors	Support System Failures	Determinant Failure ?
RESPWR				1	Y

Initiating Event - <i>Loss of Class IV Power</i>		Sequence: <i>LOP-AP</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1, RESPWR	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1, RESPWR	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2, RESPWR	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2, RESPWR	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1, RESPWR	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2, RESPWR	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1, RESPWR	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2, RESPWR	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2, RESPWR	2		1	
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2, RESPWR	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1, RESPWR	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1, RESPWR	2		1	

Table C.7 (cont.)

Initiating Event - <i>Loss of Class IV Power</i>		Sequence: <i>LOP-AQ</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-AFW-DV, RESPWR	1		1	
F-AFW-DIESEL, RESPWR	1		1	
F-AFW-PMP, RESPWR	1		1	

Initiating Event - <i>Loss of Class IV Power</i>		Sequence: <i>LOP-AR</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
RESPWR, S-EL-II-1-O			2	
RESPWR, S-PCS			2	
F-BCS-CNV1-TK, F-BCS-CNV2, RESPWR	2		1	
F-BCS-CNV1-TK, RESPWR, S-EL-II-1-E	1		2	
F-BCS-CNV1, F-BCS-CNV1-TK, RESPWR	2		1	
F-BCS-CNV1-TK, RESPWR, S-AIR	1		2	

**Table C.8 Loss of essential power supply events sequence categorization:
representative initiating event - loss of Class IV power**

Specific Initiator		Loss of Class IV power		Loss of station electric load		Offsite power lost	
IE Frequency		1×10^{-2}		1×10^{-1}		1×10^{-6}	
Sequence	Determinant Failures	Bin	Category	Bin	Category	Bin	Category
LOP-A	NA	A	EC-I	A	EC-I	A	EC-I
LOP-B	2 valves	C	EC-III	C	EC-III	C	EC-III
LOP-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-F	2 valves and/or pumps, human error and level indication	C	EC-III	C	EC-III	C	EC-III
LOP-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-I	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-J	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-K	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-L	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-M	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-N	valve	B	EC-I	B	EC-I	B	EC-I
LOP-O	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-P	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-Q	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-R	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-S	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-T	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-U	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-V	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-W	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-X	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-Y	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-Z	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-AA	support system	C	EC-III	C	EC-III	C	EC-III
LOP-AB	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-AC	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-AD	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-AE	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-AF	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-AG	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-AH	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-AI	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-AJ	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-AK	support system	C	EC-III	C	EC-III	C	EC-III
LOP-AL	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV

Table C.8 (cont.)

Specific Initiator		Loss of Class IV power		Loss of station electric load		Offsite power lost	
IE Frequency		1×10^{-2}		1×10^{-1}		1×10^{-0}	
Sequence	Determinant Failures	Bin	Category	Bin	Category	Bin	Category
LOP-AM	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-AN	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-AO	support system	C	EC-III	C	EC-III	C	EC-III
LOP-AP	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-AQ	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-AR	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-FTSD-A	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-FTSD-B	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-FTSD-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-FTSD-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-FTSD-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-FTSD-F	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-FTSD-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-FTSD-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-FTSD-I	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-FTSD-J	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-FTSD-K	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-FTSD-L	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-FTSD-M	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-FTSD-N	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOP-A5	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV

Table C.8 (cont.)

Specific Initiator		Loss of flow in one or all heat transfer loops		Decreased heat transport system flow		Pressurizer anomalies (high pressure, low pressure, spray failure)		Deformation of fuel channel structure that restricts coolant flow	
IE Frequency		1×10^{-1}		1×10^{-2}		1×10^{-3}		1×10^{-3}	
Sequence	Determinant Failures	Bin	Category	Bin	Category	Bin	Category	Bin	Category
LOP-A	NA	A	EC-I	A	EC-I	A	EC-I	E	EC-II
LOP-B	2 valves	C	EC-III	C	EC-III	C	EC-III	G	EC-III
LOP-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-F	2 valves and/or pumps, human error and level indication	C	EC-III	C	EC-III	C	EC-III	G	EC-III
LOP-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-I	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-J	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-K	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-L	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-M	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-N	valve	B	EC-I	B	EC-I	B	EC-I	F	EC-II
LOP-O	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-P	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-Q	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-R	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-S	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-T	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-U	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-V	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-W	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-X	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-Y	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-Z	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-AA	support system	C	EC-III	C	EC-III	C	EC-III	G	EC-III
LOP-AB	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-AC	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-AD	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-AE	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-AF	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-AG	≥ 3 failures	D	EC-IV	L	EC-IV	D	EC-IV	H	EC-IV
LOP-AH	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV

Table C.8 (cont.)

Specific Initiator		Loss of flow in one or all heat transfer loops		Decreased heat transport system flow		Pressurizer anomalies (high pressure, low pressure, spray failure)		Deformation of fuel channel structure that restricts coolant flow	
IE Frequency		1×10^{-1}		1×10^{-2}		1×10^{-2}		1×10^{-3}	
Sequence	Determinant Failures	Bin	Category	Bin	Category	Bin	Category	Bin	Category
LOP-AI	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-AJ	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-AK	support system	C	EC-III	C	EC-III	C	EC-III	G	EC-III
LOP-AL	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-AM	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-AN	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-AO	support system	C	EC-III	C	EC-III	C	EC-III	G	EC-III
LOP-AP	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-AQ	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-AR	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-FTSD-A	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-FTSD-B	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-FTSD-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-FTSD-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-FTSD-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-FTSD-F	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-FTSD-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-FTSD-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-FTSD-I	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-FTSD-J	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-FTSD-K	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-FTSD-L	≥ 3 failures	D	EC-IV	D	EC-IV	I	EC-IV	H	EC-IV
LOP-FTSD-M	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-FTSD-N	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV
LOP-AS	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV	H	EC-IV

Table C.9 Feedwater piping break in the reactor building sequence cut sets

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-A</i>			
Sequence Level Cut Sets		Component Failures	Human Errors	Support System Failures	Determinant Failure ?
NONE		NA	NA	NA	NA

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-B</i>			
Sequence Level Cut Sets		Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-ASD-ASD1, F-ASD-ASD2		2			Y
F-ASD-ASD2, S-EL-II-2-O		1		1	
F-ASD-ASD1, S-EL-II-2-E		1		1	

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-F</i>			
Sequence Level Cut Sets		Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-FW2-HE, F-FW2-LI-TK		1	1		Y
F-FW2-PMP1, F-FW2-PMP2		2			Y
F-FW2-IV1, F-FW2-IV2		2			Y
F-FW2-IV2, F-FW2-PMP1		2			Y
F-FW2-IV1, F-FW2-OV2		2			Y
F-FW2-OV2, F-FW2-PMP1		2			Y

Table C.9 (cont.)

F-FW2-IV1, F-FW2-PMP2	2			Y
F-FW2-OV1, F-FW2-PMP2	2			Y
F-FW2-OV1, F-FW2-OV2	2			Y
F-FW2-IV2, F-FW2-OV1	2			Y
F-FW2-OV2, S-EL-III-2-O	1		1	
F-FW2-IV2, S-EL-III-2-O	1		1	
F-FW2-PMP2, S-EL-III-2-O	1		1	
F-FW2-OV1, S-EL-III-2-E	1		1	
F-FW2-PMP1, S-EL-III-2-E	1		1	
F-FW2-IV1, S-EL-III-2-E	1		1	
F-FW2-ISV1-SG1, F-FW2-ISV1-SG2, S-EL-II-2-E	2		1	
F-FW2-ISV2-SG1, F-FW2-ISV2-SG2, S-EL-II-2-O	2		1	

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-G</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-PCS			1	Y
F-FW2-HE, F-FW2-LI-TK, F-SDC-HE	1	2		
S-EL-III-2-E, S-EL-III-2-O			2	
S-EL-II-2-E, S-EL-II-2-O			2	
F-FW2-OV1, F-FW2-OV2, F-SDC-HE	2	1		
F-FW2-IV2, F-FW2-PMP1, F-SDC-HE	2	1		
F-FW2-IV2, F-FW2-OV1, F-SDC-HE	2	1		
F-FW2-OV2, F-FW2-PMP1, F-SDC-HE	2	1		
F-FW2-OV1, F-FW2-PMP2, F-SDC-HE	2	1		
F-FW2-IV1, F-FW2-OV2, F-SDC-HE	2	1		
F-FW2-PMP1, F-FW2-PMP2, F-SDC-HE	2	1		
F-FW2-IV1, F-FW2-PMP2, F-SDC-HE	2	1		
F-FW2-IV1, F-FW2-IV2, F-SDC-HE	2	1		
F-FW2-OV2, F-SDC-HE, S-EL-III-2-O	1	1	1	
F-FW2-PMP2, F-SDC-HE, S-EL-III-2-O	1	1	1	
F-FW2-IV2, F-SDC-HE, S-EL-III-2-O	1	1	1	
F-FW2-OV1, F-SDC-PMP1, S-EL-III-2-E	2		1	

Table C.9 (cont.)

F-FW2-IV2, F-SDC-PMP2, S-EL-III-2-O	2		1	
F-FW2-IV1, F-SDC-PMP1, S-EL-III-2-E	2		1	
F-FW2-OV2, F-SDC-PMP2, S-EL-III-2-O	2		1	
F-FW2-IV1, F-SDC-HE, S-EL-III-2-E	1	1	1	
F-FW2-OV1, F-SDC-HE, S-EL-III-2-E	1	1	1	
F-FW2-PMP1, F-SDC-HE, S-EL-III-2-E	1	1	1	
F-FW2-PMP1, F-SDC-PMP1, S-EL-III-2-E	2		1	
F-FW2-PMP2, F-SDC-PMP2, S-EL-III-2-O	2		1	

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-H</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-EL-III-1-O, S-PCS			2	
F-MCS-ISV-FC, S-PCS	1		1	
F-MCS-PMP1, S-PCS	1		1	
S-PCS, S-RCW			2	
S-EL-III-1-E, S-PCS			2	
F-MCS-PMP2, S-PCS	1		1	
F-MCS-PMP1, S-EL-III-2-E, S-EL-III-2-O	1		2	
F-MCS-PMP2, S-EL-III-2-E, S-EL-III-2-O	1		2	
S-EL-III-1-E, S-EL-III-2-E, S-EL-III-2-O			3	
S-EL-III-1-O, S-EL-III-2-E, S-EL-III-2-O			3	
S-EL-III-2-E, S-EL-III-2-O, S-RCW			3	
F-MCS-ISV-FC, S-EL-III-2-E, S-EL-III-2-O	1		2	
S-EL-II-2-E, S-EL-II-2-O, S-EL-III-1-E			3	
F-MCS-PMP2, S-EL-II-2-E, S-EL-II-2-O	1		2	
F-MCS-ISV-FC, S-EL-II-2-E, S-EL-II-2-O	1		2	
F-MCS-PMP1, S-EL-II-2-E, S-EL-II-2-O	1		2	
S-EL-II-2-E, S-EL-II-2-O, S-RCW			3	
S-EL-II-2-E, S-EL-II-2-O, S-EL-III-1-O			3	

Table C.9 (cont.)

