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A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Fires Using Fault Tree Analysis

KNS 2026 Autumn Meeting

2026. 10. 29.

|주|스탠더드시험연구소

STANDARD TESTING & ENGINEERING INC.

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1. INTRODUCTION

1 Introduction

▪ Multiple Spurious Operation (MSO)

원전 내 특정 지역의 화재로 인해 손상된 케이블이 능동기기의 전기회로(전원, 제어로직, 계측 신호 및 전원 등)에 고장을 유발하여 다수의 기기가 의도치 않은 방향으로 동작하는 것.

- US NRC RG 1.189 (Fire Protection for Nuclear Power Plants)
- NEI 00-01 (Guide for Post Fire Safe Shutdown Circuit Analysis)
- 원자력안전위원회 고시 2024-9호 (화재위험도분석에 관한 기술기준)
  “다중오동작분석”을 포함한 안전정지분석을 요구

1 Introduction

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

▪ 화재위험도분석 절차

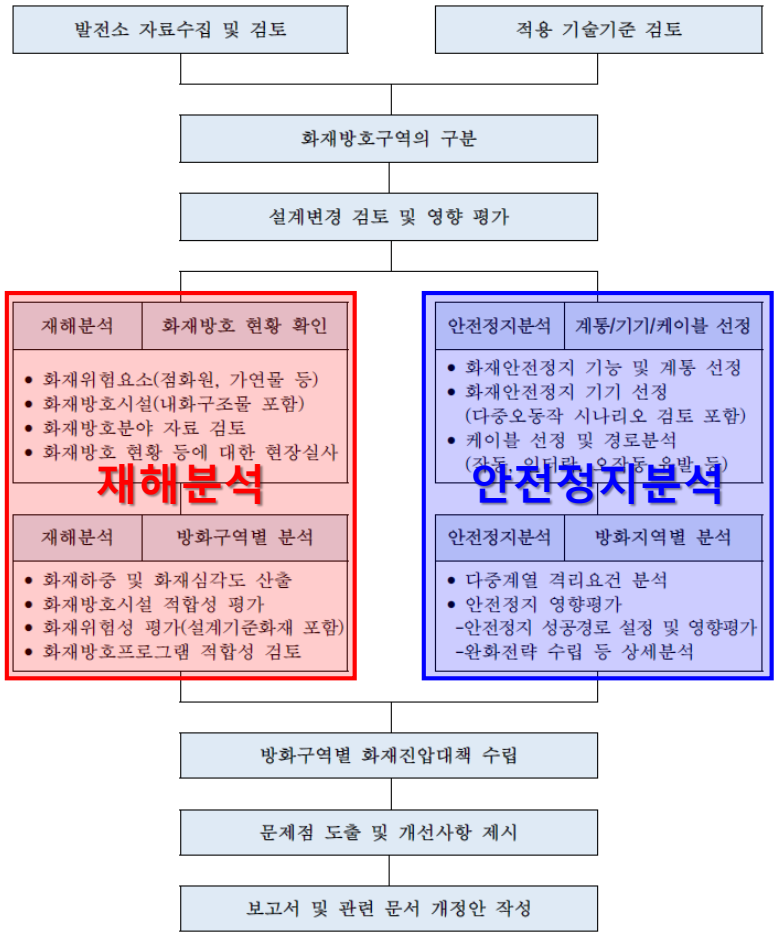
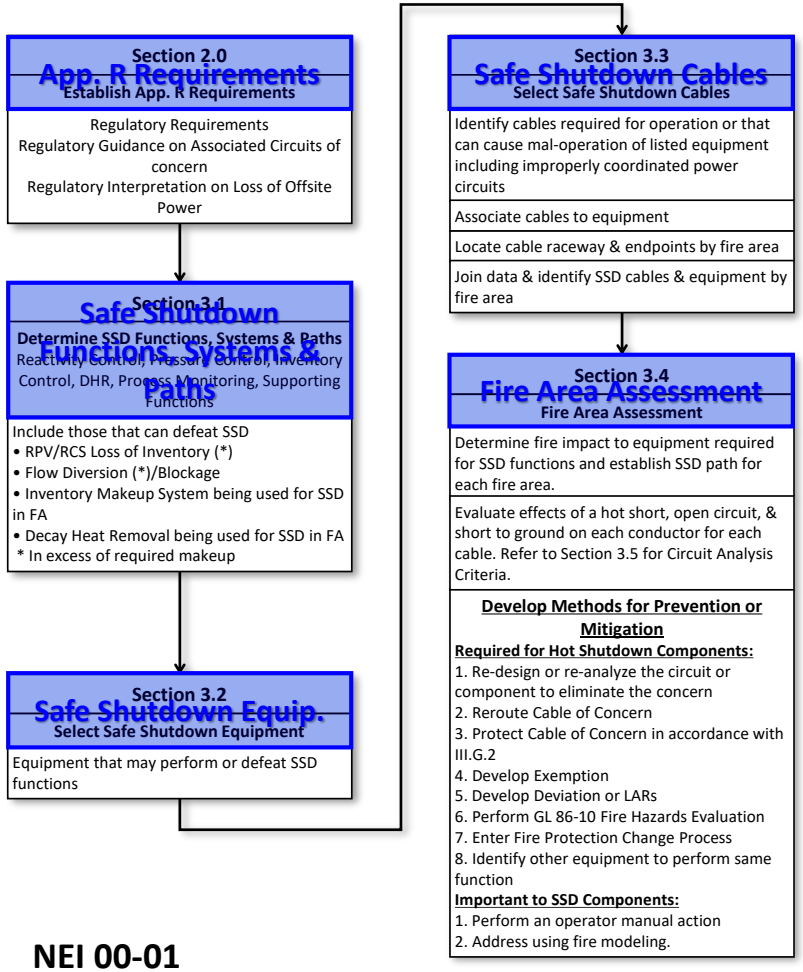


