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

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

Appendix E (Sections E.9-E.16)

Manuscript Completed: January 1994
Date Published: June 1994

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Prepared for
Division of Safety Issue Resolution
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC FIN L1922

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MASTER

ABSTRACT

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

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

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

The objective of this volume of the report is to document the approach utilized in the level-1 internal events PRA for the Surry plant, and discuss the results obtained. A phased approach was used in the level-1 program. In phase 1, which was completed in Fall 1991, a coarse screening analysis examining accidents initiated by internal events (including internal fire and flood) was performed for all plant operational states (POSS). The objective of the phase 1 study was to identify potential vulnerable plant configurations, to characterize (on a high, medium, or low basis) the potential core damage accident scenarios, and to provide a foundation for a detailed phase 2 analysis.

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

In the phase 2 study, system models applicable for shutdown conditions were developed and supporting thermal hydraulic analysis were performed to determine both the timing of the accidents and success criteria for systems. Initiating events that may occur during mid-loop operations were identified and accident sequence event trees were developed and quantified. In the preliminary quantification of the mid-loop accident sequences, it was found that the decay heat at which the accident initiating event occurs is an important parameter that determines both the success criteria for the mitigating functions and the time available for operator actions. In order to better account for the decay heat, a "time window" approach was

developed. In this approach, time windows after shutdown were defined based on the success criteria established for the various methods that can be used to mitigate the accident. Within each time window, the decay heat and accident sequence timing are more accurately defined and new event trees developed and quantified accordingly. Statistical analysis of the past outage data was performed to determine the time at which a mid-loop condition is reached, and the duration of the mid-loop operation. Past outage data were used to determine the probability that an accident initiating event occurs in each of the time windows. This probability is used in the quantification of the accident sequences.

The mean core damage frequency of the Surry plant due to internal events that may take place during mid-loop operations is $5\text{E-}06$ per year, and the 5th and 95th percentiles are $5\text{E-}07$ and $2\text{E-}05$ per year, respectively. This can be compared with the mean core damage frequency from internal events of $4\text{E-}05$ per year estimated in the NUREG-1150 study for full power operations.

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Appendix E	Event Trees and Their Associated High Level Fault Trees
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FOREWORD

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

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

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

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

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

For Grand Gulf:

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

- Volume 1: Summary of Results
- Volume 2: Analysis of Core Damage Frequency from Internal Events for Operational State 5 During a Refueling Outage
 - Part 1: Main Report
 - Part 1A: Sections 1 - 9
 - Part 1B: Section 10
 - Part 1C: Sections 11 - 14
 - Part 2: Internal Events Appendices A to H
 - Part 3: Internal Events Appendices I and J
 - Part 4: Internal Events Appendices K to M
- Volume 3: Analysis of Core Damage Frequency from Internal Fire Events for Plant Operational State 5 During a Refueling Outage
- Volume 4: Analysis of Core Damage Frequency from Internal Flooding Events for Plant Operational State 5 During a Refueling Outage
- Volume 5: Analysis of Core Damage Frequency from Seismic Events for Plant Operational State 5 During a Refueling Outage

Foreword (continued)

Volume 6: **Evaluation of Severe Accident Risks for Plant Operational State 5
During a Refueling Outage**
Part 1: Main Report
Part 2: Supporting MELCOR Calculations

For Surry:

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

Volume 1: **Summary of Results**

Volume 2: **Analysis of Core Damage Frequency from Internal Events during
Mid-loop Operations**
Part 1: Main Report
Part 1A: Chapters 1 - 6
Part 1B: Chapters 7 - 12
Part 2: Internal Events Appendices A to D
Part 3: Internal Events Appendix E
Part 3A: Sections E.1 - E.8
Part 3B: Sections E.9 - E.16

Part 4: Internal Events Appendices F to H
Part 5: Internal Events Appendix I
Volume 3: **Analysis of Core Damage Frequency from Internal Fires during
Mid-loop Operations**
Part 1: Main Report
Part 2: Appendices
Volume 4: **Analysis of Core Damage Frequency from Internal Floods during
Mid-loop Operations**
Volume 5: **Analysis of Core Damage Frequency from Seismic Events during
Mid-loop Operations**
Volume 6: **Evaluation of Severe Accident Risks during Mid-loop Operations**
Part 1: Main Report
Part 2: Appendices

Appendix E.9

Event Trees and High Level Fault Trees for Two Unit Blackout (B1)

	UNITY	IB1W1	NB1W1	2CHGW1	SEQ #	END-STATE-NAMES
<p>B1W1D6 EVENT TREE</p>					1 2 T 3 4	@ R5W1D6 CD CD

Safety valves Not Removed in Window 1

Non-Recovery of AC Power in 144 min. of LOOP

Non-Recovery of AC Power in 144 min. of LOOP

Reflux Cooling in window 1

E-545

AUXILIARY FEEDWATER TO 3 OF 3 SG WINDOW
1 - (LSW1)

SBO AT UNIT 1 - AFW 1 OF 3 SG
(SBOU1-LS) - POS 3-13

E-546

Cross-Tie of U2 CHG Flow in B1

E-547

Cross-Tie of U2 CHG Flow in B1

Gravity from RWST in B1, Window 1

Safety Valves Removed in Window 1

Restore RHR given RHR5 in Window 1

UNITY	IB1W2	VW2	NB1W2	SB1W2	2CHGW2	GB1W2	SEQ #	END-STATE-N
							1	@
							2	T R5W2R6
							3	CD
							4	CD
							5	CD
							6	T R5W2R6
							7	@
							8	CD
							9	CD

B1W2R6 EVENT TREE

	UNITY	IB1W2	NB1W2	SB1W2	2CHGW2	SEQ #	END-STATE-NAMES
<p>B1W2D6 EVENT TREE</p>						1	@
						2	R5W2D6
						3	@
						4	CD
						5	CD
						T	--