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-I</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-ISO-HE		1		Y
F-ISO-VLV-FO	1			Y
F-ISO-SIG	1			Y
S-EL-II-1-O			1	
S-AIR			1	

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-J</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-ISO-HE, F-SDC-HE		2		Y
F-ISO-HE, S-PCS		1	1	
F-ISO-VLV-FO, F-SDC-HE	1	1		Y
F-SDC-HE, S-EL-II-1-O		1	1	
F-ISO-SIG, F-SDC-HE	1	1		Y
F-SDC-HE, S-AIR		1	1	
S-EL-II-1-O, S-PCS			2	
F-ISO-VLV-FO, S-PCS	1		1	
F-ISO-SIG, S-PCS	1		1	
F-ISO-HE, F-SDC-IISV1, F-SDC-IISV2	2	1		
F-ISO-HE, F-SDC-PMP1, F-SDC-PMP2	2	1		
F-ISO-HE, F-SDC-OISV1, F-SDC-OISV2	2	1		
S-AIR, S-PCS			2	
F-ISO-HE, F-SDC-OISV2, S-EL-II-2-O	1	1	1	
F-ISO-HE, F-SDC-PMP2, S-EL-III-2-O	1	1	1	
F-ISO-HE, F-SDC-PMP1, S-EL-III-2-E	1	1	1	
F-ISO-HE, F-SDC-IISV1, S-EL-II-2-E	1	1	1	
F-ISO-HE, F-SDC-IISV2, S-EL-II-2-O	1	1	1	
F-ISO-HE, F-SDC-OISV1, S-EL-II-2-E	1	1	1	
F-SDC-PMP1, F-SDC-PMP2, S-EL-II-1-O	2		1	

Table C.9 (cont.)

F-ISO-SIG, F-SDC-OISV1, F-SDC-OISV2	3			
F-SDC-OISV1, F-SDC-OISV2, S-EL-II-1-O	2		1	
F-ISO-VLV-FO, F-SDC-OISV1, F-SDC-OISV2	3			
F-ISO-SIG, F-SDC-IISV1, F-SDC-IISV2	3			
F-ISO-SIG, F-SDC-PMP1, F-SDC-PMP2	3			
F-SDC-IISV1, F-SDC-IISV2, S-EL-II-1-O	2		1	
F-ISO-VLV-FO, F-SDC-PMP1, F-SDC-PMP2	3			
F-ISO-VLV-FO, F-SDC-IISV1, F-SDC-IISV2	3			
F-ISO-HE, S-EL-III-2-E, S-EL-III-2-O		1	2	
F-ISO-HE, S-EL-II-2-E, S-EL-II-2-O		1	2	
F-ISO-HE, F-SDC-HX1, F-SDC-HX2	2	1		
F-ISO-VLV-FO, F-SDC-PMP1, S-EL-III-2-E	2		1	
F-SDC-PMP2, S-EL-II-1-O, S-EL-III-2-O	1		2	
F-ISO-SIG, F-SDC-PMP1, S-EL-III-2-E	2		1	
F-SDC-IISV2, S-EL-II-1-O, S-EL-II-2-O	1		2	
F-SDC-PMP1, F-SDC-PMP2, S-AIR	2		1	
F-ISO-VLV-FO, F-SDC-PMP2, S-EL-III-2-O	2		1	
F-SDC-PMP1, S-EL-II-1-O, S-EL-III-2-E	1		2	
F-ISO-SIG, F-SDC-OISV1, S-EL-II-2-E	2		1	
F-SDC-IISV1, F-SDC-IISV2, S-AIR	2		1	
F-ISO-SIG, F-SDC-IISV1, S-EL-II-2-E	2		1	
F-SDC-OISV2, S-EL-II-1-O, S-EL-II-2-O	1		2	
F-ISO-VLV-FO, F-SDC-IISV1, S-EL-II-2-E	2		1	
F-SDC-IISV1, S-EL-II-1-O, S-EL-II-2-E	1		2	
F-ISO-VLV-FO, F-SDC-IISV2, S-EL-II-2-O	2		1	
F-ISO-SIG, F-SDC-IISV2, S-EL-II-2-O	2		1	
F-ISO-VLV-FO, F-SDC-OISV2, S-EL-II-2-O	2		1	
F-ISO-SIG, F-SDC-OISV2, S-EL-II-2-O	2		1	
F-ISO-VLV-FO, F-SDC-OISV1, S-EL-II-2-E	2		1	
F-ISO-SIG, F-SDC-PMP2, S-EL-III-2-O	2		1	
F-SDC-OISV1, S-EL-II-1-O, S-EL-II-2-E	1		2	
F-SDC-OISV1, F-SDC-OISV2, S-AIR	2		1	
F-ISO-SIG, S-EL-II-2-E, S-EL-II-2-O	1		2	
F-ISO-VLV-FO, S-EL-II-2-E, S-EL-II-2-O	1		2	

Table C.9 (cont.)

F-ISO-SIG, F-SDC-HX1, F-SDC-HX2	3			
F-ISO-VLV-FO, F-SDC-HX1, F-SDC-HX2	3			
F-SDC-HX1, F-SDC-HX2, S-EL-II-1-O	2		1	
S-EL-II-1-O, S-EL-III-2-E, S-EL-III-2-O			3	
F-SDC-OISV2, S-AIR, S-EL-II-2-O	1		2	
F-SDC-OISV1, S-AIR, S-EL-II-2-E	1		2	
F-SDC-IISV2, S-AIR, S-EL-II-2-O	1		2	
F-ISO-SIG, S-EL-III-2-E, S-EL-III-2-O	1		2	
F-SDC-IISV1, S-AIR, S-EL-II-2-E	1		2	
S-EL-II-1-O, S-EL-II-2-E, S-EL-II-2-O			3	
F-ISO-VLV-FO, S-EL-III-2-E, S-EL-III-2-O	1		2	
F-SDC-PMP1, S-AIR, S-EL-III-2-E	1		2	
F-SDC-PMP2, S-AIR, S-EL-III-2-O	1		2	
S-AIR, S-EL-III-2-E, S-EL-III-2-O			3	
S-AIR, S-EL-II-2-E, S-EL-II-2-O			3	
F-SDC-HX1, F-SDC-HX2, S-AIR	2		1	

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-K</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?	
F-ISO-HE, F-MCS-ISV-FC, F-SDC-HE	1	2			
F-ISO-HE, F-MCS-PMP1, F-SDC-HE	1	2			
F-ISO-HE, F-MCS-PMP2, F-SDC-HE	1	2			
F-ISO-HE, F-SDC-HE, S-EL-III-1-O		2	1		
F-ISO-HE, F-SDC-HE, S-EL-III-1-E		2	1		
F-ISO-HE, F-SDC-HE, S-RCW		2	1		
F-ISO-HE, F-MCS-ISV-FC, S-PCS	1	1	1		
F-ISO-HE, S-PCS, S-RCW		1	2		
F-ISO-HE, F-MCS-PMP2, S-PCS	1	1	1		
F-ISO-HE, F-SDC-HX1, S-RCW	1	1	1		
F-ISO-HE, S-EL-III-1-E, S-PCS		1	2		
F-ISO-HE, S-EL-III-1-O, S-PCS		1	2		
F-ISO-HE, F-MCS-PMP1, S-PCS	1	1	1		

Table C.9 (cont.)

F-ISO-HE, S-RCW, S-SW2		1	2	
F-ISO-SIG, F-MCS-PMP1, F-SDC-HE	2	1		
F-ISO-SIG, F-SDC-HE, S-EL-III-1-E	1	1	1	
F-ISO-VLV-FO, F-SDC-HE, S-RCW	1	1	1	
F-ISO-SIG, F-SDC-HE, S-EL-III-1-O	1	1	1	
F-ISO-SIG, F-MCS-PMP2, F-SDC-HE	2	1		
F-ISO-VLV-FO, F-MCS-PMP1, F-SDC-HE	2	1		
F-ISO-SIG, F-MCS-ISV-FC, F-SDC-HE	2	1		
F-ISO-VLV-FO, F-MCS-ISV-FC, F-SDC-HE	2	1		
F-ISO-VLV-FO, F-MCS-PMP2, F-SDC-HE	2	1		
F-SDC-HE, S-EL-II-1-O, S-RCW		1	2	
F-ISO-VLV-FO, F-SDC-HE, S-EL-III-1-E	1	1	1	
F-ISO-VLV-FO, F-SDC-HE, S-EL-III-1-O	1	1	1	
F-ISO-SIG, F-SDC-HE, S-RCW	1	1	1	
F-SDC-HE, S-EL-II-1-O, S-EL-III-1-E		1	2	
F-SDC-HE, S-EL-II-1-O, S-EL-III-1-O		1	2	
F-MCS-PMP2, F-SDC-HE, S-EL-II-1-O	1	1	1	
F-MCS-PMP1, F-SDC-HE, S-EL-II-1-O	1	1	1	
F-MCS-ISV-FC, F-SDC-HE, S-EL-II-1-O	1	1	1	
F-ISO-VLV-FO, S-RCW, S-SW2	1		2	
F-ISO-SIG, S-RCW, S-SW2	1		2	
F-MCS-PMP1, S-EL-II-1-O, S-PCS	1		2	
F-MCS-ISV-FC, S-EL-II-1-O, S-PCS	1		2	
F-SDC-HE, S-AIR, S-EL-III-1-O		1	2	
F-SDC-HX1, S-EL-II-1-O, S-RCW	1		2	
S-EL-II-1-O, S-RCW, S-SW2			3	
F-ISO-VLV-FO, F-SDC-HX1, S-RCW	2		1	
F-SDC-HE, S-AIR, S-RCW		1	2	
F-MCS-PMP2, S-EL-II-1-O, S-PCS	1		2	
S-EL-II-1-O, S-EL-III-1-E, S-PCS			3	
S-EL-II-1-O, S-PCS, S-RCW			3	
F-ISO-VLV-FO, S-PCS, S-RCW	1		2	
F-ISO-SIG, F-SDC-HX1, S-RCW	2		1	
F-ISO-SIG, S-PCS, S-RCW	1		2	

Table C.9 (cont.)