Fig. 3-1 Deterministic Guidance Methodology Overview

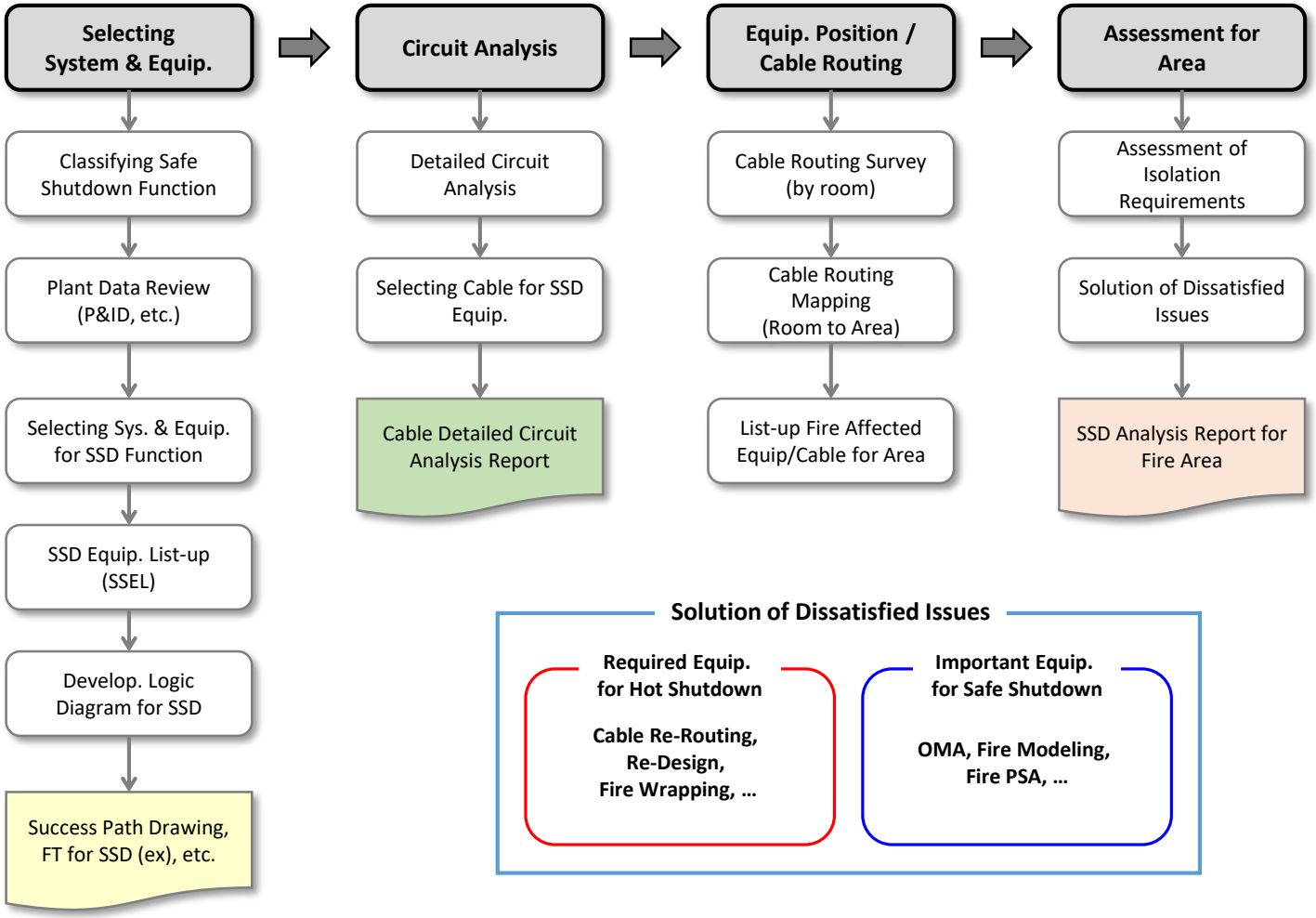


NEI 00-01
(Guide for Post Fire Safe Shutdown Circuit Analysis)

1 Introduction

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

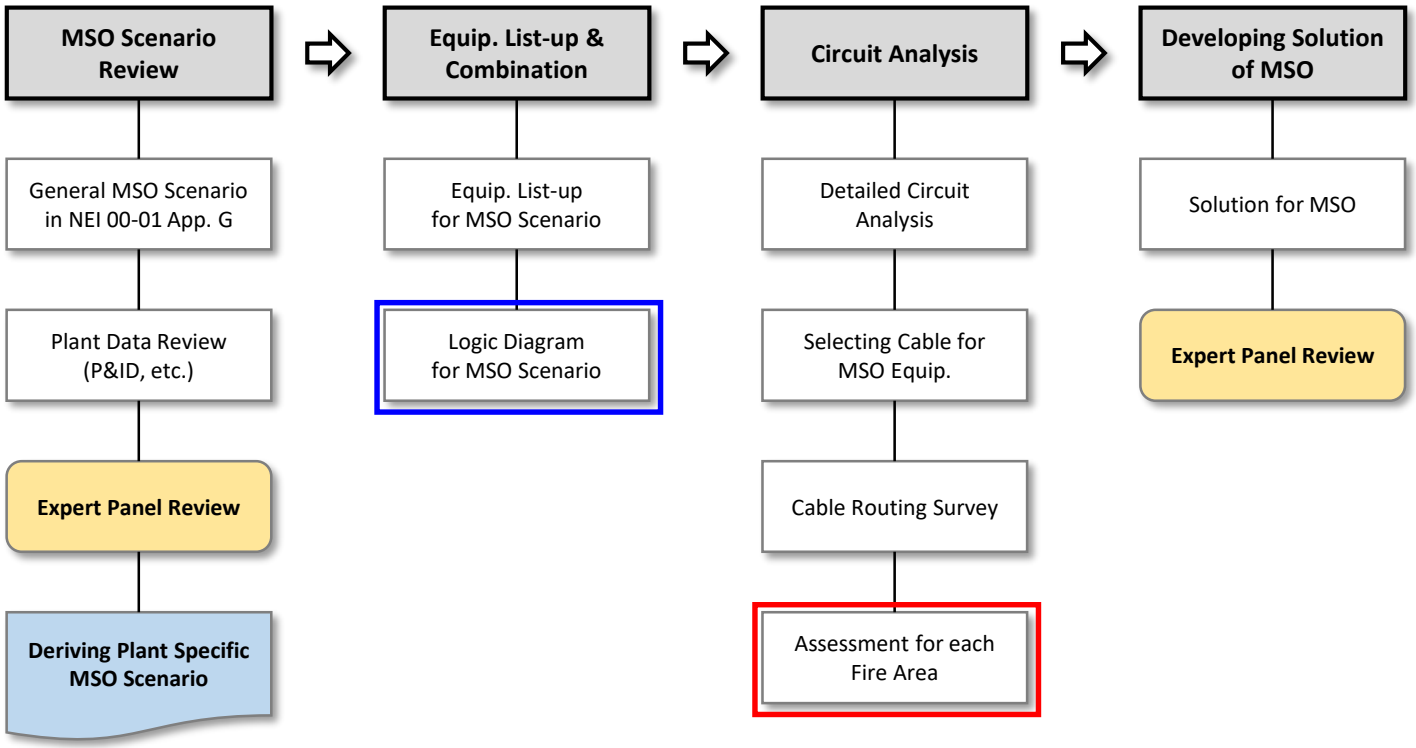
▪ General Process of the SSA



1 Introduction

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

▪ Process of MSO Analysis



1 Introduction

▪ Reasons for Applying Fault Tree in SSA/MSO

안전정지분석에 고장수목을 적용하는 이유

› Discovering Combination: F.T. clearly presents the 'Fault Path' and 'Cause'

조합의 발견: 고장수목은 '고장경로'와 '원인'을 명확히 표시

› Identifying Weak Point: Minimal Cut-Set from FTA is 'Fault Path' to be protected, and the System Succeeds if protective measures are applied for the cables in this set.

취약점 식별: 고장수목분석으로 도출된 (최소)단절집합은 방호해야 할 '고장경로'임,
이 집합의 케이블들만 보호조치를 취하면 시스템은 성공

1 Introduction

▪ Comparison of Fault Tree (PSA vs. SSA vs. MSO)

	FT in PSA	FT in SSA	FT in MSO Analysis
Goal	Sys. Failure Probability or Core Damage Frequency (Level 1)	Post-Fire Rx Safe-Shutdown	MSO Analysis (in SSA/FHA)
Applicable Target	Target System or Plant (ex. Rx Core, R/B)	Safe-Shutdown due to Fire in each Fire Area in NPP	MSO Scenario for each Fire Area in NPP
Top Event	System Failure or Core Damage	Rx Safe-Shutdown Fail	MSO Scenario (#m) Occur
Intermediate Event (Gate)	Safe Function & System (Reactivity Ctrl., RCS Inventory Ctrl., RCS Pressure Ctrl., Core & RCS Heat Removal, etc.)	Safe-Shutdown Function & System (Reactivity Ctrl., RCS Inventory Ctrl., Decay Heat Removal, Process Monitoring, Support Function)	Logical Combination of Components (related MSO Scenario)
Basic Event	Safe System Components (Assign Random Probability of Failure Rate)	Assigning equal value (0.1) to B.E. for Fire-Affected Components & Cables in each Area	Assigning equal value ('T') to B.E. for Fire-Affected Components & Cables in each Area
Initial Event	Single Event among Internal Event (LOCA, Transient), External Event (Earthquake, Fire, Flooding)	Fire in Each Fire Area (Single Fire, Fire in Single Area)	←
Quantification	Event Tree – Fault Tree Link, System Fault Tree Integration	Quantification of Area Specific Fault Tree reflected Fire-Affected Components & Cables for each Area	Logical (Boolean) Operation of Area Specific F.T. reflected Fire-Affected Components & Cables for each Area
Analysis Result	Sys. Failure Probability or CDF ⇒ Probability (<1)	Success or Failure of Rx Safe-Shutdown (Top = 0.0: Success, Top > 0.0: Fail)	MSO Occur or Not (Top = 'F' → Not Occur, OK Top = 'T' → MSO Occur)
Cut-Set	Minimal Cut-Set	All Cut-Set List	←