E-554

Safety valves Not Removed in Window 2

Non-Recovery of AC Power in W2

Non-Recovery of AC Power in W2

Reflux Cooling in window 2

E-559

Cross-Tie of U2 CHG Flow in B1

Cross-Tie of U2 CHG Flow in B1

Gravity from RWST in B1, Window 2

Safety Valves Removed in Window 2

.Restore RHR given RHR5 in Window 2

UNITY	IBIW3	NBIW3	SBIW3	2CHGW3	SEQ #	END-STATE-NAMES
1	@
					2	T
					3	R5W3D6
					4	@
					5	CD

B1W3D6 EVENT TREE

Safety valves Not Removed in Window 3

1 top event for B1 LOSP - B1 in window 3

Non-Recovery of AC Power

Non-Recovery of AC Power

Reflux Cooling in window 3

E-573

Cross-Tie of U2 CHG Flow in B1

Cross-Tie of U2 CHG Flow in B1

Gravity from RWST in B1, Window 3

Safety Valves Removed in Window 3

Restore RHR given RHR5 in Window 3

	UNITY	IB1W4	VW4	NB1W4	2CHGW4	GB1W4	SEQ #	END-STATE-NAMES
<p>B1W4R6 EVENT TREE</p>							1	@
							2	T R5W4R6
							3	@
							4	@
							5	CD
							6	T R5W4R6
							7	@
							8	CD

UNITY	IB1W4	VW4	NB1W4	2CHGW4	GB1W4	SEQ #	END-STATE-NAMES
						1	@
						2	T R5W4R10
						3	@
						4	@
						5	CD
						6	T R5W4R10
						7	@
						8	CD

B1W4R10 EVENT TREE

	UNITY	IB1W4	NB1W4	SB1W4	2CHGW4	SEQ #	END-STATE-NAMES
<p>B1W4D6 EVENT TREE</p>						1 2 3 4 5	@ R5W4D6 @ @ CD

1 top event for B1 LOSP - B1 in window 4

Safety valves Not Removed in Window 4

Non-Recovery of AC Power

Reflux Cooling in window 4

AUXILIARY FEEDWATER TO 1 OF 3 SG WINDOW 4 - (LSW4)

Cross-Tie of U2 CHG Flow in B1

Cross-Tie of U2 CHG Flow in B1

Gravity from RWST in B1, Window 4

Safety Valves Removed in Window 4

Restore RHR given RHR5 in Window 4

Appendix E.10 Event Trees and High Level Fault Trees for Two Unit Blackout(B2)

	UNITY	IB2W1	VW1	NB2W1	GB2W1	SEQ #	END-STATE-NAMES
<p>B2W1R6 EVENT TREE</p>						1 2 T 3 4 5 T 6	@ R5W1R6 CD CD R5W1R6 CD

UNITY	IB2W1	NB2W1	SEQ #	END-STATE-NAMES
<p>B2W1D6 - UNIT 1&2 BLACKOUT WINDOW 1, POS_D6</p>			<p>1 2 T 3</p>	<p>@ R5W1D6 CD</p>

E-595

Non-Recovery of AC Power in 144 min. of LOOP

Non-Recovery of AC Power in 144 min. of LOOP

Gravity from RWST in B2, Window 1

	UNITY	IB2W2	VW2	NB2W2	GB2W2	SEQ #	END-STATE-NAMES
<p>B2W2R6 EVENT TREE</p>						1 2 T 3 4 5 T 6	@ R5W2R6 CD CD R5W2R6 CD

E-600

UNITY	IB2W2	NB2W2	SEQ #	END-STATE-NAMES
<p>B2W2D6 EVENT TREE</p>			1 2 T 3	@ R5W2D6 CD

1 top event for B2 LOSP - B2 in window 2

Non-Recovery of AC Power in W2

Non-Recovery of AC Power in W2

Gravity from RWST in B2, Window 2

	UNITY	IB2W3	VW3	NB2W3	GB2W3	SEQ #	END-STATE-NAMES
<p>B2W3R6 EVENT TREE</p>						1 2 T 3 4 5 T 6	@ R5W3R6 CD CD R5W3R6 CD

	UNITY	IB2W3	VW3	NB2W3	GB2W3	SEQ #	END-STATE-NAMES
<p>B2W3R10 EVENT TREE</p>						1 2 T 3 4 5 T 6	@ R5W3R10 CD CD R5W3R10 CD

UNITY	IB2W3	NB2W3	SEQ #	END-STATE-NAMES
<p>B2W3D6 EVENT TREE</p>			<p>1 2 3 T</p>	<p>@ R5W3D6 CD</p>

1 top event for B2 LOSP - B2 in window 3

Non-Recovery of AC Power

Non-Recovery of AC Power

Gravity from RWST in B2, Window 3

	UNITY	IB2W4	VW4	NB2W4	GB2W4	SEQ #	END-STATE-NAMES
<p>B2W4R6 EVENT TREE</p>						1 2 T 3 4 5 T 6	@ R5W4R6 @ CD R5W4R6 CD

	UNITY	IB2W4	VW4	NB2W4	GB2W4	SEQ #	END-STATE-NAMES
<p>B2W4R10 EVENT TREE</p>						1 2 T 3 4 5 T 6	@ R5W4R10 @ CD R5W4R10 CD

UNITY	IB2W4	NB2W4	SEQ #	END-STATE-NAMES
<div> </div> <div>B2W4D6 EVENT TREE</div>			<div> 1 2 3 </div> <div>T</div>	<div> @ R5W4D6 CD </div>