F-ISO-SIG, S-EL-III-1-O, S-PCS	1		2	
F-ISO-VLV-FO, F-MCS-PMP1, S-PCS	2		1	
F-ISO-VLV-FO, S-EL-III-1-E, S-PCS	1		2	
F-MCS-PMP2, F-SDC-HE, S-AIR	1	1	1	
F-SDC-HE, S-AIR, S-EL-III-1-E		1	2	
F-ISO-VLV-FO, F-MCS-PMP2, S-PCS	2		1	
F-MCS-PMP1, F-SDC-HE, S-AIR	1	1	1	
F-ISO-VLV-FO, F-MCS-ISV-FC, S-PCS	2		1	
S-EL-II-1-O, S-EL-III-1-O, S-PCS			3	
F-ISO-VLV-FO, S-EL-III-1-O, S-PCS	1		2	
F-ISO-SIG, S-EL-III-1-E, S-PCS	1		2	
F-ISO-SIG, F-MCS-PMP1, S-PCS	2		1	
F-MCS-ISV-FC, F-SDC-HE, S-AIR	1	1	1	
F-ISO-SIG, F-MCS-PMP2, S-PCS	2		1	
F-ISO-SIG, F-MCS-ISV-FC, S-PCS	2		1	
F-MCS-PMP1, S-AIR, S-PCS	1		2	
F-SDC-HX1, S-AIR, S-RCW	1		2	
S-AIR, S-EL-III-1-O, S-PCS			3	
S-AIR, S-RCW, S-SW2			3	
F-MCS-PMP2, S-AIR, S-PCS	1		2	
S-AIR, S-PCS, S-RCW			3	
F-MCS-ISV-FC, S-AIR, S-PCS	1		2	
S-AIR, S-EL-III-1-E, S-PCS			3	

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-L</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-SD1-CR-BD-CM			1	Y
F-SD1-CR-COIL-CM			1	Y
F-SD1-TLB-REL2, F-SD1-TLB-REL3	2			Y
F-SD1-TLB-REL1, F-SD1-TLB-REL2	2			Y
F-SD1-TLA-REL1, F-SD1-TLA-REL2	2			Y
F-SD1-TLB-REL1, F-SD1-TLB-REL3	2			Y

Table C.9 (cont.)

F-SD1-TLA-REL2, F-SD1-TLA-REL3	2			Y
F-SD1-TLA-REL1, F-SD1-TLA-REL3	2			Y
F-SD1-TC-D, F-SD1-TC-E	2			Y
F-SD1-TC-D, F-SD1-TC-F	2			Y
F-SD1-TC-E, F-SD1-TC-F	2			Y

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-M</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-ASD-ASD1, F-ASD-ASD2, F-SD1-CR-BD-CM	2		1	
F-ASD-ASD1, F-ASD-ASD2, F-SD1-CR-COIL-CM	2		1	
F-ASD-ASD2, F-SD1-CR-BD-CM, S-EL-II-2-O	1		2	
F-ASD-ASD2, F-SD1-CR-COIL-CM, S-EL-II-2-O	1		2	
F-ASD-ASD1, F-SD1-CR-BD-CM, S-EL-II-2-E	1		2	
F-ASD-ASD1, F-SD1-CR-COIL-CM, S-EL-II-2-E	1		2	

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-Q</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-FW2-HE, F-FW2-LI-TK, F-SD1-CR-BD-CM	1	1	1	
F-FW2-HE, F-FW2-LI-TK, F-SD1-CR-COIL-CM	1	1	1	
F-FW2-IV1, F-FW2-OV2, F-SD1-CR-COIL-CM	2		1	
F-FW2-IV1, F-FW2-IV2, F-SD1-CR-COIL-CM	2		1	
F-FW2-IV1, F-FW2-PMP2, F-SD1-CR-COIL-CM	2		1	
F-FW2-PMP1, F-FW2-PMP2, F-SD1-CR-COIL-CM	2		1	
F-FW2-IV2, F-FW2-OV1, F-SD1-CR-BD-CM	2		1	
F-FW2-OV1, F-FW2-OV2, F-SD1-CR-BD-CM	2		1	
F-FW2-OV1, F-FW2-PMP2, F-SD1-CR-BD-CM	2		1	
F-FW2-IV2, F-FW2-PMP1, F-SD1-CR-COIL-CM	2		1	
F-FW2-IV2, F-FW2-OV1, F-SD1-CR-COIL-CM	2		1	
F-FW2-OV2, F-FW2-PMP1, F-SD1-CR-COIL-CM	2		1	

Table C.9 (cont.)

F-FW2-IV1, F-FW2-OV2, F-SD1-CR-BD-CM	2		1	
F-FW2-IV1, F-FW2-IV2, F-SD1-CR-BD-CM	2		1	
F-FW2-OV1, F-FW2-OV2, F-SD1-CR-COIL-CM	2		1	
F-FW2-PMP1, F-FW2-PMP2, F-SD1-CR-BD-CM	2		1	
F-FW2-IV1, F-FW2-PMP2, F-SD1-CR-BD-CM	2		1	
F-FW2-IV2, F-FW2-PMP1, F-SD1-CR-BD-CM	2		1	
F-FW2-OV2, F-FW2-PMP1, F-SD1-CR-BD-CM	2		1	
F-FW2-OV1, F-FW2-PMP2, F-SD1-CR-COIL-CM	2		1	
F-FW2-OV2, F-SD1-CR-COIL-CM, S-EL-III-2-O	1		2	
F-FW2-PMP2, F-SD1-CR-COIL-CM, S-EL-III-2-O	1		2	
F-FW2-IV2, F-SD1-CR-COIL-CM, S-EL-III-2-O	1		2	
F-FW2-IV1, F-SD1-CR-BD-CM, S-EL-III-2-E	1		2	
F-FW2-IV2, F-SD1-CR-BD-CM, S-EL-III-2-O	1		2	
F-FW2-OV1, F-SD1-CR-BD-CM, S-EL-III-2-E	1		2	
F-FW2-OV2, F-SD1-CR-BD-CM, S-EL-III-2-O	1		2	
F-FW2-IV1, F-SD1-CR-COIL-CM, S-EL-III-2-E	1		2	
F-FW2-OV1, F-SD1-CR-COIL-CM, S-EL-III-2-E	1		2	
F-FW2-PMP1, F-SD1-CR-COIL-CM, S-EL-III-2-E	1		2	
F-FW2-PMP1, F-SD1-CR-BD-CM, S-EL-III-2-E	1		2	
F-FW2-PMP2, F-SD1-CR-BD-CM, S-EL-III-2-O	1		2	

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-R</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-SD1-CR-COIL-CM, S-PCS			2	
F-SD1-CR-BD-CM, S-PCS			2	
F-SD1-TLB-REL1, F-SD1-TLB-REL3, S-PCS	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL2, S-PCS	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL2, S-PCS	2		1	
F-SD1-TLB-REL2, F-SD1-TLB-REL3, S-PCS	2		1	
F-SD1-TLA-REL2, F-SD1-TLA-REL3, S-PCS	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL3, S-PCS	2		1	
F-SD1-CR-COIL-CM, S-EL-III-2-E, S-EL-III-2-O			3	

Table C.9 (cont.)

F-SD1-CR-BD-CM, S-EL-III-2-E, S-EL-III-2-O			3	
F-SD1-CR-COIL-CM, S-EL-II-2-E, S-EL-II-2-O			3	
F-SD1-TC-D, F-SD1-TC-F, S-PCS	2		1	
F-SD1-TC-D, F-SD1-TC-E, S-PCS	2		1	
F-SD1-TC-E, F-SD1-TC-F, S-PCS	2		1	
F-SD1-CR-BD-CM, S-EL-II-2-E, S-EL-II-2-O			3	

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-S</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-SD1-CR-BD-CM, S-EL-III-1-O, S-PCS			3	
F-MCS-PMP1, F-SD1-CR-COIL-CM, S-PCS	1		2	
F-SD1-CR-COIL-CM, S-EL-III-1-O, S-PCS			3	
F-SD1-CR-BD-CM, S-PCS, S-RCW			3	
F-MCS-PMP1, F-SD1-CR-BD-CM, S-PCS	1		2	
F-SD1-CR-COIL-CM, S-PCS, S-RCW			3	
F-SD1-CR-COIL-CM, S-EL-III-1-E, S-PCS			3	
F-MCS-PMP2, F-SD1-CR-BD-CM, S-PCS	1		2	
F-MCS-ISV-FC, F-SD1-CR-COIL-CM, S-PCS	1		2	
F-MCS-PMP2, F-SD1-CR-COIL-CM, S-PCS	1		2	
F-MCS-ISV-FC, F-SD1-CR-BD-CM, S-PCS	1		2	
F-SD1-CR-BD-CM, S-EL-III-1-E, S-PCS			3	

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-T</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-ISO-HE, F-SD1-CR-COIL-CM		1	1	
F-ISO-HE, F-SD1-CR-BD-CM		1	1	
F-SD1-CR-COIL-CM, S-EL-II-1-O			2	
F-ISO-VLV-FO, F-SD1-CR-BD-CM	1		1	
F-ISO-SIG, F-SD1-CR-BD-CM	1		1

4 of 4

Table C.9 (cont.)

F-ISO-VLV-FO, F-SD1-CR-COIL-CM	1		1	
F-SD1-CR-BD-CM, S-EL-II-1-O			2	
F-ISO-SIG, F-SD1-CR-COIL-CM	1		1	
F-ISO-HE, F-SD1-TLA-REL1, F-SD1-TLA-REL2	2	1		
F-ISO-HE, F-SD1-TLB-REL1, F-SD1-TLB-REL2	2	1		
F-ISO-HE, F-SD1-TLB-REL1, F-SD1-TLB-REL3	2	1		
F-ISO-HE, F-SD1-TLA-REL1, F-SD1-TLA-REL3	2	1		
F-ISO-HE, F-SD1-TLB-REL2, F-SD1-TLB-REL3	2	1		
F-ISO-HE, F-SD1-TLA-REL2, F-SD1-TLA-REL3	2	1		
F-SD1-CR-BD-CM, S-AIR			2	
F-SD1-CR-COIL-CM, S-AIR			2	
F-ISO-VLV-FO, F-SD1-TLA-REL1, F-SD1-TLA-REL2	3			
F-ISO-SIG, F-SD1-TLA-REL1, F-SD1-TLA-REL2	3			
F-ISO-SIG, F-SD1-TLB-REL2, F-SD1-TLB-REL3	3			
F-SD1-TLB-REL1, F-SD1-TLB-REL3, S-EL-II-1-O	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL2, S-EL-II-1-O	2		1	
F-ISO-VLV-FO, F-SD1-TLB-REL1, F-SD1-TLB-REL3	3			
F-ISO-SIG, F-SD1-TLB-REL1, F-SD1-TLB-REL3	3			
F-ISO-SIG, F-SD1-TLB-REL1, F-SD1-TLB-REL2	3			
F-SD1-TLB-REL2, F-SD1-TLB-REL3, S-EL-II-1-O	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL2, S-EL-II-1-O	2		1	
F-ISO-VLV-FO, F-SD1-TLB-REL1, F-SD1-TLB-REL2	3			
F-ISO-VLV-FO, F-SD1-TLA-REL1, F-SD1-TLA-REL3	3			
F-SD1-TLA-REL1, F-SD1-TLA-REL3, S-EL-II-1-O	2		1	
F-ISO-SIG, F-SD1-TLA-REL1, F-SD1-TLA-REL3	3			
F-SD1-TLA-REL2, F-SD1-TLA-REL3, S-EL-II-1-O	2		1	
F-ISO-VLV-FO, F-SD1-TLB-REL2, F-SD1-TLB-REL3	3			
F-ISO-VLV-FO, F-SD1-TLA-REL2, F-SD1-TLA-REL3	3			
F-ISO-SIG, F-SD1-TLA-REL2, F-SD1-TLA-REL3	3			
F-ISO-HE, F-SD1-TC-D, F-SD1-TC-E	2	1		
F-ISO-HE, F-SD1-TC-D, F-SD1-TC-F	2	1		
F-ISO-HE, F-SD1-TC-E, F-SD1-TC-F	2	1		
F-SD1-TLB-REL1, F-SD1-TLB-REL2, S-AIR	2		1	
F-SD1-TLB-REL1, F-SD1-TLB-REL3, S-AIR	2		1	

Table C.9 (cont.)