Probabilistic

Deterministic

2. MSO Analysis Method Using FTA

2 MSO Analysis Method using FTA

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.1 Selection Plant Specific MSO Scenario from NEI 00-01

2.2 Preparing Plant Common Fault Tree for MSO Scenarios

2.3 Identifying Fire Affected Components & Cables for each Fire Area

2.4 Generating Area Specific Fault Tree applied the Components/Cables

2.5 Assessment for each Fire Area

2 MSO Analysis Method using FTA

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.1 Selection Plant Specific MSO Scenario from NEI 00-01

No.	PWR MSO Scenario	No.	PWR MSO Scenario
1	Loss of all RCP Seal Cooling (Injection & Cooling Isol.)	33a	Excess Feed Flow to S/G (AFWP, MFWP Start)
2	Loss of all RCP Seal Cooling (Diversion & Cooling Isol.)	33b	Excess Feed Flow to S/G Fails TD Pump
3	Thermally Shocking RCP Seals (Cooling loss & Re-injection)	34	S/G Blowdown (Valve open)
4	Catastrophic RCP Seal Failure (Injection, Cooling Isol. & RCP Start)	35	Secondary Sample System (Valve open)
5	RCP Seal No. 2 Failure	36	RCS Pressure Decrease (Spray v/v open, HTR off)
6	Letdown Fails to Isolated and Inventory Lost to CVCS	37	RCS Pressure Increase (Spray v/v close, HTR on)
7	Letdown Fails to Isolated and Inventory Lost to PRT	38	Inadvertent Boron Dilution (Un-borated Water makeup)
8	Excess Letdown Fails to Isolate	39	Fire Prevents Reactor Trip (RPS fail)
9	RCS Makeup Isolation	40	CCW Header Isolation
10	Charging Pump Failure (VCT, RWST v/v Isol.)	41	CCW to Credited Loads (CCW Isol.)
11	Charging Pump Failure (RWST 2 Parallel v/v Isol.)	42	CCW Flow Diversion to Non-Credited Loop
12	Charging Pump Failure (H_2 enters into Charging line)	43	ESW Header Isolation
13	Charging Pump Failure (LD Isol. fail & LD Hx. CCW Isol.)	44	ESW to Credited Loads
14	Charging Pump Failure (Runout)	45	ESW Flow Diversion to Non-Credited Loops/Systems
15	RWST Drain Down via Containment Sump	46	Emergency Power (Overload by non-class load)
16	RWST Drain Down via Containment Spray	47	Emergency Power (Overload by class load simultaneously)
17	Interfacing System LOCA (High-Low Pressure)	48	Emergency Power (EDG Start without cooling)
18	Multiple Pressurizer PORVs	49	Emergency Power (Non-synchronous Paralleling)
19	Pressurizer PORV and Block Valve	49.I	Emergency Power (Norm.↔Alt, BKR Inadvertent close)
20	Reactor Head Vent Valves	50	Generic – Loss of Pump Suction
21	Excess RCS Makeup	51	Generic – Pump Shutoff Head
22	Primary Sample System	52	Generic – Pump Outside Design Flow
23	Inadvertent Steam Dumping (MSADV, Block v/v open)	53	Generic Flow Diversion
24	Inadvertent Steam Dumping (MSIV, CSDV etc. open)	54	Loss of HVAC
25	Inadvertent Steam Dumping (MSIV bypass, CSDV etc. open)	55	Valve Failure (Motor-Operated AND Bypass torque & limit switch)
26	Inadvertent Steam Dumping (Drain, TDAFWP Steam open)	56	Fire-Induced Inadvertent ESFAS
27	Turbine Driven AFW Pump Steam Supply (Valve open)	56a	RCS Makeup Pump Failure (SI signal & Suction v/v Isol.)
28	AFW Flow Isolation (Discharge v/v close)	56b	Loss of all Seal Cooling (Injection & Cooling Isol.)
29	AFW Flow Isolation (TD AFWP Disch. v/v Isol.)	56c	Loss of all Seal Cooling (Diversion & Cooling Isol.)
30	AFW Flow Diversion (Disch. v/v open to the other S/G)	56d	RWST Drain Down (through Containment Spray)
31	AFW Pump Runout	56e	PORV(s) Open
32	CST Diversion to Condenser (Valve open)	56f	RCS Makeup Pump Failure (RAS & loss of pump suction)

Generic MSO Scenario List in NEI 00-01 rev. 4 (App. G)

(63 Scenarios)

2 MSO Analysis Method using FTA

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.1 Selection Plant Specific MSO Scenario from NEI 00-01

MSO	Plant System	Function
MSO 1 ~ 5	Reactor Coolant System (RC)	RCS Inventory Ctrl. / RCS Integrity
MSO 6 ~ 14	Chemical and Volume Control System (CV)	
MSO 15 ~ 16	Containment Spray System (CS)	
MSO 17	Safety Injection System (SI)	
MSO 18 ~ 19	Reactor Coolant System (RC)	
MSO 20	Reactor Coolant Gas Vent System (RV)	
MSO 21	Chemical and Volume Control System (CV)	
MSO 22	Primary Sampling System	
MSO 23 ~ 27	Main Steam System, Main Turbine and Auxiliary System (MS)	Decay Heat Removal
MSO 28 ~ 33	Auxiliary Feed Waster System (AF)	
MSO 34	Steam Blowdown System	
MSO 35	Secondary Sampling System	
MSO 36 ~ 37	Reactor Coolant System (RC)	RCS Pressure Ctrl.
MSO 38	Chemical and Volume Control System (CV)	Support Functions
MSO 39	N/A	
MSO 40 ~ 45	Component Cooling Water (CCW) & Essential Service Water (ESW)	
MSO 46 ~ 49	Emergency Power Supply System	
MSO 50 ~ 53	Generic – Loss of Pump Suction, Pump Shutoff Head, Flow Diversion, Etc.	Other Scenarios
MSO 54	Loss of HVAC	
MSO 55	Valve Failure	
MSO 56	Fire-Induced Inadvertent ESFAS (56a ~ 56f)	

2 MSO Analysis Method using FTA

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.1 Selection Plant Specific MSO Scenario from NEI 00-01

❯ Example of MSO Scenario (1. Loss of all RCP Seal Cooling)