1 top event for B2 LOSP - B2 in window 4

Non-Recovery of AC Power

- Gravity from RWST in B2, Window 4

Appendix E.11 Event Trees and High Level Fault Trees for Loss of 4KV Bus(4K)

UNITY	I4KW1	H4KW1	R4KW1	F4KW1	C4KW1	SEQ #	END-STATE
<p>The event tree diagram illustrates the sequence of events following a 'Loss of 4KV Bus - W1/D6'. It starts with a single line on the left, which branches into two paths. The upper path leads to a box, which then branches into two paths. The lower path leads to another box, which then branches into two paths. The final paths lead to the 'END-STATE' column, which contains the following states: @, @, @, CD, CD, @, @, CD, CD.</p> <p>Event Tree for Loss of 4KV Bus - W1/D6</p>						1 2 3 4 5 6 7 8 9	@ @ @ CD CD @ @ CD CD

UNITY	I4KW1	H4KW1	R4KW1	VW1	S4KW1	F4KW1	G4KW1	C4KW1	SEQ #	END-STATE-NAMES
<p>The diagram is an event tree starting from a single point on the left. It branches out into two main paths. The upper path has three levels of branching, leading to eight final states (sequences 1-8). The lower path also has three levels of branching, leading to eleven final states (sequences 9-19). Each branch is represented by a horizontal line that steps to the right at each event point.</p>									1	@
									2	@
									3	@
									4	CD
									5	CD
									6	CD
									7	@
									8	@
									9	CD
									10	CD
									11	@
									12	@
									13	CD
									14	CD
									15	CD
									16	@
									17	@
									18	CD
									19	CD

Event Tree for
Loss of 4KV Bus - W1/R5

1. top event for loss of 4KV in window 1.

4KV SYSTEM RECOVERY IN WINDOW 1

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 1

E-623

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 1

E-624

Reflux Cooling in window 1

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Reflux Cooling in window 1

Feed and Bleed the RCS in Window 1

Feed and Bleed the RCS in Window 1

Feed and Bleed the RCS with V failed in Window 1

Feed and Bleed the RCS with V failed in Window 1

Gravity from RWST in Window 1

Gravity from RWST in Window 1

E-633

Failure of High Pressure Recirculation in Window 1

Failure of High Pressure Recirculation in Window 1

E-636

Failure of Recirculation Spray in Window 1 HPR failure

Failure of Recirculation Spray in Window 1 HPR failure

Failure of Recirculation Spray in Window 1 HPR failure

Failure of Recirculation Spray in Window 1 HPR failure

Failure of Recirculation Spray in Window 1—cause HPR failure

Failure of Recirculation Spray in Window 1—cause HPR failure

Failure of Recirculation Spray in Window 1--cause HPR failure

Failure of Recirculation Spray in Window 1—cause HPR failure

E-646

UNITY	I4KW2	H4KW2	R4KW2	VW2	S4KW2	F4KW2	G4KW2	C4KW2	SEQ #	END-STATE-NAMES
<p>Event Tree for Loss of 4KV Bus - W2/R6</p>									1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19	@ @ @ CD CD CD @ @ CD CD @ @ CD CD CD @ CD CD

1 top event for loss of 4KV in window 2

4KV SYSTEM RECOVERY IN WINDOW 2

E-648

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 2

E-649

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 2

E-650

E-651

Feed and Bleed the RCS in Window 2

Feed and Bleed the RCS with V failed in Window 2

Feed and Bleed the RCS with V failed in Window 2

Gravity from RWST in Window 2

Gravity from RWST in Window 2

Reflux Cooling in window 2

Reflux Cooling in window 2

Failure of High Pressure Recirculation in Window 2

Failure of High Pressure Recirculation in Window 2

Failure of High Pressure Recirculation in Window 2

Failure of High Pressure Recirculation in Window 2

Failure of Recirculation Spray in Window 2 HPR failure

Failure of Recirculation Spray in Window 2 HPR failure

E-664

Failure of Recirculation Spray in Window 2 HPR failure

Failure of Recirculation Spray in Window 2—cause HPR failure

Failure of Recirculation Spray in Window 2-cause HPR failure

Failure of Recirculation Spray in Window 2—cause HPR failure

Failure of Recirculation Spray in Window 2—cause HPR failure

Failure of Recirculation Spray in Window 2 HPR failure

UNITY	I4KW3	H4KW3	R4KW3	S4KW3	F4KW3	SEQ #	END-STATE
<p>Event Tree for Loss of 4KV Bus - W3/D6</p>						1 2 3 4 5 6 7 8 9	@ @ OK @ CD @ OK @ CD

UNITY	I4KW3	H4KW3	R4KW3	VW3	F4KW3	G4KW3	SEQ #	END-STATE-NAMES
							1	e
							2	e
							3	e
							4	CD
							5	CD
							6	e
							7	CD
							8	e
							9	e
							10	CD
							11	CD
							12	e
							13	CD

Event Tree for
Loss of 4KV Bus - W3/R10

UNITY	I4KW3	H4KW3	R4KW3	VW3	F4KW3	G4KW3	SEQ #	END-STATE-NAMES
1	@
							2	@
							3	@
							4	CD
							5	CD
							6	@
							7	CD
							8	@
							9	@
							10	CD
							11	CD
							12	@
							13	CD
Event Tree for Loss of 4KV Bus - W3/R6								

1 top event for loss of 4KV in window 3

4KV SYSTEM RECOVERY IN WINDOW 3

E-675

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 3

E-676

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 3

E-677

Feed and Bleed the RCS in Window 3

Feed and Bleed the RCS in Window 3

Feed and Bleed the RCS with V failed in Window 3

Feed and Bleed the RCS with V failed in Window 3

Reflux Cooling in window 3

Reflux Cooling in window 3

Gravity from RWST in Window 3

Gravity from RWST in Window 3

UNITY	I4KW4	H4KW4	R4KW4	S4KW4	F4KW4	SEQ #	END-STATE
<p>Event Tree for Loss of 4KV Bus - W4/D6</p>						1	@
						2	@
						3	OK
						4	@
						5	CD
						6	@
						7	OK
						8	@
						9	CD