F-SD1-TLA-REL1, F-SD1-TLA-REL2, S-AIR	2		1	
F-SD1-TLA-REL2, F-SD1-TLA-REL3, S-AIR	2		1	
F-SD1-TLA-REL1, F-SD1-TLA-REL3, S-AIR	2		1	
F-SD1-TLB-REL2, F-SD1-TLB-REL3, S-AIR	2		1	
F-SD1-TC-D, F-SD1-TC-F, S-EL-II-1-O	2		1	
F-ISO-SIG, F-SD1-TC-D, F-SD1-TC-E	3			
F-ISO-SIG, F-SD1-TC-D, F-SD1-TC-F	3			
F-ISO-VLV-FO, F-SD1-TC-D, F-SD1-TC-E	3			
F-SD1-TC-E, F-SD1-TC-F, S-EL-II-1-O	2		1	
F-SD1-TC-D, F-SD1-TC-E, S-EL-II-1-O	2		1	
F-ISO-SIG, F-SD1-TC-E, F-SD1-TC-F	3			
F-ISO-VLV-FO, F-SD1-TC-D, F-SD1-TC-F	3			
F-ISO-VLV-FO, F-SD1-TC-E, F-SD1-TC-F	3			
F-SD1-TC-D, F-SD1-TC-F, S-AIR	2		1	
F-SD1-TC-D, F-SD1-TC-E, S-AIR	2		1	
F-SD1-TC-E, F-SD1-TC-F, S-AIR	2		1	

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-U</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-ISO-HE, F-SD1-CR-COIL-CM, F-SDC-HE		2	1	
F-ISO-HE, F-SD1-CR-BD-CM, F-SDC-HE		2	1	
F-ISO-HE, F-SD1-CR-BD-CM, S-PCS		1	2	
F-ISO-HE, F-SD1-CR-COIL-CM, S-PCS		1	2	
F-ISO-SIG, F-SD1-CR-BD-CM, F-SDC-HE	1	1	1	
F-ISO-VLV-FO, F-SD1-CR-COIL-CM, F-SDC-HE	1	1	1	
F-ISO-SIG, F-SD1-CR-COIL-CM, F-SDC-HE	1	1	1	
F-ISO-VLV-FO, F-SD1-CR-BD-CM, F-SDC-HE	1	1	1	
F-SD1-CR-BD-CM, F-SDC-HE, S-EL-II-1-O	1	1	1	
F-SD1-CR-COIL-CM, F-SDC-HE, S-EL-II-1-O		1	2	
F-ISO-SIG, F-SD1-CR-BD-CM, S-PCS	1		2	
F-SD1-CR-COIL-CM, F-SDC-HE, S-AIR		1	2	
F-ISO-SIG, F-SD1-CR-COIL-CM, S-PCS	1		2	

Table C.9 (cont.)

F-SD1-CR-BD-CM, F-SDC-HE, S-AIR		1	2	
F-ISO-VLV-FO, F-SD1-CR-COIL-CM, S-PCS	1		2	
F-SD1-CR-BD-CM, S-EL-II-1-O, S-PCS			3	
F-SD1-CR-COIL-CM, S-EL-II-1-O, S-PCS			3	
F-ISO-VLV-FO, F-SD1-CR-BD-CM, S-PCS	1		2	
F-SD1-CR-BD-CM, S-AIR, S-PCS			3	
F-SD1-CR-COIL-CM, S-AIR, S-PCS			3	

Initiating Event - <i>Feedwater Piping Break in the Reactor Building</i>		Sequence: <i>LOFWRB-FTSD-A</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT2	2		1		
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT5	2		1		
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT5	2		1		
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT5	2		1		
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT2	2		1		
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT5	2		1		
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT5	2		1		
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT5	2		1		
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT3	2		1		
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT5	2		1		
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT5	2		1		
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT5	2		1		
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT3	2		1		
F-SD1-CR-BD-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT5	2		1		
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT5	2		1		
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT5	2		1		
F-SD1-CR-BD-CM, F-SD2-TL-G, F-SD2-TL-J	2		1		
F-SD1-CR-COIL-CM, F-SD2-TL-G, F-SD2-TL-J	2		1		
F-SD1-CR-COIL-CM, F-SD2-TL-H, F-SD2-TL-J	2		1		
F-SD1-CR-BD-CM, F-SD2-TL-H, F-SD2-TL-J	2		1		
F-SD1-CR-BD-CM, F-SD2-TL-G, F-SD2-TL-H	2		1		
F-SD1-CR-COIL-CM, F-SD2-TL-G, F-SD2-TL-H	2		1		

Table C.9 (cont.)

F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT6	2		1	

Table C.9 (cont.)

F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT4, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT3	2		1	

Table C.9 (cont.)

F-SD1-CR-BD-CM, F-SD2-ISV1-PT3, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT3	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT2	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT5, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT5, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT4, F-SD2-ISV2-PT2	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV1-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT2, F-SD2-ISV2-PT4	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT5, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT6, F-SD2-ISV2-PT1	2		1	
F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV2-PT6	2		1	

Table C.9 (cont.)

F-SD1-CR-BD-CM, F-SD2-ISV1-PT1, F-SD2-ISV1-PT6	2		1	
F-SD1-CR-COIL-CM, F-SD2-ISV2-PT1, F-SD2-ISV2-PT5	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-J, F-SD2-TL-H	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-H, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TL-H	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-G, F-SD2-TL-H	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-H, F-SD2-TL-G	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-H, F-SD2-TL-G	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-J, F-SD2-TL-H	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-G, F-SD2-TL-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-J, F-SD2-TL-G	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-J, F-SD2-TL-G	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-H, F-SD2-TL-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TC-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-G, F-SD2-TC-H	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-G, F-SD2-TC-H	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-H, F-SD2-TC-J	2		1	
F-SD1-CR-COIL-CM, F-SD2-TC-H, F-SD2-TC-J	2		1	
F-SD1-CR-BD-CM, F-SD2-TC-G, F-SD2-TC-J	2		1	

**Table C.10 Undercooling events sequence categorization:
representative initiating event - feedwater piping break in the reactor building**

Specific Initiator		Feedwater piping break in the reactor building		Steam generator tube failure	
IE Frequency		1×10^{-5}		1×10^{-3}	
Sequence	Determinant Failures	Bin	Category	Bin	Category
LOFWRB-A	N/A	I	EC-III	E	EC-II
LOFWRB-B	2 valves	K	EC-IV	G	EC-III
LOFWRB-C	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-D	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-E	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-F	tank level indicator and human error, 2 pumps and/or valves	K	EC-IV	G	EC-III
LOFWRB-G	support system	K	EC-IV	G	EC-III
LOFWRB-H	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-I	signal failure, valve failure, human error	J	EC-III	F	EC-II
LOFWRB-J	signal or valve and human error, 2 human errors	K	EC-IV	G	EC-III
LOFWRB-K	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-L	common mode, 2 trip logic relays, 2 trip computers	K	EC-IV	G	EC-III
LOFWRB-M	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-N	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-O	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-P	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-Q	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-R	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-S	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-T	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-U	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-FTSD-A	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-FTSD-B	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-FTSD-C	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-FTSD-D	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-FTSD-E	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-FTSD-F	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-FTSD-G	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-FTSD-H	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-FTSD-I	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-FTSD-J	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-FTSD-K	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-FTSD-L	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-FTSD-M	≥ 3 failures	L	EC-IV	H	EC-IV
LOFWRB-FTSD-N	≥ 3 failures	L	EC-IV	H	EC-IV

Table C.11 Feedwater piping break in the turbine building cut sets

Initiating Event - <i>Feedwater Piping Break in the Turbine Building</i>		Sequence: <i>LOFWTB-A</i>			
Sequence Level Cut Sets		Component Failures	Human Errors	Support System Failures	Determinant Failure ?
NONE		NA	NA	NA	NA

Initiating Event - <i>Feedwater Piping Break in the Turbine Building</i>		Sequence: <i>LOFWTB-B</i>			
Sequence Level Cut Sets		Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-AIR				1	Y
F-ASD-ASD1, F-ASD-ASD2		2			Y
F-ASD-ASD2, S-EL-II-2-O		1		1	
F-ASD-ASD1, S-EL-II-2-E		1		1	

Initiating Event - <i>Feedwater Piping Break in the Turbine Building</i>		Sequence: <i>LOFWTB-C</i>			
Sequence Level Cut Sets		Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1, S-AIR		2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1, S-AIR		2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2, S-AIR		2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2, S-AIR		2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1, S-AIR		2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2, S-AIR		2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1, S-AIR		2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2, S-AIR		2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2, S-AIR		2		1	
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2, S-AIR		2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1, S-AIR		2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1, S-AIR		2		1	

Table C.11 (cont.)