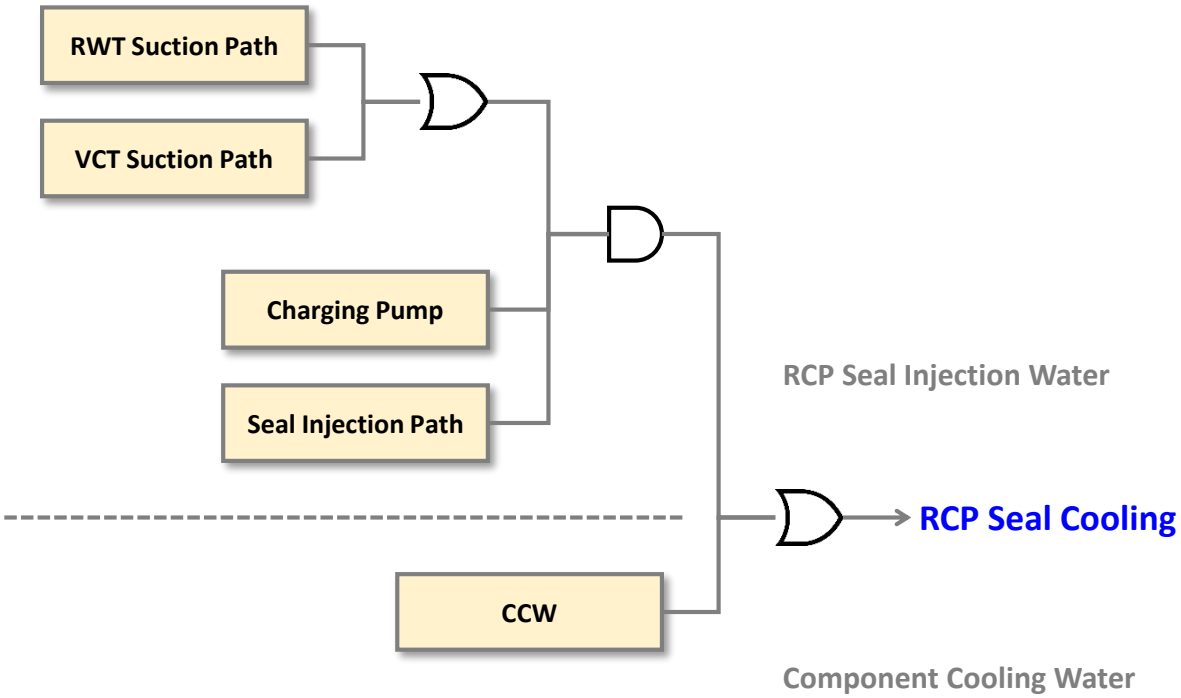
ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
RCS INVENTORY CONTROL / RCS INTEGRITY					
1	Loss of all RCP Seal Cooling	Spurious isolation of seal injection header flow, *AND* Spurious isolation of CCW flow to Thermal Barrier Heat Exchanger (TBHX)	Scenario causes loss of all RCP seal cooling and subsequent increase in RCP seal leakage, challenging the RCS Inventory Control Function. Westinghouse Tech Bulletin 04-22 Rev. 1 provides a summary of the issue. Tech Bulletin references provide additional detail. B&W plants with Westinghouse designed seals may have similar concerns. Seal injection flow isolation can occur at main header or at supply to each individual pump. In addition, scenarios that cause loss of all charging (i.e., multiple pump failure due to loss of suction, non-spurious pump failures such as loss of power, etc.) can also cause loss of seal injection. Loss of all seal cooling to any individual RCP is a problem (i.e., does not have to occur on all RCPs to be a problem) Westinghouse plants refer to Letter LTR-RAM-I-10-053 of White Paper on Westinghouse Reactor Coolant Pump Seal Behavior for Fire Scenarios, Revision 2. * CE plants generally do not have seal injection and can lose seal cooling for an extended period of time without increased seal leakage. These plants can lose all seal cooling due to spurious isolation of CCW. Refer to WCAP-16175.	B&W CE* W	"IMPORTANT" RCP Seal Cooling is not part of the "required" SSD path. Consequence is a large flow diversion from the RCS. Similar to spurious opening of PORV(s), reactor head vents, RHR letdown, normal letdown, and excess letdown causing flow diversions from the RCS. Refer to Scenario 9 for loss of makeup (i.e. Seal Injection) Note that this scenario is "REQUIRED" if seal injection is required RCS makeup flow path.

2

MSO Analysis Method using FTA

2.2 Preparing Plant Common Fault Tree for MSO Scenarios

› Success Path of MSO #1 (Loss of all RCP Seal Cooling)



2

MSO Analysis Method using FTA

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.2 Preparing Plant Common Fault Tree for MSO Scenarios

› Example of MSO Scenario (MSO #1 ~ #4)

No.	Scenario	Description	Remark
1	Loss of all RCP Seal Cooling (Isolation)	Spurious isolation of seal injection header flow, AND Spurious Isolation of CCW flow to Thermal Barrier Heat Exchanger (TBHX)	RCP Seal Cooling Flow Isolation
2	Loss of all RCP Seal Cooling (Diversion)	Spurious opening of valves causing flow diversion away from seals, AND Spurious isolation of CCW flow to thermal barrier heat exchanger	RCP Seal Cooling Flow Diversion
3	Thermally Shocking RCP Seals (Cooling Loss & Re-Injection)	Loss of all seal cooling to any RCP(s) (#1, #2), AND Spurious re-initiation of seal cooling	Loss of RCP Seal Cooling (MSO #1 OR MSO #2) AND Re-Injection Seal Cooling
4	Catastrophic RCP Seal Failure (Cooling Loss & RCP Start)	Loss of all seal cooling to any RCP(s) (#1, #2), AND Fire prevents tripping, or spuriously starts, RCP(s)	Loss of RCP Seal Cooling (MSO #1 OR MSO #2) AND RCP Start

※ System: RCS, CCW / Function: RCS Inventory Ctrl.

2 MSO Analysis Method using FTA

2.2 Preparing Plant Common Fault Tree for MSO Scenarios

Example of Components List for MSO Scenario #1

Description	Equip. No.	Type	Function Code (Initial-Required)
RCP PP01A HP COOLER CW01A INLET VALVE	431-V-446	MOV	431-V-446 : OPEN-OPEN
RCP PP01B HP COOLER CW01B INLET VALVE	431-V-447	MOV	431-V-447 : OPEN-OPEN
RCP PP02A HP COOLER CW02A INLET VALVE	431-V-448	MOV	431-V-448 : OPEN-OPEN
RCP PP02B HP COOLER CW01B INLET VALVE	431-V-449	MOV	431-V-449 : OPEN-OPEN
RCP PP01A HP COOLER CW01A OUTLET VALVE	431-V-450	MOV	431-V-450 : OPEN-OPEN
RCP PP01B HP COOLER CW01B OUTLET VALVE	431-V-451	MOV	431-V-451 : OPEN-OPEN
RCP PP02A HP COOLER CW02A OUTLET VALVE	431-V-452	MOV	431-V-452 : OPEN-OPEN
RCP PP02B HP COOLER CW01B OUTLET VALVE	431-V-453	MOV	431-V-453 : OPEN-OPEN
CHARGING PUMP 1	451-M-01P	PP	451-M-01P : START-START
CHARGING PUMP 2	451-M-02P	PP	451-M-02P : STOP-START
AUXILIARY CHARGING PUMP	451-M-03P	PP	451-M-03P : STOP-START
SEAL INJECTION ISOLATION VALVE	451-V-231P	AOV	451-V-231P : OPEN-OPEN
SEAL INJECTION FLOW CONTROL VALVE	451-V-241	AOV	451-V-241 : OPEN-OPEN
SEAL INJECTION FLOW CONTROL VALVE	451-V-242	AOV	451-V-242 : OPEN-OPEN
SEAL INJECTION FLOW CONTROL VALVE	451-V-243	AOV	451-V-243 : OPEN-OPEN
SEAL INJECTION FLOW CONTROL VALVE	451-V-244	AOV	451-V-244 : OPEN-OPEN
SEAL INJECTION CNMT ISOLATION VALVE	451-V-255	MOV	451-V-255 : OPEN-OPEN
VOLUME CONTROL TANK DISCHARGE ISOLATION VALVE	451-V-501	MOV	451-V-501 : OPEN-OPEN
VOLUME CONTROL TANK DISCHARGE ISOLATION VALVE	451-V-504	MOV	451-V-504 : OPEN-OPEN
REFUELING WATER TANK TO ESF PUMP & FEED ISOLATION VALVE	451-V-530	MOV	451-V-530 : OPEN-OPEN
REFUELING WATER TANK TO ESF PUMP & FEED ISOLATION VALVE	451-V-532	AOV	451-V-532 : OPEN-OPEN
REFUELING WATER TANK TO CHARGING PUMP GRAVITY FEED ISOL. VALVE	451-V-534	MOV	451-V-534 : CLOSE-OPEN
REFUELING WATER TANK TO CHARGING PUMP GRAVITY FEED ISOL. VALVE	451-V-536	MOV	451-V-536 : CLOSE-OPEN
COMPONENT COOLING WATER PUMP 01PA	461-M-01PA	PP	461-M-01PA : START-START
COMPONENT COOLING WATER PUMP 02PA	461-M-02PA	PP	461-M-02PA : START-START
COMPONENT COOLING WATER PUMP 03PA	461-M-03PA	PP	461-M-03PA : STOP-START
CCW HEAT EXCHANGER 1A OUTLET ISOLATION VALVE	461-V-061	MOV	461-V-061 : OPEN-OPEN
CCW HEAT EXCHANGER 2A OUTLET ISOLATION VALVE	461-V-063	MOV	461-V-063 : OPEN-OPEN
CCW HEAT EXCHANGER 3A OUTLET ISOLATION VALVE	461-V-065	MOV	461-V-065 : CLOSE-OPEN
RCP COOLER CCW OUTLET CONTAINMENT ISOLATION VALVE	461-V-161	MOV	461-V-161 : OPEN-OPEN
RCP COOLER CCW INLET CONTAINMENT ISOLATION VALVE	461-V-162	MOV	461-V-162 : OPEN-OPEN
RCP COOLER CCW OUTLET CONTAINMENT ISOLATION VALVE	461-V-164	MOV	461-V-164 : OPEN-OPEN