E-687

UNITY	I4KW4	H4KW4	R4KW4	VW4	F4KW4	G4KW4	SEQ #	END-STATE-NAMES
1	@
							2	@
							3	@
							4	OK
							5	CD
							6	@
							7	CD
							8	@
							9	@
							10	OK
							11	CD
							12	@
							13	CD

Event Tree for
Loss of 4KV Bus - W4/R10

UNITY	I4KW4	H4KW4	R4KW4	VW4	F4KW4	G4KW4	SEQ #	END-STATE-NAMES
<p>Event Tree for Loss of 4KV Bus - W4/R6</p>							1	@
							2	@
							3	@
							4	OK
							5	CD
							6	@
							7	CD
							8	@
							9	@
							10	OK
							11	CD
							12	@
							13	CD

E-689

4KV SYSTEM RECOVERY IN WINDOW 4

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 4

E-691

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 4

Feed and Bleed the RCS in Window 4

Feed and Bleed the RCS in Window 4

Feed and Bleed the RCS with V failed in Window 4

Feed and Bleed the RCS with V failed in Window 4

E-697

Reflux Cooling in window 4

E-698

Gravity - from RWST in Window 4

Gravity from RWST in Window 4

Appendix E.12 Event Trees and High Level Fault Trees for Loss of Vital Bus(VB)

UNITY	IVBW1	HVBW1	RVBW1	FVBW1	CVBW1	SEQ #	END-STATE
	<p>Event Tree for Loss of Vital Bus - W1/D6</p>					1 2 3 4 5 6 7 8 9	@ @ @ CD CD @ @ CD CD

UNITY	IVBW1	HVBW1	RVBW1	VW1	SVBW1	FVBW1	GVBW1	CVBW1	SEQ #	END-STATE-NAMES
<p>Event Tree for Loss of Vital Bus - W1/R6</p>									1	@
									2	@
									3	@
									4	CD
									5	CD
									6	CD
									7	@
									8	@
									9	CD
									10	CD
									11	@
									12	@
									13	CD
									14	CD
									15	CD
									16	@
									17	@
									18	CD
									19	CD

E-704

VITAL BUS SYSTEM RECOVERY IN WINDOW 1

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 1

E-706

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 1

Feed and Bleed the RCS in Window 1

Feed and Bleed the RCS in Window 1

Feed and Bleed the RCS with V failed in Window 1

Feed and Bleed the RCS with V failed in Window 1

Reflux Cooling in window 1

Reflux Cooling in window 1

Gravity from RWST in Window 1

Gravity from RWST in Window 1

Failure of High-Pressure Recirculation in Window 1

E-717

E-718

Failure of High Pressure Recirculation in Window 1

Failure of Recirculation Spray in Window 1 HPR failure

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Failure of Recirculation Spray in Window 1 HPR failure

Failure of Recirculation Spray in Window 1 HPR failure

Failure of Recirculation Spray in Window 1 HPR failure

Failure of Recirculation Spray in Window 1—cause HPR failure

Failure of Recirculation Spray in Window 1—cause HPR failure

Failure of Recirculation Spray in Window 1—cause HPR failure

Failure of Recirculation Spray in Window 1—cause HPR failure

UNITY	IVBW2	HVBW2	RVBW2	VW2	SVBW2	FVBW2	GVBW2	CVBW2	SEQ #	END-STATE-NAMES
<p>Event Tree for Loss of Vital Bus - W2/R6</p>									1	@
									2	@
									3	@
									4	CD
									5	CD
									6	CD
									7	@
									8	@
									9	CD
									10	CD
									11	@
									12	@
									13	CD
									14	CD
									15	CD
									16	@
									17	@
									18	CD
									19	CD

E-729

E-730

VITAL BUS SYSTEM RECOVERY IN WINDOW 2

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 2

E-732

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 2

E-733

Feed and Bleed the RCS in Window 2

Feed and Bleed the RCS in Window 2

Feed and Bleed the RCS with V failed in Window 2

Feed and Bleed the RCS with V failed in Window 2

Reflux Cooling in window 2

Reflux Cooling in window 2

Gravity from RWST in Window 2

Gravity from RWST in Window 2

Failure of High Pressure Recirculation in Window 2

E-742

Failure of High Pressure Recirculation in Window 2

######

E-745

Failure of Recirculation Spray in Window 2 HPR failure

Failure of Recirculation Spray in Window 2 HPR failure

Failure of Recirculation Spray in Window 2 HPR failure

Failure of Recirculation Spray in Window 2 HPR failure

Failure of Recirculation Spray in Window 2—cause HPR failure

Failure of Recirculation Spray in Window 2—cause HPR failure

Failure of Recirculation Spray in Window 2-cause HPR failure

Failure of Recirculation Spray in Window 2—cause HPR failure

E-754

UNITY	IVBW3	HVBW3	RVBW3	SVBW3	FVBW3	SEQ #	END-STATE
<p>Event Tree for Loss of Vital Bus - W3/D6</p>						1 2 3 4 5 6 7 8 9	@ @ OK @ CD @ OK @ CD

E-7SS

UNITY	IVBW3	HVBW3	RVBW3	VW3	FVBW3	GVBW3	SEQ #	END-STATE-NAMES
							1	@
							2	@
							3	@
							4	CD
							5	CD
							6	@
							7	CD
							8	@
							9	@
							10	CD
							11	CD
							12	@
							13	CD