Initiating Event - <i>Feedwater Piping Break in the Turbine Building</i>		Sequence: <i>LOFWTB-F</i>			
Sequence Level Cut Sets		Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-FW2-HE, F-FW2-LI-TK		1	1		Y
F-FW2-PMP1, F-FW2-PMP2		2			Y
F-FW2-IV1, F-FW2-IV2		2			Y
F-FW2-IV2, F-FW2-PMP1		2			Y
F-FW2-IV1, F-FW2-OV2		2			Y
F-FW2-OV2, F-FW2-PMP1		2			Y
F-FW2-IV1, F-FW2-PMP2		2			Y
F-FW2-OV1, F-FW2-PMP2		2			Y
F-FW2-OV1, F-FW2-OV2		2			Y
F-FW2-IV2, F-FW2-OV1		2			Y
F-FW2-OV2, S-EL-III-2-O		1		1	
F-FW2-IV2, S-EL-III-2-O		1		1	
F-FW2-PMP2, S-EL-III-2-O		1		1	
F-FW2-OV1, S-EL-III-2-E		1		1	
F-FW2-PMP1, S-EL-III-2-E		1		1	
F-FW2-IV1, S-EL-III-2-E		1		1	
F-FW2-ISV1-SG1, F-FW2-ISV1-SG2, S-EL-II-2-E		2		1	
F-FW2-ISV2-SG1, F-FW2-ISV2-SG2, S-EL-II-2-O		2		1	

Initiating Event - <i>Feedwater Piping Break in the Turbine Building</i>		Sequence: <i>LOFWTB-G</i>			
Sequence Level Cut Sets		Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-PCS				1	Y
F-FW2-HE, F-FW2-LI-TK, F-SDC-HE		1	2		
S-EL-III-2-E, S-EL-III-2-O				2	
S-EL-II-2-E, S-EL-II-2-O				2	
F-FW2-OV1, F-FW2-OV2, F-SDC-HE		2	1		
F-FW2-IV2, F-FW2-PMP1, F-SDC-HE		2	1		
F-FW2-IV2, F-FW2-OV1, F-SDC-HE		2	1		

Table C.11 (cont.)

F-FW2-OV2, F-FW2-PMP1, F-SDC-HE	2	1		
F-FW2-OV1, F-FW2-PMP2, F-SDC-HE	2	1		
F-FW2-IV1, F-FW2-OV2, F-SDC-HE	2	1		
F-FW2-PMP1, F-FW2-PMP2, F-SDC-HE	2	1		
F-FW2-IV1, F-FW2-PMP2, F-SDC-HE	2	1		
F-FW2-IV1, F-FW2-IV2, F-SDC-HE	2	1		
F-FW2-OV2, F-SDC-HE, S-EL-III-2-O	1	1	1	
F-FW2-PMP2, F-SDC-HE, S-EL-III-2-O	1	1	1	
F-FW2-IV2, F-SDC-HE, S-EL-III-2-O	1	1	1	
F-FW2-OV1, F-SDC-PMP1, S-EL-III-2-E	2		1	
F-FW2-IV2, F-SDC-PMP2, S-EL-III-2-O	2		1	
F-FW2-IV1, F-SDC-PMP1, S-EL-III-2-E	2		1	
F-FW2-OV2, F-SDC-PMP2, S-EL-III-2-O	2		1	
F-FW2-IV1, F-SDC-HE, S-EL-III-2-E	1	1	1	
F-FW2-OV1, F-SDC-HE, S-EL-III-2-E	1	1	1	
F-FW2-PMP1, F-SDC HE, S-EL-III-2-E	1	1	1	
F-FW2-PMP1, F-SDC-PMP1, S-EL-III-2-E	2		1	
F-FW2-PMP2, F-SDC-PMP2, S-EL-III-2-O	2		1	

Initiating Event - <i>Feedwater Piping Break in the Turbine Building</i>		Sequence: <i>LOFWTB-H</i>		
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-EL-III-1-O, S-PCS			2	
F-MCS-ISV-FC, S-PCS	1		1	
F-MCS-PMP1, S-PCS	1		1	
S-PCS, S-RCW			2	
S-EL-III-1-E, S-PCS			2	
F-MCS-PMP2, S-PCS	1		1	
F-MCS-PMP1, S-EL-III-2-E, S-EL-III-2-O	1		2	
F-MCS-PMP2, S-EL-III-2-E, S-EL-III-2-O	1		2	
S-EL-III-1-E, S-EL-III-2-E, S-EL-III-2-O			3	
S-EL-III-1-O, S-EL-III-2-E, S-EL-III-2-O			3	
S-EL-III-2-E, S-EL-III-2-O, S-RCW			3	

Table C.11 (cont.)

F-MCS-ISV-FC, S-EL-III-2-E, S-EL-III-2-O	1		2	
S-EL-II-2-E, S-EL-II-2-O, S-EL-III-1-E			3	
F-MCS-PMP2, S-EL-II-2-E, S-EL-II-2-O	1		2	
F-MCS-ISV-FC, S-EL-II-2-E, S-EL-II-2-O	1		2	
F-MCS-PMP1, S-EL-II-2-E, S-EL-II-2-O	1		2	
S-EL-II-2-E, S-EL-II-2-O, S-RCW			3	
S-EL-II-2-E, S-EL-II-2-O, S-EL-III-1-O			3	

**Table C.12 Undercooling events sequence categorization:
representative initiating event - *feedwater piping break in the turbine building***

Specific Initiator		<i>Feedwater piping break in the turbine building</i>		Turbine trip		Loss of condenser vacuum		Loss of normal feedwater flow	
IE Frequency		1×10^{-3}		1×10^{-6}		1×10^{-1}		1×10^{-6}	
Sequence	Determinant Failures	Bin	Category	Bin	Category	Bin	Category	Bin	Category
LOFWTB-A	NA	E	EC-II	A	EC-I	A	EC-I	A	EC-I
LOFWTB-B	2 valves, support system	G	EC-III	C	EC-III	C	EC-III	C	EC-III
LOFWTB-C	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-D	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-E	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-F	tank level indicator and human error, 2 pumps and/or valves	G	EC-III	C	EC-III	C	EC-III	C	EC-III
LOFWTB-G	support system	G	EC-III	C	EC-III	C	EC-III	C	EC-III
LOFWTB-H	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-A	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-B	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-C	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-D	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-E	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-F	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-G	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-H	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-I	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-J	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-K	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-L	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-M	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-N	≥ 3 failures	H	EC-IV	D	EC-IV	D	EC-IV	D	EC-IV

Table C.12 (cont.)

Specific Initiator		Failure of the steam generator pressure control resulting closure of the turbine throttle valves		Loss of condensate pumps		Failure of steam generator level control	
IE Frequency		1×10^{-2}		1×10^{-1}		1×10^{-2}	
Sequence	Determinant Failures	Bin	Category	Bin	Category	Bin	Category
LOFWTB-A	NA	A	EC-I	A	EC-I	A	EC-I
LOFWTB-B	2 valves, support system	C	EC-III	C	EC-III	C	EC-III
LOFWTB-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-F	tank level indicator and human error, 2 pumps and/or valves	C	EC-III	C	EC-III	C	EC-III
LOFWTB-G	support system	C	EC-III	C	EC-III	C	EC-III
LOFWTB-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-A	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-B	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-F	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-I	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-J	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOWFTB-FTSD-K	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-L	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-M	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
LOFWTB-FTSD-N	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV

Table C.13 SCRAM sequence cut sets

Initiating Event - <i>SCRAM</i>	Sequence: <i>SCRAM-A</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
NONE	NA	NA	NA	NA

Initiating Event - <i>SCRAM</i>	Sequence: <i>SCRAM-B</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
S-PCS			1	Y
S-AIR			1	Y
S-EL-II-2-E, S-EL-II-2-O			2	
F-ASD-ASD1, F-CSD-SDV3, S-EL-II-2-E	2		1	
F-ASD-ASD1, F-CSD-SDV1, S-EL-II-2-E	2		1	
F-ASD-ASD2, F-CSD-SDV2, S-EL-II-2-O	2		1	
F-ASD-ASD2, F-CSD-SDV4, S-EL-II-2-O	2		1	

Initiating Event - <i>SCRAM</i>	Sequence: <i>SCRAM-C</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1, S-AIR	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1, S-AIR	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2, S-AIR	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2, S-AIR	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1, S-AIR	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2, S-AIR	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1, S-AIR	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2, S-AIR	2		1	

Table C.13 (cont.)

F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2, S-AIR	2		1	
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2, S-AIR	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1, S-AIR	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1, S-AIR	2		1	

Initiating Event - <i>SCRAM</i>	Sequence: <i>SCRAM-D</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-MSV-MSSV3-SG1, F-MSV-MSSV4-SG1, S-PCS	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV3-SG1, S-PCS	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV2-SG2, S-PCS	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV3-SG2, S-PCS	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV3-SG1, S-PCS	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV3-SG2, S-PCS	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV4-SG1, S-PCS	2		1	
F-MSV-MSSV2-SG2, F-MSV-MSSV4-SG2, S-PCS	2		1	
F-MSV-MSSV1-SG2, F-MSV-MSSV4-SG2, S-PCS	2		1	
F-MSV-MSSV3-SG2, F-MSV-MSSV4-SG2, S-PCS	2		1	
F-MSV-MSSV1-SG1, F-MSV-MSSV2-SG1, S-PCS	2		1	
F-MSV-MSSV2-SG1, F-MSV-MSSV4-SG1, S-PCS	2		1	

Initiating Event - <i>SCRAM</i>	Sequence: <i>SCRAM-G</i>			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-FW1-ISV2, S-PCS	1		1	
F-FW1-ISV1, S-PCS	1		1	
S-AIR, S-PCS			2	
F-FW1-CNV2, S-EL-II-1-O, S-PCS	1		2	
S-EL-II-1-E, S-EL-II-1-O, S-PCS			3	
F-FW1-CNV1, S-EL-II-1-E, S-PCS	1		2	
F-FW1-CNV1, F-FW1-CNV2, S-PCS	2		1	
S-EL-IV-E, S-EL-IV-O, S-PCS			3	
F-FW1-PMP1, F-FW1-PMP2, S-PCS	2		1	

Table C.13 (cont.)