2 MSO Analysis Method using FTA

2.2 Preparing Plant Common Fault Tree for MSO Scenarios

› Example of Components Combination for MSO Scenario #1

- **Components Combination: [{(1) AND (2)} OR (3) OR (4)] AND (5)**

(1) RWT Suction Path Isolation:

(451-V-530 Close OR 451-V-534 Close) AND (451-V-532 Close OR 451-V-536 Close)

(2) VCT Suction Path Isolation:

451-V-501 Close OR 451-V-504 Close

(3) Charging Pump Stop:

451-M-01P Stop AND 451-M-02P Stop AND 451-M-03P Stop

(4) Seal Injection Path Isolation:

451-V-231P Close OR 451-V-255 Close
OR (451-V-241 Close OR 431-V-446 Close OR 431-V-450 Close)
OR (451-V-242 Close OR 431-V-447 Close OR 431-V-451 Close)
OR (451-V-243 Close OR 431-V-448 Close OR 431-V-452 Close)
OR (451-V-244 Close OR 431-V-449 Close OR 431-V-453 Close)

(5) CCW Isolation:

(461-M-01PA Stop AND 461-M-02PA Stop AND 461-M-03PA Stop)
OR (461-V-061 Close AND 461-V-063 Close AND 461-V-065 Close)
OR (461-V-162 Close OR 461-V-161 Close OR 461-V-164 Close)

2

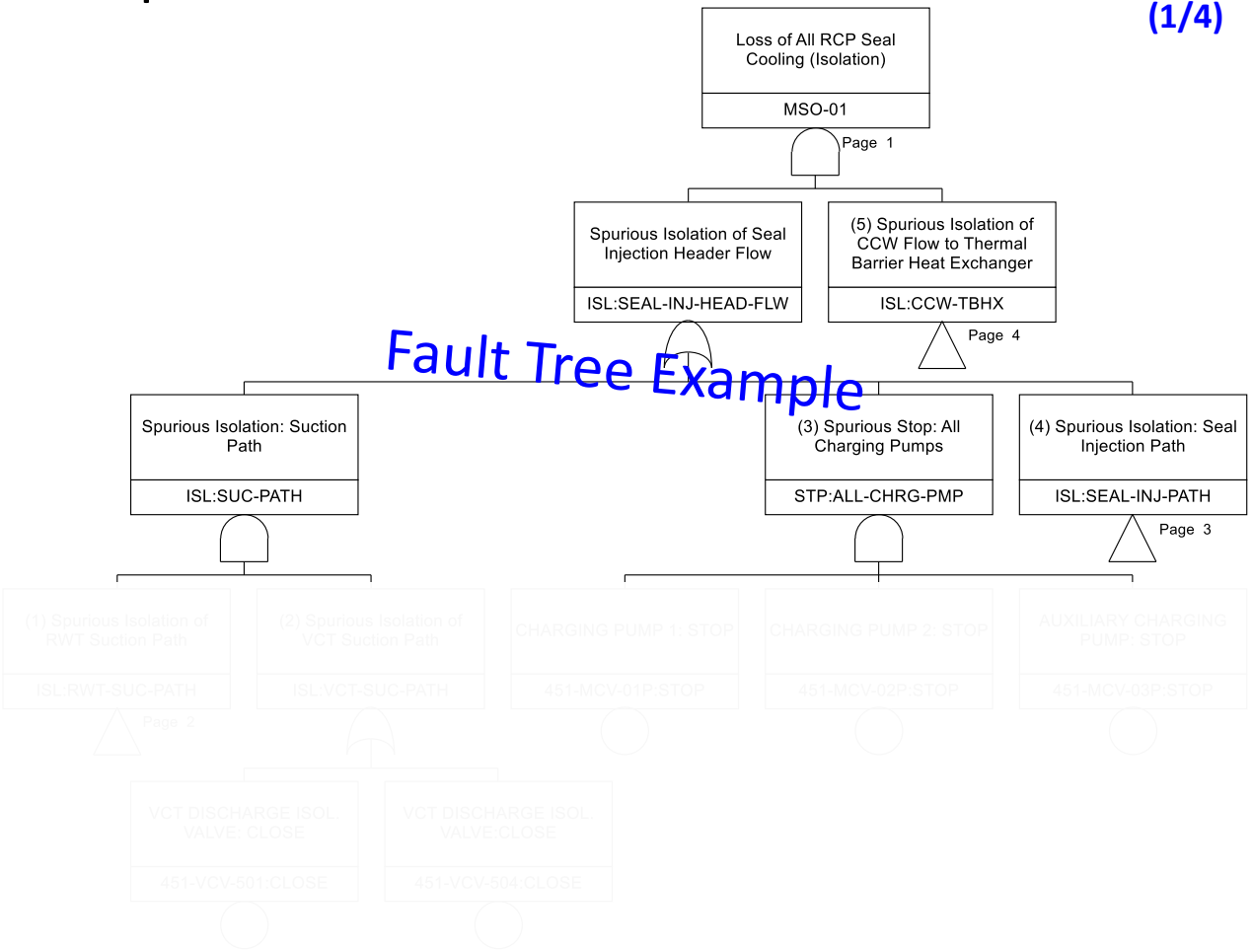
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2.2 Preparing Plant Common Fault Tree for MSO Scenarios

F.T. Example of MSO Scenario #1

(1/4)



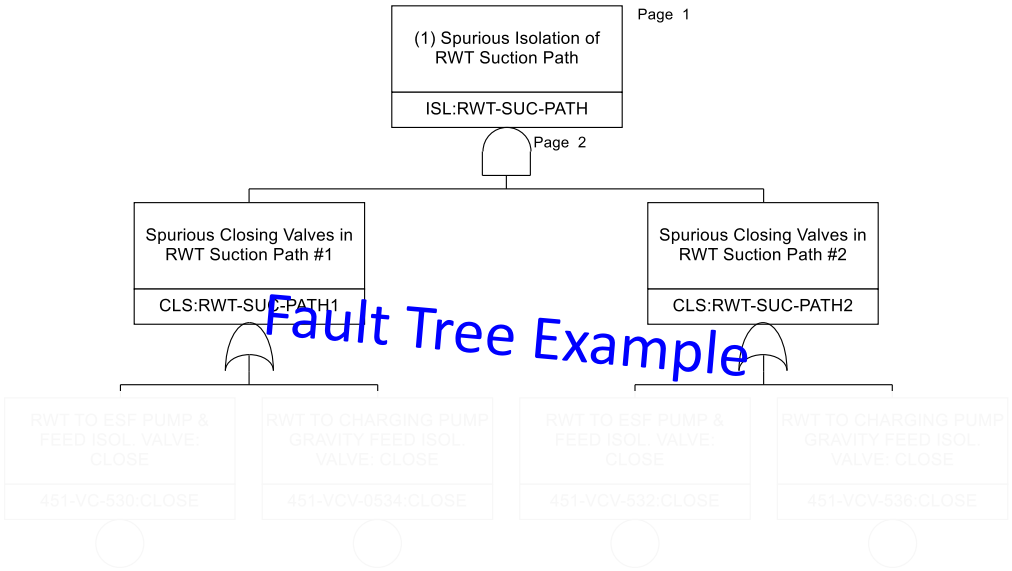
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A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.2 Preparing Plant Common Fault Tree for MSO Scenarios

F.T. Example of MSO Scenario #1 (cont.)