Event Tree for
Loss of Vital Bus - W3/R10

UNITY	IVBW3	HVBW3	RVBW3	VW3	FVBW3	GVBW3	SEQ #	END-STATE-NAMES
							1 2 3 4 5 6 7 8 9 10 11 12 13	e e e CD CD e CD e e CD CD e CD
								Event Tree for Loss of Vital Bus - W3/R6

1 top event for loss of VB in window 3

E-757

VITAL BUS SYSTEM RECOVERY IN WINDOW 3

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 3

E-759

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 3

Feed and Bleed the RCS in Window 3

Feed and Bleed the RCS in Window 3

Feed and Bleed the RCS with V failed in Window 3

Feed and Bleed the RCS with V failed in Window 3

Reflux Cooling in window 3

Reflux Cooling in window 3

Gravity from RWST in Window 3

Gravity from RWST in Window 3

UNITY	IVBW4	HVBW4	RVBW4	SVBW4	FVBW4	SEQ #	END-STATE
						1 2 3 4 5 6 7 8 9	@ @ OK @ CD @ OK @ CD
<div>Event Tree for Loss of Vital Bus - W4/D6</div>

UNITY	IVBW4	HVBW4	RVBW4	VW4	FVBW4	GVBW4	SEQ #	END-STATE-NAMES
<pre> graph LR Start(()) --- B1[] B1 --- B2[] B1 --- B3[] B2 --- B4[] B2 --- B5[] B3 --- B6[] B3 --- B7[] B4 --- B8[] B4 --- B9[] B5 --- B10[] B5 --- B11[] B6 --- B12[] B6 --- B13[] B8 --- S1[1] B8 --- S2[2] B8 --- S3[3] B9 --- S4[4] B9 --- S5[5] B9 --- S6[6] B10 --- S7[7] B10 --- S8[8] B11 --- S9[9] B12 --- S10[10] B12 --- S11[11] B13 --- S12[12] B13 --- S13[13] S1 --- E1[@] S2 --- E2[@] S3 --- E3[@] S4 --- E4[OK] S5 --- E5[CD] S6 --- E6[@] S7 --- E7[CD] S8 --- E8[@] S9 --- E9[@] S10 --- E10[OK] S11 --- E11[CD] S12 --- E12[@] S13 --- E13[CD] </pre> <p>Event Tree for Loss of Vital Bus - W4/R10</p>							1	@
							2	@
							3	@
							4	OK
							5	CD
							6	@
							7	CD
							8	@
							9	@
							10	OK
							11	CD
							12	@
							13	CD

UNITY	IVBW4	HVBW4	RVBW4	VW4	FVBW4	GVBW4	SEQ #	END-STATE-NAMES
							1	@
							2	@
							3	@
							4	OK
							5	CD
							6	@
							7	CD
							8	@
							9	@
							10	OK
							11	CD
							12	@
							13	CD
<p>Event Tree for Loss of Vital Bus - W4/R6</p>								

1 top event for loss of VB in window 4

VITAL BUS SYSTEM RECOVERY IN WINDOW 4

RESTORE RHR GIVEN LOSS OF 4KV
EMERGENCY BUS H IN
window 4

E-774

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 4

Feed and Bleed the RCS in Window 4

Feed and Bleed the RCS in Window 4

Feed and Bleed the RCS with V failed in Window 4

Feed and Bleed the RCS with V failed in Window 4

Reflux Cooling in window 4

E-781

Gravity from RWST in Window 4

Gravity from RWST in Window 4

**Appendix E.13 Event Trees and High Level Fault Trees for Spurious Safety Injection
Signal(SI)**

UNITY	ISIW1	HSIW1	RSIW1	FSIW1	CSIW1	SEQ #	END-STATE
<p>The event tree diagram shows a sequence of events starting from a single point on the left. It branches into two main paths. The top path has three sub-branches, and the bottom path has two sub-branches. Each sub-branch is represented by a horizontal line with a vertical step at its end. The lines are connected by vertical lines, forming a tree structure. The final states are listed in the 'END-STATE' column.</p> <p>Event Tree for Spurious SI - W1/D6</p>						1 2 3 4 5 6 7 8 9	@ @ @ CD CD @ @ CD CD

UNITY	ISIW1	HSIW1	RSIW1	VW1	SSIW1	FSIW1	GSIW1	CSIW1	SEQ #	END-STATE-NAMES
<p>Event Tree for Spurious SI - W1/R6</p>									1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19	@ @@ CD CD CD @ CD CD @ CD CD @ CD CD CD @ CD CD

1 top event for loss of SI in window 1

SI SYSTEM RECOVERY IN WINDOW 1

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 1

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 1

Feed and Bleed the RCS in Window 1

Feed and Bleed the RCS in Window 1

Feed and Bleed the RCS with V failed in Window 1

Feed and Bleed the RCS with V failed in Window 1

Reflux Cooling in window 1

Reflux Cooling in window 1

Gravity from RWST in Window 1

Gravity from RWST in Window 1

E-799

Failure of High Pressure Recirculation in Window 1

Failure of High Pressure Recirculation in Window 1

- Failure of High Pressure Recirculation
in Window 1

Failure of Recirculation Spray in Window 1 HPR failure

Failure of Recirculation Spray in Window 1 HPR failure

Failure of Recirculation Spray in Window 1 HPR failure

Failure of Recirculation Spray in Window 1 HPR failure

Failure of Recirculation Spray in Window 1—cause HPR failure

Failure of Recirculation Spray in Window 1—cause HPR failure

Failure of Recirculation Spray in Window 1—cause HPR failure

Failure of Recirculation Spray in Window 1—cause HPR failure

UNITY	ISIW2	HSIW2	RSIW2	SSIW2	FSIW2	CSIW2	SEQ #	END-S'
<p>Event Tree for Spurious SI - W2/D6</p>							1 2 3 4 5 6 7 8 9 10 11	@ @ OK @ CD CD @ OK @ CD CD