F-FW1-DV2, S-EL-IV-O, S-PCS	1		2	
F-FW1-DV1, F-FW1-DV2, S-PCS	2		1	
F-FW1-DV2, F-FW1-PMP1, S-PCS	2		1	
F-FW1-PMP1, S-EL-IV-E, S-PCS	1		2	
F-FW1-DV1, S-EL-IV-E, S-PCS	1		2	
F-FW1-DV1, F-FW1-PMP2, S-PCS	2		1	
F-FW1-PMP2, S-EL-IV-O, S-PCS	1		2	

Initiating Event - SCRAM	Sequence: SCRAM-H			
Sequence Level Cut Sets	Component Failures	Human Errors	Support System Failures	Determinant Failure ?
F-FW1-HE, S-PCS, S-RCW		1	2	
F-FW1-ISV2, F-MCS-ISV-FC, S-PCS	2		1	
F-FW1-ISV2, S-EL-III-1-O, S-PCS	1		2	
F-FW1-ISV2, S-PCS, S-RCW	1		2	
F-FW1-ISV1, S-PCS, S-RCW	1		2	
F-FW1-ISV1, F-MCS-PMP1, S-PCS	2		1	
S-FIW, S-PCS, S-RCW			3	
F-FW1-ISV1, S-EL-III-1-O, S-PCS	1		2	
F-FW1-ISV2, F-MCS-PMP2, S-PCS	2		1	
F-FW1-ISV2, F-MCS-PMP1, S-PCS	2		1	
F-FW1-ISV1, F-MCS-PMP2, S-PCS	2		1	
F-FW1-ISV1, F-MCS-ISV-FC, S-PCS	2		1	
F-FW1-ISV2, S-EL-III-1-E, S-PCS	1		2	
F-FW1-ISV1, S-EL-III-1-E, S-PCS	1		2	
S-AIR, S-EL-III-1-O, S-PCS			3	
S-AIR, S-PCS, S-RCW			3	
F-MCS-PMP1, S-AIR, S-PCS	1		2	
F-MCS-PMP2, S-AIR, S-PCS	1		2	
S-AIR, S-EL-III-1-E, S-PCS			3	
F-MCS-ISV-FC, S-AIR, S-PCS	1		2	

**Table C.14 Reactivity transient events sequence categorization:
representative initiating event - SCRAM**

Specific Initiator		SCRAM		Uncontrolled control rod assembly withdrawal		Control rod maloperation (part length control rods, rod ejection, or rod drop)	
IE Frequency		1×10^{-6}		1×10^{-2}		1×10^{-6}	
Sequence	Determinant Failures	Bin	Category	Bin	Category	Bin	Category
SCRAM-A	NA	A	EC-I	A	EC-I	A	EC-I
SCRAM-B	support systems	C	EC-III	C	EC-III	C	EC-III
SCRAM-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-F	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-A	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-B	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-F	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-I	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-J	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-K	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-L	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-M	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-N	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV

Table C.14 (cont.)

Specific Initiator		Rod position error (pressure, temperature, power imbalance)		Moderator anomalies		Feedwater system malfunctions that result in an increase in feedwater flow or a decrease in feedwater temperature	
IE Frequency		1×10^{-1}		1×10^{-2}		1×10^{-6}	
Sequence	Determinant Failures	Bin	Category	Bin	Category	Bin	Category
SCRAM-A	NA	A	EC-I	A	EC-I	A	EC-I
SCRAM-B	support systems	C	EC-III	C	EC-III	C	EC-III
SCRAM-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-F	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-A	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-B	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-F	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-I	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-J	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-K	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-L	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-M	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-N	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV

Table C.14 (cont.)

Specific Initiator		Steam pressure regulator malfunction or failure that results in increasing steam flow (turbine overspeed)		Inadvertent opening of a steam generator relief or safety valve		Increased heat transfer flow or inventory	
IE Frequency		1×10^{-2}		1×10^{-2}		1×10^{-2}	
Sequence	Determinant Failures	Bin	Category	Bin	Category	Bin	Category
SCRAM-A	NA	A	EC-I	A	EC-I	A	EC-I
SCRAM-B	support systems	C	EC-III	C	EC-III	C	EC-III
SCRAM-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-F	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-A	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-B	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-F	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-I	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-J	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-K	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-L	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-M	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-N	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV

Table C.14 (cont.)

Specific Initiator		Steamline piping breaks inside or outside containment		Startup of an inactive heat transfer loop or recirculating loop at an incorrect temperature		Degradation or loss of moderator flow	
IE Frequency		1×10^{-5}		1×10^{-3}		1×10^{-2}	
Sequence	Determinant Failures	Bin	Category	Bin	Category	Bin	Category
SCRAM-A	NA	E	EC-II	E	EC-II	A	EC-I
SCRAM-B	support systems	G	EC-III	G	EC-III	C	EC-III
SCRAM-C	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-D	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-E	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-F	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-G	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-H	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-FTSD-A	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-FTSD-B	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-FTSD-C	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-FTSD-D	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-FTSD-E	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-FTSD-F	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-FTSD-G	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-FTSD-H	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-FTSD-I	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-FTSD-J	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-FTSD-K	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-FTSD-L	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-FTSD-M	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV
SCRAM-FTSD-N	≥ 3 failures	H	EC-IV	H	EC-IV	D	EC-IV

Table C.14 (cont.)

Specific Initiator		Degradation or loss of moderator cooling		Loss of moderator inventory		Failure of the cover gas system	
IE Frequency		1×10^{-2}		1×10^{-2}		1×10^{-2}	
Sequence	Determinant Failures	Bin	Category	Bin	Category	Bin	Category
SCRAM-A	NA	A	EC-I	A	EC-I	A	EC-I
SCRAM-B	support systems	C	EC-III	C	EC-III	C	EC-III
SCRAM-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-F	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-A	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-B	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-C	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-D	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-E	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-F	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-G	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-H	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-I	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-J	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-K	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-L	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-M	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV
SCRAM-FTSD-N	≥ 3 failures	D	EC-IV	D	EC-IV	D	EC-IV

Table C.14 (cont.)

Specific Initiator		Moderator deuterium excursion		Loss of calandria structural integrity	
IE Frequency		1×10^{-4}		1×10^{-3}	
Sequence	Determinant Failures	Bin	Category	Bin	Category
SCRAM-A	NA	E	EC-II	E	EC-II
SCRAM-B	support systems	G	EC-III	G	EC-III
SCRAM-C	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-D	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-E	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-F	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-G	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-H	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-FTSD-A	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-FTSD-B	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-FTSD-C	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-FTSD-D	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-FTSD-E	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-FTSD-F	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-FTSD-G	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-FTSD-H	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-FTSD-I	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-FTSD-J	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-FTSD-K	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-FTSD-L	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-FTSD-M	≥ 3 failures	H	EC-IV	H	EC-IV
SCRAM-FTSD-N	≥ 3 failures	H	EC-IV	H	EC-IV

Appendix D

Check of Methodology Integrity

Although the methodology described in Chap. 3 is qualitative, it has a basis in quantitative analysis. The event category criteria used in the methodology discriminates based on single, double, or more failures, with multiple failures being assigned to categories of higher consequences. This is done to acknowledge that larger numbers of independent failures, while usually leading to more severe consequences, are decreasingly less likely to occur. The check of the methodology described below takes advantage of this underlying quantitative basis. Performing these checks lends confidence to the methodology by demonstrating the consistency between both methods.

For this methodology check, the fault trees are quantified using very conservative values for the identified failures. These values include:

Human error (nonroutine or low training factor)	10^{-1}
Human error (routine or high training factor)	10^{-2}
Active component failure	10^{-2}
Passive component failure	10^{-3}
Support system failure (safety related)	10^{-3}
Support system failure (nonsafety related)	10^{-2}

The quantification is carried through the fault and event trees. Solution of the event trees yields a frequency of

occurrence for each sequence. The frequency for each sequence is the product of the initiating event frequency and the probability associated with each failed system(s) (obtained from quantification of the fault trees). The quantified sequences were classified according to the following frequency of occurrence:

- EC-I— $P(\text{per year}) \geq 10^{-2}$ (one or more in a plant lifetime)
- EC-II— $10^{-2} > P(\text{per year}) \geq 10^{-4}$
- EC-III— $10^{-4} > P(\text{per year}) \geq 10^{-6}$
- EC-IV— $10^{-6} > P(\text{per year})$

The EC-II limit was set at 10^{-4} because this corresponded to an event that occurs once in the 100-year lifetime of a population of plants (assumed to be 100 plants). Also frequencies of 10^{-4} to 10^{-5} are currently acknowledged for core damage events in probabilistic risk assessment analyses. Flagging differences of two or more categories is done to reflect uncertainty associated with the rigor of this analysis.

Tables D.1 through D.7 show the comparisons of sequence categorizations by the two methods for the representative initiating events.

Table D.1 Feeder tube header break sequence comparisons

Sequence	Sequence Frequency	Categorization by Frequency	Categorization by Primary Method	Consistent
LB-A	1E-02	EC-I	EC-II	Y
LB-B	1E-08	EC-IV	EC-III	Y
LB-C	2E-09	EC-IV	EC-IV	Y
LB-D	4E-08	EC-IV	EC-III	Y
LB-E	2E-09	EC-IV	EC-IV	Y
LB-F	2E-07	EC-IV	EC-III	Y
LB-G	1E-08	EC-IV	EC-IV	Y
LB-H	6E-06	EC-III	EC-II	Y
LB-I	7E-10	EC-IV	EC-IV	Y
LB-J	6E-11	EC-IV	EC-IV	Y
LB-K	2E-09	EC-IV	EC-IV	Y
LB-L	ϵ^1	EC-IV	EC-IV	Y
LB-M	1E-08	EC-IV	EC-IV	Y
LB-N	3E-10	EC-IV	EC-IV	Y
LB-O	3E-07	EC-IV	EC-III	Y
LB-P	2E-11	EC-IV	EC-IV	Y
LB-Q	2E-12	EC-IV	EC-IV	Y
LB-R	8E-11	EC-IV	EC-IV	Y
LB-S	ϵ	EC-IV	EC-IV	Y
LB-T	5E-10	EC-IV	EC-IV	Y
LB-U	1E-11	EC-IV	EC-IV	Y
LB-V	2E-08	EC-IV	EC-IV	Y
LB-W	ϵ	EC-IV	EC-IV	Y
LB-X	ϵ	EC-IV	EC-IV	Y
LB-Y	ϵ	EC-IV	EC-IV	Y
LB-Z	ϵ	EC-IV	EC-IV	Y
LB-AA	1E-11	EC-IV	EC-IV	Y
LB-AB	ϵ	EC-IV	EC-IV	Y
LB-AC	1E-09	EC-IV	EC-IV	Y

¹Value is below the cutoff of 1E-15.

Table D.2 Liquid relief valve failure sequence comparisons

Sequence	Sequence Frequency	Categorization by Frequency	Categorization by Primary Method	Consistent
LRVF-A	1E-01	EC-I	EC-I	Y
LRVF-B	1E-04	EC-II	EC-II	Y
LRVF-C	1E-07	EC-IV	EC-IV	Y
LRVF-D	e	EC-IV	EC-IV	Y
LRVF-E	e	EC-IV	EC-IV	Y
LRVF-F	e	EC-IV	EC-IV	Y
LRVF-G	e	EC-IV	EC-IV	Y
LRVF-H	e	EC-IV	EC-IV	Y
LRVF-I	1E-03	EC-II	EC-III	Y
LRVF-J	4E-07	EC-IV	EC-IV	Y
LRVF-K	e	EC-IV	EC-IV	Y
LRVF-L	1E-06	EC-III	EC-IV	Y
LRVF-M	e	EC-IV	EC-IV	Y
LRVF-N	2E-06	EC-III	EC-IV	Y
LRVF-O	2E-07	EC-IV	EC-IV	Y
LRVF-P	7E-06	EC-III	EC-IV	Y
LRVF-Q	3E-07	EC-IV	EC-IV	Y
LRVF-R	3E-04	EC-II	EC-III	Y
LRVF-S	3E-07	EC-IV	EC-IV	Y
LRVF-T	e	EC-IV	EC-IV	Y
LRVF-U	e	EC-IV	EC-IV	Y
LRVF-V	e	EC-IV	EC-IV	Y
LRVF-W	e	EC-IV	EC-IV	Y
LRVF-X	e	EC-IV	EC-IV	Y
LRVF-Y	e	EC-IV	EC-IV	Y
LRVF-Z	3E-06	EC-III	EC-IV	Y
LRVF-AA	e	EC-IV	EC-IV	Y
LRVF-AB	e	EC-IV	EC-IV	Y
LRVF-AC	e	EC-IV	EC-IV	Y
LRVF-AD	e	EC-IV	EC-IV	Y
LRVF-AE	4E-09	EC-IV	EC-IV	Y
LRVF-AF	e	EC-IV	EC-IV	Y
LRVF-AG	1E-08	EC-IV	EC-IV	Y
LRVF-AH	e	EC-IV	EC-IV	Y

Table D.2 (cont.)