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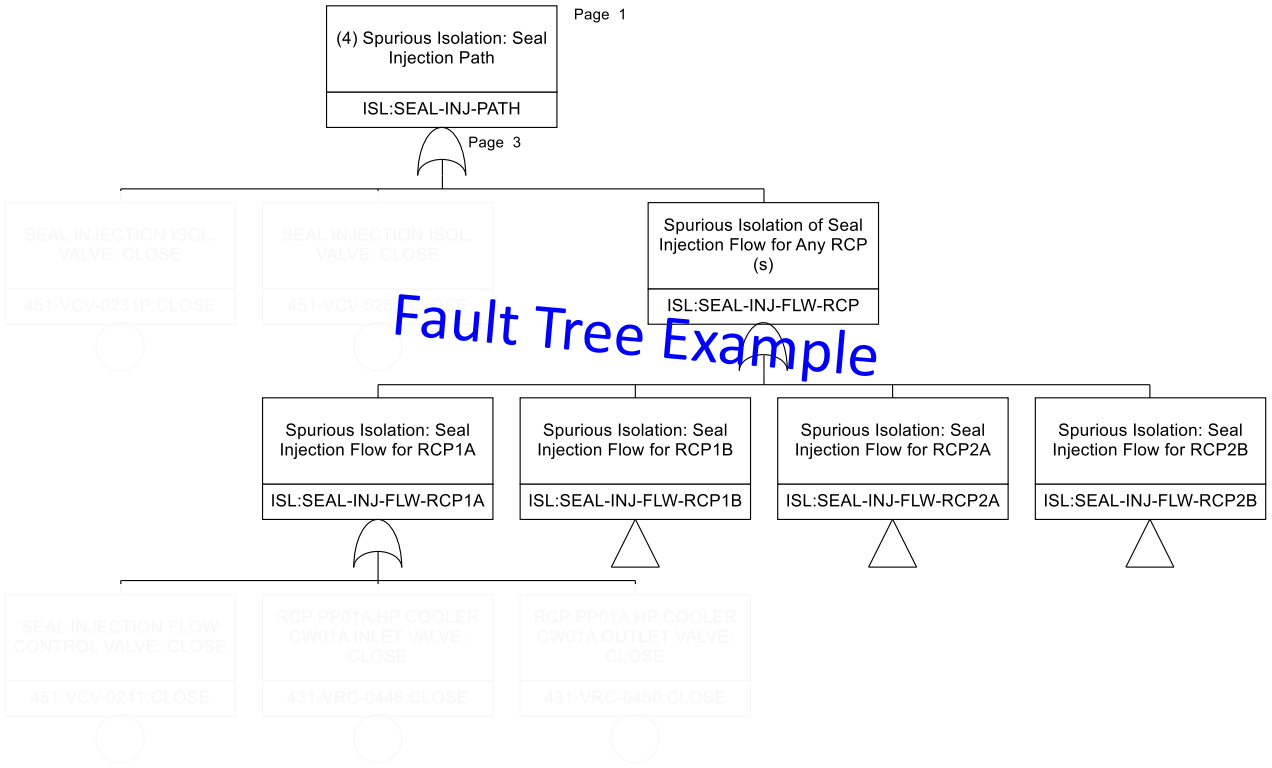
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2.2 Preparing Plant Common Fault Tree for MSO Scenarios

F.T. Example of MSO Scenario #1 (cont.)

(3/4)



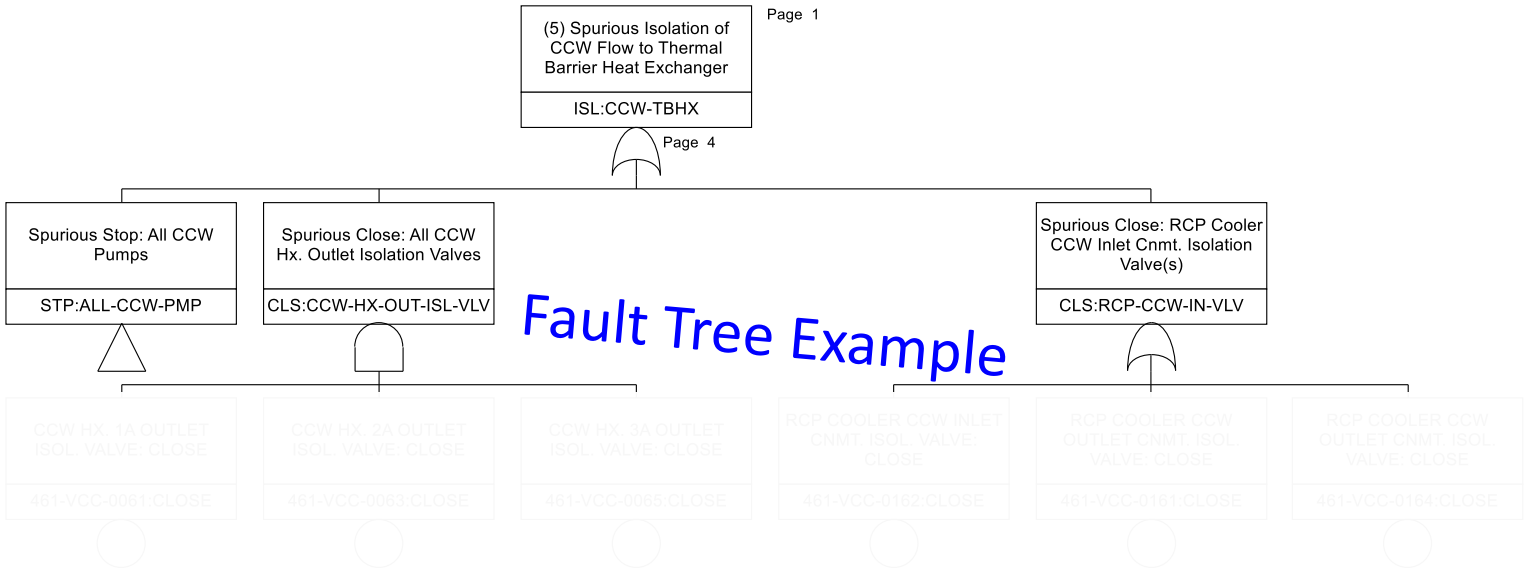
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A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.2 Preparing Plant Common Fault Tree for MSO Scenarios

F.T. Example of MSO Scenario #1 (cont.)

(4/4)