UNITY	ISIW2	HSIW2	RSIW2	VW2	SSIW2	FSIW2	GSIW2	CSIW2	SEQ #	END-STATE-NAMES
<p>Event Tree for Spurious SI - W2/R6</p>									1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19	@ @ @ CD CD CD @ @ CD CD @ @ CD CD CD @ @ CD CD

1 top event for loss of SI in window 2

SI SYSTEM RECOVERY IN WINDOW 2

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 2

E-815

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RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 2

E-816

Feed and Bleed the RCS in Window 2

Feed and Bleed the RCS in Window 2

Feed and Bleed the RCS with V failed in Window 2

Feed and Bleed the RCS with V failed in Window 2

Reflux Cooling in window 2

Reflux Cooling in window 2

Gravity from RWST in Window 2

Gravity from RWST in Window 2

Failure of High Pressure Recirculation in Window 2

E-826

Failure of High Pressure Recirculation in Window 2

Failure of Recirculation Spray in Window 2 HPR failure

Failure of Recirculation Spray in Window 2 HPR failure

Failure of Recirculation Spray in Window 2 HPR failure

Failure of Recirculation Spray in Window 2 HPR. failure

Failure of Recirculation Spray in Window 2—cause HPR failure

Failure of Recirculation Spray in Window 2—cause HPR failure

Failure of Recirculation Spray in Window 2—cause HPR failure

Failure of Recirculation Spray in Window 2—cause HPR failure

UNITY	ISIW3	HSIW3	RSIW3	SSIW3	FSIW3	SEQ #	END-STATE
<p>Event Tree for Spurious SI - W3/D6</p>						1 2 3 4 5 6 7 8 9	@ @ OK @ CD @ OK @ CD

UNITY	ISIW3	HSIW3	RSIW3	VW3	FSIW3	GSIW3	SEQ #	END-STATE-NAMES
<p>Event Tree for Spurious SI - W3/R10</p>							1	@
							2	@
							3	@
							4	CD
							5	CD
							6	@
							7	CD
							8	@
							9	@
							10	CD
							11	CD
							12	@
							13	CD

E-840

SI SYSTEM RECOVERY IN WINDOW 3

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 3

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 3

Safety valves Not Removed in Window 3

Feed and Bleed the RCS in Window 3

Feed and Bleed the RCS in Window 3

Feed and Bleed the RCS with V failed in Window 3

Feed and Bleed the RCS with V failed in Window 3

Reflux Cooling in window 3

Gravity from RWST in Window 3

Gravity from RWST in Window 3

E-853

UNITY	ISIW4	HSIW4	RSIW4	VW4	FSIW4	GSIW4	SEQ #	END-STATE-NAMES
<p>Event Tree for Spurious SI - W4/R10</p>							1 2 3 4 5 6 7 8 9 10 11 12 13	@ @ @ OK CD @ CD @ @ OK CD @ CD

E-854

UNITY	ISIW4	HSIW4	RSIW4	VW4	FSIW4	GSIW4	SEQ #	END-STATE-NAMES
<p>Event Tree for Spurious SI - W4/R6</p>							1 2 3 4 5 6 7 8 9 10 11 12 13	@ @ @ OK CD @ CD @ @ OK CD @ CD

1 top event for loss of SI in window 4

SI SYSTEM RECOVERY IN WINDOW 4

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 4

RESTORE RHR GIVEN LOSS OF 4KV EMERGENCY BUS H IN window 4

E-858

Feed and Bleed the RCS in Window 4

Feed and Bleed the RCS in Window 4

Feed and Bleed the RCS with V failed in Window 4

Feed and Bleed the RCS with V failed in Window 4

Reflux Cooling in window 4

Reflux Cooling in window 4

Gravity from RWST in Window 4

Gravity from RWST in Window 4

Appendix E.14

Event Trees and High Level Fault Trees for Loss of Component Cooling Water(CC)

E-868

UNITY	ICCW1	HCCW1	FCCW1V	CCCW1V	SEQ #	END-STATE-NAMES
1 2 3 4 5	OK OK CD CD
Event Tree for Loss of CCW in D6-Window 1						

UNITY	ICCW1	HCCW1	VW1	SCCW1	FCCW1	GCCW1	CCCW1	SEQ #	END-STATE-NAMES
<p>Event Tree for Loss of CCW in R6-Window 1</p>								1 2 3 4 5 6 7 8 9 10	OK OK OK CD CD CD CD OK OK CD CD

1 top event for loss of CCW in window 1

CCW SYSTEM RECOVERY IN WINDOW 1

Feed and Bleed the RCS in Window 1

Feed and Bleed the RCS with V failed in Window 1

Reflux Cooling in window 1

Gravity from RWST in Window 1

Failure of High Pressure Recirculation in Window 1

E-877

Failure of Recirculation Spray in Window 1 HPR failure

Failure of Recirculation Spray in Window 1—cause HPR failure

UNITY	ICCW2	HCCW2	SCW2	FCCW2V	CCCW2V	SEQ #	END-STATE-NAMES
						1 2 3 4 5 6	OK OK OK OK CD CD

Event Tree for
Loss of CCW in D6-Window 2

E-881

UNITY	ICCW2	HCCW2	VW2	SCCW2	FCCW2	GCCW2	CCCW2	SEQ #	END-STATE-NAMES
<p>Event Tree for Loss of CCW in R6- Window 2</p>								1 2 3 4 5 6 7 8 9 10	OK OK OK CD CD CD CD OK OK CD CD