Sequence	Sequence Frequency	Categorization by Frequency	Categorization by Primary Method	Consistent
LRVF-FTSD-A	1E-06	EC-III	EC-IV	Y
LRVF-FTSD-B	<i>e</i>	EC-IV	EC-IV	Y
LRVF-FTSD-C	<i>e</i>	EC-IV	EC-IV	Y
LRVF-FTSD-D	<i>e</i>	EC-IV	EC-IV	Y
LRVF-FTSD-E	<i>e</i>	EC-IV	EC-IV	Y
LRVF-FTSD-F	<i>e</i>	EC-IV	EC-IV	Y
LRVF-FTSD-G	<i>e</i>	EC-IV	EC-IV	Y
LRVF-FTSD-H	<i>e</i>	EC-IV	EC-IV	Y
LRVF-FTSD-I	<i>e</i>	EC-IV	EC-IV	Y
LRVF-FTSD-J	<i>e</i>	EC-IV	EC-IV	Y
LRVF-FTSD-K	<i>e</i>	EC-IV	EC-IV	Y
LRVF-FTSD-L	<i>e</i>	EC-IV	EC-IV	Y
LRVF-FTSD-M	<i>e</i>	EC-IV	EC-IV	Y
LRVF-FTSD-N	<i>e</i>	EC-IV	EC-IV	Y

Table D.3 Feeder tube break sequence comparisons

Sequence	Sequence Frequency	Categorization by Frequency	Categorization by Primary Method	Consistent
SBLFB-A	1E-02	EC-I	EC-I	Y
SBLFB-B	4E-06	EC-III	EC-III	Y
SBLFB-C	2E-07	EC-IV	EC-IV	Y
SBLFB-D	9E-06	EC-III	EC-III	Y
SBLFB-E	6E-07	EC-IV	EC-IV	Y
SBLFB-F	2E-07	EC-IV	EC-IV	Y
SBLFB-G	2E-08	EC-IV	EC-IV	Y
SBLFB-H	5E-05	EC-III	EC-III	Y
SBLFB-I	3E-06	EC-III	EC-IV	Y
SBLFB-J	3E-05	EC-III	EC-III	Y
SBLFB-K	8E-09	EC-IV	EC-IV	Y
SBLFB-L	e	EC-IV	EC-IV	Y
SBLFB-M	2E-08	EC-IV	EC-IV	Y
SBLFB-N	e	EC-IV	EC-IV	Y
SBLFB-O	4E-10	EC-IV	EC-IV	Y
SBLFB-P	e	EC-IV	EC-IV	Y
SBLFB-Q	1E-07	EC-III	EC-IV	Y
SBLFB-R	5E-09	EC-IV	EC-IV	Y
SBLFB-FTSD-A	1E-07	EC-IV	EC-IV	Y
SBLFB-FTSD-B	e	EC-IV	EC-IV	Y
SBLFB-FTSD-C	e	EC-IV	EC-IV	Y
SBLFB-FTSD-D	e	EC-IV	EC-IV	Y
SBLFB-FTSD-E	e	EC-IV	EC-IV	Y
SBLFB-FTSD-F	e	EC-IV	EC-IV	Y
SBLFB-FTSD-G	e	EC-IV	EC-IV	Y
SBLFB-FTSD-H	e	EC-IV	EC-IV	Y
SBLFB-FTSD-I	e	EC-IV	EC-IV	Y
SBLFB-FTSD-J	e	EC-IV	EC-IV	Y
SBLFB-FTSD-K	e	EC-IV	EC-IV	Y
SBLFB-FTSD-L	e	EC-IV	EC-IV	Y
SBLFB-FTSD-M	e	EC-IV	EC-IV	Y
SBLFB-FTSD-N	e	EC-IV	EC-IV	Y

Table D.4 Loss of Class IV power sequence comparisons

Sequence	Sequence Frequency	Categorization by Frequency	Categorization by Primary Method	Consistent
LOP-A	1E-02	EC-I	EC-I	Y
LOP-B	1E-06	EC-III	EC-III	Y
LOP-C	ϵ	EC-IV	EC-IV	Y
LOP-D	ϵ	EC-IV	EC-IV	Y
LOP-E	ϵ	EC-IV	EC-IV	Y
LOP-F	2E-05	EC-III	EC-III	Y
LOP-G	1E-08	EC-IV	EC-IV	Y
LOP-H	ϵ	EC-IV	EC-IV	Y
LOP-I	ϵ	EC-IV	EC-IV	Y
LOP-J	ϵ	EC-IV	EC-IV	Y
LOP-K	6E-07	EC-IV	EC-IV	Y
LOP-L	6E-10	EC-IV	EC-IV	Y
LOP-M	ϵ	EC-IV	EC-IV	Y
LOP-N	3E-04	EC-II	EC-I	Y
LOP-O	1E-05	EC-III	EC-IV	Y
LOP-P	1E-08	EC-IV	EC-IV	Y
LOP-Q	ϵ	EC-IV	EC-IV	Y
LOP-R	ϵ	EC-IV	EC-IV	Y
LOP-S	6E-07	EC-IV	EC-IV	Y
LOP-T	2E-08	EC-IV	EC-IV	Y
LOP-U	ϵ	EC-IV	EC-IV	Y
LOP-V	ϵ	EC-IV	EC-IV	Y
LOP-W	ϵ	EC-IV	EC-IV	Y
LOP-X	ϵ	EC-IV	EC-IV	Y
LOP-Y	ϵ	EC-IV	EC-IV	Y
LOP-Z	ϵ	EC-IV	EC-IV	Y
LOP-AA	1E-04	EC-II	EC-III	Y
LOP-AB	4E-08	EC-IV	EC-IV	Y
LOP-AC	ϵ	EC-IV	EC-IV	Y
LOP-AD	9E-08	EC-IV	EC-IV	Y
LOP-AE	ϵ	EC-IV	EC-IV	Y
LOP-AF	2E-07	EC-IV	EC-IV	Y
LOP-AG	1E-10	EC-IV	EC-IV	Y

Table D.4 (cont.)

Sequence	Sequence Frequency	Categorization by Frequency	Categorization by Primary Method	Consistent
LOP-AH	ϵ	EC-IV	EC-IV	Y
LOP-AI	ϵ	EC-IV	EC-IV	Y
LOP-AJ	ϵ	EC-IV	EC-IV	Y
LOP-AK	1E-05	EC-III	EC-III	Y
LOP-AL	6E-07	EC-IV	EC-IV	Y
LOP-AM	7E-07	EC-IV	EC-IV	Y
LOP-AN	3E-08	EC-IV	EC-IV	Y
LOP-AO	1E-05	EC-III	EC-III	Y
LOP-AP	1E-08	EC-IV	EC-IV	Y
LOP-AQ	3E-07	EC-IV	EC-IV	Y
LOP-AR	1E-07	EC-IV	EC-IV	Y
LOP-FTSD-A	ϵ	EC-IV	EC-IV	Y
LOP-FTSD-B	ϵ	EC-IV	EC-IV	Y
LOP-FTSD-C	ϵ	EC-IV	EC-IV	Y
LOP-FTSD-D	ϵ	EC-IV	EC-IV	Y
LOP-FTSD-E	ϵ	EC-IV	EC-IV	Y
LOP-FTSD-F	ϵ	EC-IV	EC-IV	Y
LOP-FTSD-G	ϵ	EC-IV	EC-IV	Y
LOP-FTSD-H	ϵ	EC-IV	EC-IV	Y
LOP-FTSD-I	ϵ	EC-IV	EC-IV	Y
LOP-FTSD-J	ϵ	EC-IV	EC-IV	Y
LOP-FTSD-K	ϵ	EC-IV	EC-IV	Y
LOP-FTSD-L	ϵ	EC-IV	EC-IV	Y
LOP-FTSD-M	ϵ	EC-IV	EC-IV	Y
LOP-FTSD-N	ϵ	EC-IV	EC-IV	Y
LOP-AS	ϵ	EC-IV	EC-IV	Y

Table D.5 Feedwater piping break in the reactor building sequence comparisons

Sequence	Sequence Frequency	Categorization by Frequency	Categorization by Primary Method	Consistent
LOFWRB-A	1E-05	EC-III	EC-III	Y
LOFWRB-B	1E-09	EC-IV	EC-IV	Y
LOFWRB-C	e	EC-IV	EC-IV	Y
LOFWRB-D	e	EC-IV	EC-IV	Y
LOFWRB-E	e	EC-IV	EC-IV	Y
LOFWRB-F	2E-08	EC-IV	EC-IV	Y
LOFWRB-G	1E-08	EC-IV	EC-IV	Y
LOFWRB-H	6E-10	EC-IV	EC-IV	Y
LOFWRB-I	1E-06	EC-III	EC-III	Y
LOFWRB-J	1E-08	EC-IV	EC-IV	Y
LOFWRB-K	9E-10	EC-IV	EC-IV	Y
LOFWRB-L	3E-08	EC-IV	EC-IV	Y
LOFWRB-M	2E-12	EC-IV	EC-IV	Y
LOFWRB-N	e	EC-IV	EC-IV	Y
LOFWRB-O	e	EC-IV	EC-IV	Y
LOFWRB-P	e	EC-IV	EC-IV	Y
LOFWRB-Q	4E-11	EC-IV	EC-IV	Y
LOFWRB-R	3E-11	EC-IV	EC-IV	Y
LOFWRB-S	1E-12	EC-IV	EC-IV	Y
LOFWRB-T	3E-09	EC-IV	EC-IV	Y
LOFWRB-U	3E-11	EC-IV	EC-IV	Y
LOFWRB-FTSD-A	1E-10	EC-IV	EC-IV	Y
LOFWRB-FTSD-B	e	EC-IV	EC-IV	Y
LOFWRB-FTSD-C	e	EC-IV	EC-IV	Y
LOFWRB-FTSD-D	e	EC-IV	EC-IV	Y
LOFWRB-FTSD-E	e	EC-IV	EC-IV	Y
LOFWRB-FTSD-F	e	EC-IV	EC-IV	Y
LOFWRB-FTSD-G	e	EC-IV	EC-IV	Y
LOFWRB-FTSD-H	e	EC-IV	EC-IV	Y
LOFWRB-FTSD-I	e	EC-IV	EC-IV	Y
LOFWRB-FTSD-J	e	EC-IV	EC-IV	Y
LOFWRB-FTSD-K	e	EC-IV	EC-IV	Y
LOFWRB-FTSD-L	e	EC-IV	EC-IV	Y
LOFWRB-FTSD-M	e	EC-IV	EC-IV	Y
LOFWRB-FTSD-N	e	EC-IV	EC-IV	Y