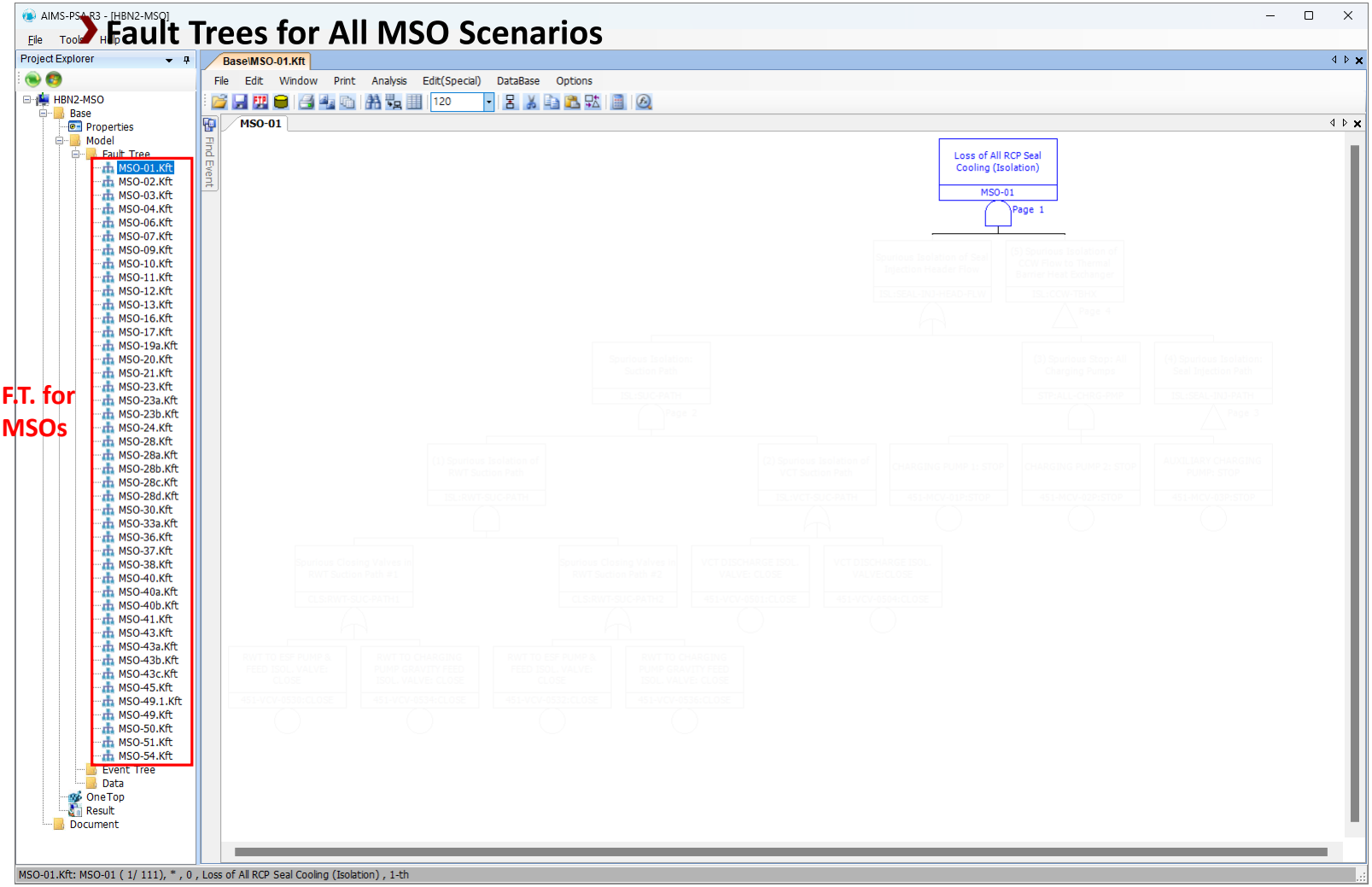


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2.2 Preparing Plant Common Fault Tree for MSO Scenarios

❯ Fault Trees for All MSO Scenarios

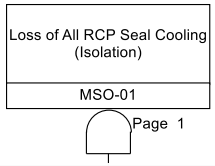


2 MSO Analysis Method using FTA

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.2 Preparing Plant Common Fault Tree for MSO Scenarios

› **Common F.T. for Plant Specific MSO Scenario #m**



Common Fault Tree for MSO Scenario #m

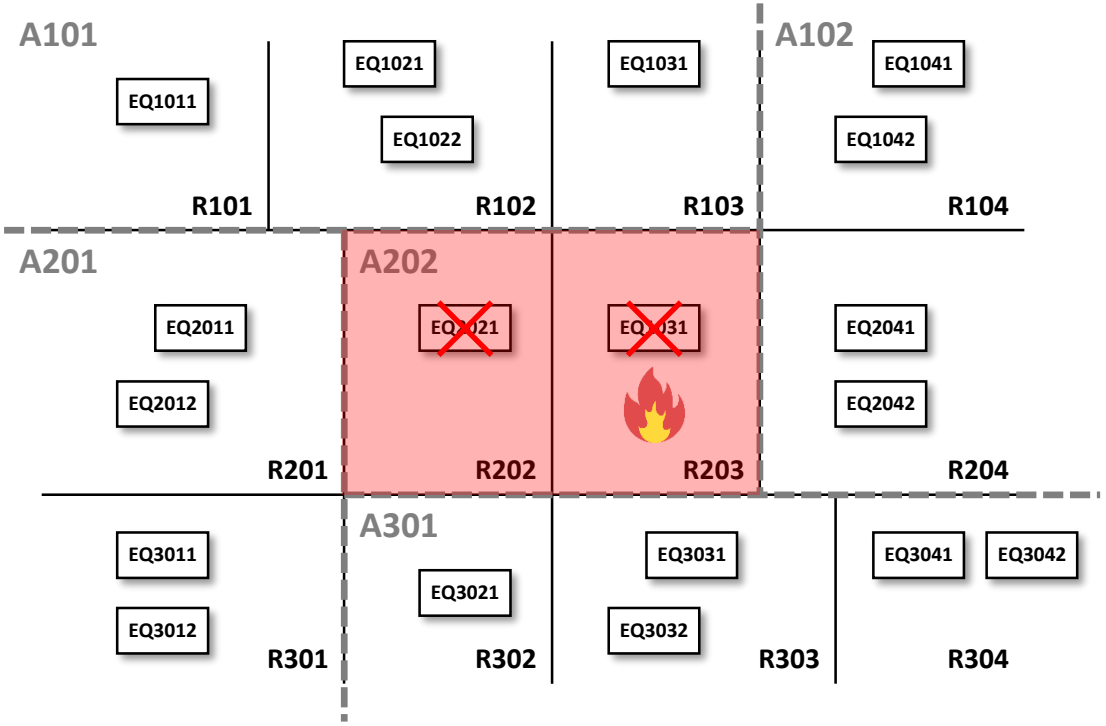
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2.3 Identifying Fire Affected Components & Cables for each Fire Area

Components Affected by Fire in Area

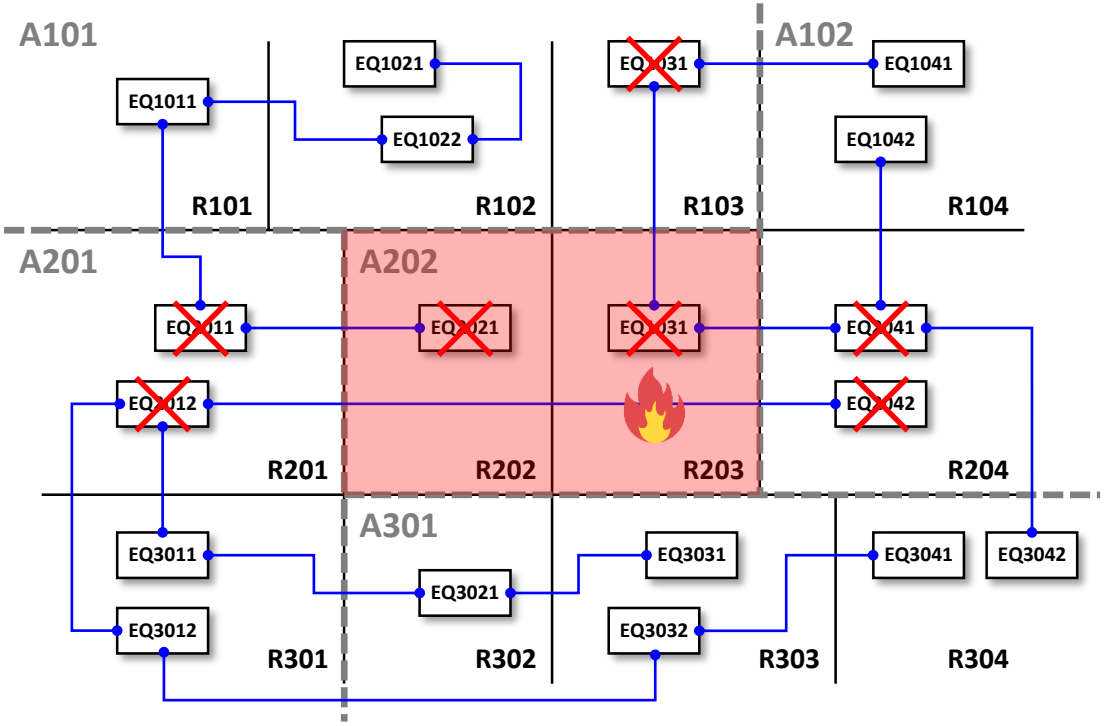


2 MSO Analysis Method using FTA

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.3 Identifying Fire Affected Components & Cables for each Fire Area