E-882

CCW SYSTEM RECOVERY IN WINDOW 2

Feed and Bleed the RCS in Window 2

Feed and Bleed the RCS with V failed in Window 2

Reflux Cooling in window 2

Gravity from RWST in Window 2

Failure of High Pressure Recirculation in Window 2

Failure of High Pressure Recirculation in Window 2

Failure of Recirculation Spray in Window 2 HPR failure

Failure of Recirculation Spray in Window 2—cause HPR failure

UNITY	ICCW3	HCCW3	SCCW3	FCCW3V	SEQ #	END-STATE-NAMES
<div><div><div></div><div></div><div></div><div></div><div></div></div><div>1 2 3 4 5</div></div> <div>Event Tree for Loss of CCW in D6-Window 3</div> <div>OK OK OK OK CD</div>						

UNITY	ICW3	HCCW3	VW3	FCCW3	GCCW3	SEQ #	END-STATE-NAMES
<p>Event Tree for Loss of CCW in R10-Window 3</p>							OK OK OK CD CD OK CD

UNITY	ICCW3	HCCW3	VW3	FCCW3	GCCW3	SEQ #	END-STATE-NAMES
						1 2 3 4 5 6 7	OK OK OK CD CD OK CD

OK
OK
OK
CD
CD
OK
CD

1
2
3
4
5
6
7

Event Tree for
Loss of CCW in R6-Window 3

1 top event for loss of CCW in window 3

CCW SYSTEM RECOVERY IN WINDOW 3

Feed and Bleed the RCS in Window 3

Feed and Bleed the RCS with V failed in Window 3

Reflux Cooling in window 3

Gravity from RWST in Window 3

E-901

UNITY	ICCW4	HCCW4	SCCW4	FCCW4V	SEQ #	END-STATE-NAMES
<p>Event Tree for Loss of CCW in D6-Window 4</p>					1 2 3 4 5	OK OK OK OK CD

E-902

UNITY	ICCW4	HCCW4	VW4	FCCW4	GCCW4	SEQ #	END-STATE-NAMES
1 2 3 4 5 6 7	OK OK OK OK CD OK CD

E-903

UNITY	ICCW4	HCCW4	VW4	FCCW4	GCCW4	SEQ #	END-STATE-NAMES
<p>Event Tree for Loss of CCW in R6-Window 4</p>						1 2 3 4 5 6 7	OK OK OK OK CD OK CD

1 top event for loss of CCW in window 4

CCW SYSTEM RECOVERY IN WINDOW 4

Feed and Bleed the RCS in Window 4

Feed and Bleed the RCS with V failed in Window 4

Reflux Cooling in window 4

Gravity from RWST in Window 4

Appendix E.15

Event Trees and High Level Fault Trees for Loss of Instrument Air (AR)

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UNITY	IARW1	HARW1	RARW1	VW1	SARW1	FARW1	GARW1	CARW1	SEQ #	END-STATE-1
									1 2 3 4 5 6 7 8 9 10 11	OK OK OK OK CD CD CD OK OK CD CD
<div>ARW1R6 Event Tree</div>										

ARW1D6 Event Tree

Top Event for Loss of Instrument Air in Window 1

E-913

Non-Recovery of Instrument Air in Window 1

Restore RHR given Loss of Instrument Air in Window 1

Safety Valves Not Removed in Window 1

Reflux Cooling in Window 1

RCS Loops Isolated to Cause Failure of Reflux in Window 1

Feed and Bleed the RCS Given Loss of Air in Window 1

Safety Valves Removed in Window 1

Feed and Bleed the RCS with V failed in Window 1 Given Loss of Air

Gravity from RWST Given Loss of Instrument Air in Window 1

Failure of Recirculation Spray in Window 1—cause HPR failure

Failure of High Pressure Recirculation in Window 1

UNITY	IARW2	HARW2	RARW2	SARW2	FARW2V	CARW2V	SEQ #	END-STATE-NAMES
							1 2 3 4 5 6 7	OK OK OK OK OK CD CD
ARW2D6 Event Tree								

1 Top Event for Loss of Instrument Air in Window 2

Non-Recovery of Instrument Air in Window 2

Restore RHR given Loss of Instrument Air in Window 2

Safety Valves Not Removed in Window 2

Reflux Cooling in Window 2

RCS Loops Isolated to Cause Failure of Reflux in Window 2

Feed and Bleed the RCS Given Loss of Air in Window 2

Safety Valves Removed in Window 2

Feed and Bleed the RCS with V failed in Window 2 Given Loss of Air

Gravity from RWST given Loss of Instrument Air in Window 2

Failure of High Pressure Recirculation in Window 2

E-938

Failure of Recirculation Spray in Window 2—cause HPR failure

Failure of High Pressure Recirculation in Window 2

E-940

UNITY	IARW3	HARW3	RARW3	VW3	FARW3	GARW3	SEQ #	END-STATE-NAMES
<p>ARW3R6 Event Tree</p>							1	OK
							2	OK
							3	OK
							4	OK
							5	CD
							6	CD
							7	OK
							8	CD

E-942

UNITY	IARW3	HARW3	RARW3	VW3	FARW3	GARW3	SEQ #	END-STATE-NAMES
<p>ARW3R10 Event Tree</p>							1 2 3 4 5 6 7 8	OK OK OK OK CD CD OK CD

UNITY	IARW3	HARW3	RARW3	SARW3	PARW3V	SEQ #	END-STATE-NAMES
						1	OK
						2	OK
						3	OK
						4	OK
						5	OK
						6	CD