Table D.6 Feedwater piping break in the turbine building sequence comparisons

Sequence	Sequence Frequency	Categorization by Frequency	Categorization by Primary Method	Consistent
LOFWTB-A	1E-03	EC-II	EC-II	Y
LOFWTB-B	1E-06	EC-III	EC-III	Y
LOFWTB-C	1E-09	EC-IV	EC-IV	Y
LOFWTB-D	e	EC-IV	EC-IV	Y
LOFWTB-E	e	EC-IV	EC-IV	Y
LOFWTB-F	2E-06	EC-III	EC-III	Y
LOFWTB-G	1E-06	EC-III	EC-III	Y
LOFWTB-H	6E-08	EC-IV	EC-IV	Y
LOFWTB-FTSD-A	e	EC-IV	EC-IV	Y
LOFWTB-FTSD-B	e	EC-IV	EC-IV	Y
LOFWTB-FTSD-C	e	EC-IV	EC-IV	Y
LOFWTB-FTSD-D	e	EC-IV	EC-IV	Y
LOFWTB-FTSD-E	e	EC-IV	EC-IV	Y
LOFWTB-FTSD-F	e	EC-IV	EC-IV	Y
LOFWTB-FTSD-G	e	EC-IV	EC-IV	Y
LOFWTB-FTSD-H	e	EC-IV	EC-IV	Y
LOFWTB-FTSD-I	e	EC-IV	EC-IV	Y
LOFWTB-FTSD-J	e	EC-IV	EC-IV	Y
LOFWTB-FTSD-K	e	EC-IV	EC-IV	Y
LOFWTB-FTSD-L	e	EC-IV	EC-IV	Y
LOFWTB-FTSD-M	e	EC-IV	EC-IV	Y
LOFWTB-FTSD-N	e	EC-IV	EC-IV	Y

Table D.7 SCRAM sequence comparisons

Sequence	Sequence Frequency	Categorization by Frequency	Categorization by Primary Method	Consistent
SCRAM-A	1E+00	EC-I	EC-I	Y
SCRAM-B	2E-03	EC-II	EC-III	Y
SCRAM-C	1E-06	EC-III	EC-IV	Y
SCRAM-D	1E-06	EC-III	EC-IV	Y
SCRAM-E	e	EC-IV	EC-IV	Y
SCRAM-F	e	EC-IV	EC-IV	Y
SCRAM-G	2E-05	EC-III	EC-IV	Y
SCRAM-H	2E-06	EC-III	EC-IV	Y
SCRAM-FTSD-A	e	EC-IV	EC-IV	Y
SCRAM-FTSD-B	e	EC-IV	EC-IV	Y
SCRAM-FTSD-C	e	EC-IV	EC-IV	Y
SCRAM-FTSD-D	e	EC-IV	EC-IV	Y
SCRAM-FTSD-E	e	EC-IV	EC-IV	Y
SCRAM-FTSD-F	e	EC-IV	EC-IV	Y
SCRAM-FTSD-G	e	EC-IV	EC-IV	Y
SCRAM-FTSD-H	e	EC-IV	EC-IV	Y
SCRAM-FTSD-I	e	EC-IV	EC-IV	Y
SCRAM-FTSD-J	e	EC-IV	EC-IV	Y
SCRAM-FTSD-K	e	EC-IV	EC-IV	Y
SCRAM-FTSD-L	e	EC-IV	EC-IV	Y
SCRAM-FTSD-M	e	EC-IV	EC-IV	Y
SCRAM-FTSD-N	e	EC-IV	EC-IV	Y

Appendix E

Comparison to AECL Analyzed Events

This appendix is included to show the comparison of events contained in this analysis to the events contained in Atomic Energy of Canada, Limited (AECL) CANDU 3 Conceptual Safety Report (CSR).¹ This was done for the sake of confidence that the events analyzed in this report are representative of the spectrum of events for the CANDU 3 design.

Four types of events are analyzed in the CANDU 3 CSR:¹

Category A—Assessment of the performance of safety systems.

Category B—Assessment of the most probable plant response to disturbances to identify the dependence of that response to operator corrective action, and to demonstrate independence between the initiating event and the mitigating systems.

Category C—Assessment of the plant's capability for safe shutdown, decay heat removal, and containment of radioactivity for common-cause events, such as earthquakes.

Category D—Assessment of the features of the plant design or operation that reduce the probability of certain postulated events to such an extremely low level that failure consequences need not be further considered.

The specific events analyzed in the CSR are the following:

Category A

1. Large Loss of Coolant
2. Large Loss of Coolant with ECCS Unavailable
3. Pressure Tube Rupture with ECCS Unavailable
4. Large Loss of Coolant with Failure of Containment Local Air Coolers*
5. Steam Line Break with Failure of Containment Local Air Coolers*
6. Loss of Class IV Power
7. Single Heat Transport Pump Trip
8. Single Heat Transport Pump Seizure
9. Large Loss of Coolant with Loss of Class IV Power

Category B

1. Failures of Electric Power Supplies
2. Failures of Service Water Supplies*
3. Loss of Steam Inventory via a Steamline Break

4. Condensate System Failures Resulting in Interruption of Condensate Flow*
6. Condensate Line Breaks*
7. Condenser Failure Resulting in Loss of Feedwater Circulating Flow
8. Failure of Boiler Pressure Control
9. Feedwater Line Breaks
10. Total Interruption or Reduction of Feedwater to the Steam Generators
11. Pressure Tube Rupture
12. Large Loss of Coolant
13. Small Loss of Coolant
14. Pressure Tube Leak Into the Annulus Gas System*
15. Fueling Machine Failure while on Reactor Causing an End Fitting Failure

Category C*

1. Earthquake
2. Site Flooding from External Sources
3. Station Fires
4. Tornadoes

Category D*

1. Steam Generator Support Failure
2. Steam Generator Shell Failure
3. Turbine Breakup
4. Massive Failure of Cooling Water Intake Tunnel
5. Massive Failure of Cooling Water Discharge Duct
6. Failure of Heat Transport Pump Casing or Drive Shaft
7. Pressurizer Failure
8. Degasser-Condenser Failure

The preceding categories or events marked with an "*" are events that were not covered by this analysis. Events involving the containment or initiated by failure of a support system were not covered in this analysis. Category C events were not covered because external event analysis was not included in the scope of this analysis. Category D events are events that require structural or other type of analyses, which are well beyond the rigor and scope of this analysis.

Table E.1 is provided to show the correspondence of the events analyzed for this report to the events listed above. Some of the events were specifically analyzed and others were represented by one of the analyzed events. Those represented by an event are indicated by bold italics.

Table E.1 Correspondence of sequences to CSR events

Analyzed Event	CORRESPONDING CSR EVENT
Feeder Tube Header Break	A-1, A-2, <i>A-9</i> , B-12
Liquid Relief Valve Failure	B-13
Feeder Tube Break	<i>A-3</i> , <i>B-11</i> , B-13, <i>B-15</i>
Loss of Class IV Power	A-6, <i>A-7</i> , <i>A-8</i> , B-1
Feedwater Piping Break in the Reactor Building	B-9, B-10
Feedwater Piping Break in the Turbine Building	<i>B-7</i> , <i>B-8</i> , B-9, B-10
SCRAM	<i>B-3</i>

Reference

- 1 Atomic Energy of Canada, Limited, "CANDU 3 Conceptual Safety Report," Vols. 1 and 2, 1989.*

*Available in NRC PDR for inspection and copying for a fee.

Internal Distribution

1. S. J. Ball	17-18. M. Olszewski
2. W. P. Barthold	19. R. T. Primm
3. J. J. Carbajo	20. C. E. Pugh
4. N. Clapp	21. C. C. Southmayd
5. G. J. Dyer	22. R. P. Wichner
6-7. M. H. Fontana	23. V. K. Wilkinson
8. E. C. Fox	24-25. J. R. Wolfgong
9. J. E. Jones Jr.	26-27. A. L. Wright
10. T. S. Kress	28. ORNL Patent Section
11-12. M. A. Linn	29. Central Research Library
13. W. A. McAfee	30. Document Reference Section
14. D. G. Morris	31-32. Laboratory Records Department
15. G. A. Murphy	33. Laboratory Records (RC)
16. S. C. Nelson	

External Distribution

34. B. W. Sheron, Director, Division of Systems Research, U.S. Nuclear Regulatory Commission, Washington, DC 20555
35. T. L. King, Division of Systems Research, U.S. Nuclear Regulatory Commission, Washington, DC 20555
36. L. M. Shotkin, Division of Systems Research, U.S. Nuclear Regulatory Commission, Washington, DC 20555
- 37-39. A. J. Szukiewicz, Division of Systems Research, U.S. Nuclear Regulatory Commission, Washington, DC 20555
40. R. O. Meyer, Division of Systems Research, U.S. Nuclear Regulatory Commission, Washington, DC 20555
41. Z. R. Rosztoczy, Division of Systems Research, U.S. Nuclear Regulatory Commission, Washington, DC 20555
42. D. D. Ebert, Division of Systems Research, U.S. Nuclear Regulatory Commission, Washington, DC 20555
43. T. H. Cox, Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, Washington, DC 20555
44. J. N. Donohew, Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, Washington, DC 20555
45. E. D. Throm, Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, Washington, DC 20555
46. L. Rib, AECL Technologies, 9210 Corporate Boulevard, Suite 410, Rockville, MD 20850
47. R. Curtis, AECL Technologies, 9210 Corporate Boulevard, Suite 410, Rockville, MD 20850
48. M. Fletcher, AECL Technologies, 9210 Corporate Boulevard, Suite 410, Rockville, MD 20850
49. Office of Assistant Manager for Energy Research and Development, DOE-ORO, Oak Ridge, TN 37831
- 50-51. Office of Scientific and Technical Information, P. O. Box 62, Oak Ridge, TN 37831

**DATE
FILMED**

9/28/93

END