ARW3D6 Event Tree

1 Top Event for Loss of Instrument Air in Window 3

Non-Recovery of Instrument Air in Window 3

Restore RHR given Loss of Instrument Air in Window 3

Safety Valves Not Removed in Window 3

Reflux Cooling in Window 3

RCS Loops Isolated to Cause Failure of Reflux in Window 3

Feed and Bleed the RCS Given Loss of Air in Window 3

Safety Valves Removed in Window 3

Feed and Bleed the RCS with V failed in Window 3 Given Loss of Air

Gravity from RWST given Loss of Instrument Air in Window 3

UNITY	IARW4	HARW4	RARW4	VW4	FARW4	GARW4	SEQ #	END-STATE-NAMES
<p>ARW4R6 Event Tree</p>							1 2 3 4 5 6 7 8	OK OK OK OK OK CD OK CD

UNITY	IARW4	HARW4	RARW4	VW4	FARW4	GARW4	SEQ #	END-STATE-NAMES
<p>ARW4R10 Event Tree</p>							1 2 3 4 5 6 7 8	OK OK OK OK OK CD OK CD

UNITY	IARW4	HARW4	RARW4	SARW4	FARW4V	SEQ #	END-STATE-NAMES
<p>ARW4D6 Event Tree</p>						1 2 3 4 5 6	OK OK OK OK OK CD

I Top Event for Loss of Instrument Air in Window 4

Non-Recovery of Instrument Air in Window 4

Restore RHR given Loss of Instrument Air in Window 4

Safety Valves Not Removed in Window 4

Reflux Cooling in Window 4

RCS Loops Isolated to Cause Failure of Reflux in Window 4

Feed and Bleed the RCS Given Loss of Air in Window 4

Safety Valves Removed in Window 4

Feed and Bleed the RCS with V failed in Window 4 Given Loss of Air

Gravity from RWST given Loss of Instrument Air in Window 4

**Appendix E.16 Event Trees and High Level Fault Trees for Loss of Switchgear Room
Cooling(SR)**

	UNITY	ISRW1	ARCW1	VW1	SSRW1	2CHSW1	GSRW1	SEQ #	END-STATE-NAME
1	@
								2	@
								3	CD
								4	CD
								5	CD
								6	@
								7	CD
								8	CD
SRW1R6 EVENT TREE - LOSS OF ESGR COOLING									

E-970

Safety valves Not Removed in Window 1

Reflux Cooling in window 1

E-974

Cross-Tie of U2 CHG Flow in SR, POS 6 - Refueling

Gravity from RWST in SR

Safety Valves Removed in Window 1

	UNITY	ISRW2	ARCW2	SSRW2	2CHSW2	SEQ #	END-STATE-NAMES
<p>SRW2D6 EVENT TREE - LOSS OF ESGR COOLING</p>						1 2 3 4 5	@ @ @ CD CD

E-980

Safety valves Not Removed in Window 2

Reflux Cooling in window 2

Cross-Tie of U2 CHG Flow in SR, POS 6 - Refueling

Gravity from RWST in SR

Safety Valves Removed in Window 2

	UNITY	ISRW3	ARCW3	VW3	2CHSW3	GSRW3	SEQ #	END-STATE-NAMES
							1	@
							2	@
							3	@
							4	CD
							5	CD
							6	@
							7	CD
SRW3R6 EVENT TREE - LOSS OF ESGR COOLING

E-991

Safety valves Not Removed in Window 3

Cross-Tie of U2 CHG Flow in SR, POS 6 - Refueling

Reflux Cooling in window 3

Cross-Tie of U2 CHG Flow in SR, POS 6 - Refueling

Gravity from RWST in SR

Safety Valves Removed in Window 3

	UNITY	ISRW4	ARCW4	VW4	2CHSW4	GSRW4	SEQ #	END-STATE-NAMES
							1	@
							2	@
							3	@
							4	@
							5	CD
							6	@
							7	CD
SRW4R6 EVENT TREE - LOSS OF ESGR COOLING								

SRW4D6 EVENT TREE
- LOSS OF ESGR COOLING

1 TOP EVENT FOR ESGR COOLING LOSS - SR

Safety valves Not Removed in Window 4

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Reflux Cooling in window 4

Cross-Tie of U2 CHG Flow in SR, POS 6 - Refueling

Cross-Tie of U2 CHG Flow in SR, POS 6 - Refueling

Gravity from RWST in SR

Safety Valves Removed in Window 4

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(See instructions on the reverse)

1. REPORT NUMBER
(Assigned by NRC. Add Vol., Supp., Rev.,
and Addendum Numbers, if any.)

NUREG/CR-6144
BNL-NUREG-52399
Vol.2, Part 3B

3. DATE REPORT PUBLISHED

MONTH YEAR

June 1994

4. FIN OR GRANT NUMBER

L1922

6. TYPE OF REPORT

7. PERIOD COVERED (Inclusive Dates)

2. TITLE AND SUBTITLE

Evaluation of Potential Severe Accidents During Low
Power and Shutdown Operations at Surry, Unit 1:
Analysis of Core Damage Frequency from Internal
Events During Mid-loop Operations-Appendices E
(Sections E.9-E.16)

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9. SPONSORING ORGANIZATION - NAME AND ADDRESS (If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)

Division of Safety Issue Resolution
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

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

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

Surry-1 Reactor-Reactor Shutdown; Surry-1 Reactor-Risk Assessment;
Surry-2 Reactor-Reactor Shutdown; Surry-2 Reactor-Risk Assessment;
Failure Mode Analysis, Reactor Accidents, Reactor Core Disruption,
Reactor Start-up, RHR Systems, Systems Analysis, Thermodynamics,
Sandia National Laboratories

13. AVAILABILITY STATEMENT

Unlimited

14. SECURITY CLASSIFICATION

(This Page)

Unclassified

(This Report)

Unclassified

15. NUMBER OF PAGES

16. PRICE

DATE

FILMED

9 / 1 / 94

END