Components Affected by Cable Routing in Area

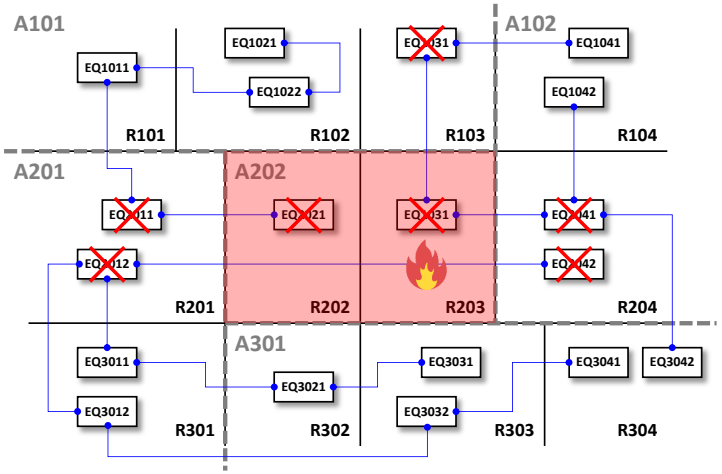


2 MSO Analysis Method using FTA

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.3 Identifying Fire Affected Components & Cables for each Fire Area

Equip. Function Code to Basic Event in F.T.



Fire Affected Components/Cables

Fire Affected Cable List in Area

MSO ID	Area ID	Cable No.
MSO-01	3-000-RCB	3431CRC25B
MSO-01	3-000-RCB	3431CRC25D
MSO-01	3-000-RCB	3431CRC26B
MSO-01	3-000-RCB	3431CRC26D
MSO-01	3-000-RCB	3431CRC27B
MSO-01	3-000-RCB	3431CRC27D
MSO-01	3-000-RCB	3431CRC28B
MSO-01	3-000-RCB	3431CRC28D
MSO-01	3-000-RCB	3431CRC29B
MSO-01	3-000-RCB	3431CRC29D
MSO-01	3-000-RCB	3431CRC30B
MSO-01	3-000-RCB	3431CRC30D
MSO-01	3-000-RCB	3431CRC31B
MSO-01	3-000-RCB	3431CRC31D
MSO-01	3-000-RCB	3431CRC32B
MSO-01	3-000-RCB	3431CRC32D
MSO-01	3-000-RCB	3451CCV60A

2 MSO Analysis Method using FTA

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.3 Identifying Fire Affected Components & Cables for each Fire Area

› Equip. Function Code to Basic Event in F.T.

Equip. No. & Function Code List in Area (RCB) for MSO-01

MSO ID	Area ID	Equip. No.	Function Code	Normal Condition	Required Condition	Failed Condition
MSO-01	3-000-RCB	431-VRC-0446	431-VRC-0446 OPEN-OPEN	431-VRC-0446:OPEN	431-VRC-0446:OPEN	431-VRC-0446:CLOSE
MSO-01	3-000-RCB	431-VRC-0447	431-VRC-0447 OPEN-OPEN	431-VRC-0447:OPEN	431-VRC-0447:OPEN	431-VRC-0447:CLOSE
MSO-01	3-000-RCB	431-VRC-0448	431-VRC-0448 OPEN-OPEN	431-VRC-0448:OPEN	431-VRC-0448:OPEN	431-VRC-0448:CLOSE
MSO-01	3-000-RCB	431-VRC-0449	431-VRC-0449 OPEN-OPEN	431-VRC-0449:OPEN	431-VRC-0449:OPEN	431-VRC-0449:CLOSE
MSO-01	3-000-RCB	431-VRC-0450	431-VRC-0450 OPEN-OPEN	431-VRC-0450:OPEN	431-VRC-0450:OPEN	431-VRC-0450:CLOSE
MSO-01	3-000-RCB	431-VRC-0451	431-VRC-0451 OPEN-OPEN	431-VRC-0451:OPEN	431-VRC-0451:OPEN	431-VRC-0451:CLOSE
MSO-01	3-000-RCB	431-VRC-0452	431-VRC-0452 OPEN-OPEN	431-VRC-0452:OPEN	431-VRC-0452:OPEN	431-VRC-0452:CLOSE
MSO-01	3-000-RCB	431-VRC-0453	431-VRC-0453 OPEN-OPEN	431-VRC-0453:OPEN	431-VRC-0453:OPEN	431-VRC-0453:CLOSE
MSO-01	3-000-RCB	451-VCV-0241	451-VCV-0241 OPEN-OPEN	451-VCV-0241:OPEN	451-VCV-0241:OPEN	451-VCV-0241:CLOSE
MSO-01	3-000-RCB	451-VCV-0242	451-VCV-0242 OPEN-OPEN	451-VCV-0242:OPEN	451-VCV-0242:OPEN	451-VCV-0242:CLOSE
MSO-01	3-000-RCB	451-VCV-0243	451-VCV-0243 OPEN-OPEN	451-VCV-0243:OPEN	451-VCV-0243:OPEN	451-VCV-0243:CLOSE
MSO-01	3-000-RCB	451-VCV-0244	451-VCV-0244 OPEN-OPEN	451-VCV-0244:OPEN	451-VCV-0244:OPEN	451-VCV-0244:CLOSE
MSO-01	3-000-RCB	461-MCC-02PA	461-MCC-02PA STOP-START	461-MCC-02PA:STOP	461-MCC-02PA:START	461-MCC-02PA:STOP
MSO-01	3-000-RCB	461-MCC-03PA	461-MCC-03PA STOP-START	461-MCC-03PA:STOP	461-MCC-03PA:START	461-MCC-03PA:STOP
MSO-01	3-000-RCB	461-VCC-0065	461-VCC-0065 CLOSE-OPEN	461-VCC-0065:CLOSE	461-VCC-0065:OPEN	461-VCC-0065:CLOSE
MSO-01	3-000-RCB	461-VCC-0161	461-VCC-0161 OPEN-OPEN	461-VCC-0161:OPEN	461-VCC-0161:OPEN	461-VCC-0161:CLOSE

2

MSO Analysis Method using FTA

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.3 Identifying Fire Affected Components & Cables for each Fire Area

› Equip. Function Code to Basic Event in F.T.

Basic Event List in Area (RCB) for MSO-01

Area ID	Basic Event Name	Condition	Basic Event Description
3-000-RCB	431-VRC-0446:CLOSE	Failed	RCP PP01A HP COOLER CW01A INLET VALVE: CLOSE
3-000-RCB	431-VRC-0447:CLOSE	Failed	RCP PP01B HP COOLER CW01B INLET VALVE: CLOSE
3-000-RCB	431-VRC-0448:CLOSE	Failed	RCP PP02A HP COOLER CW02A INLET VALVE: CLOSE
3-000-RCB	431-VRC-0449:CLOSE	Failed	RCP PP02A HP COOLER CW02B INLET VALVE: CLOSE
3-000-RCB	431-VRC-0450:CLOSE	Failed	RCP PP01A HP COOLER CW01A OUTLET VALVE: CLOSE
3-000-RCB	431-VRC-0451:CLOSE	Failed	RCP PP01B HP COOLER CW01B OUTLET VALVE: CLOSE
3-000-RCB	431-VRC-0452:CLOSE	Failed	RCP PP02A HP COOLER CW02A OUTLET VALVE: CLOSE
3-000-RCB	431-VRC-0453:CLOSE	Failed	RCP PP02B HP COOLER CW02B OUTLET VALVE: CLOSE
3-000-RCB	451-VCV-0241:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	451-VCV-0242:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	451-VCV-0243:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	451-VCV-0244:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	461-MCC-02PA:STOP	Failed	CCW PUMP 02PA: STOP
3-000-RCB	461-MCC-03PA:STOP	Failed	CCW PUMP 03PA: STOP
3-000-RCB	461-VCC-0065:CLOSE	Failed	CCW HX. 3A OUTLET ISOL. VALVE: CLOSE
3-000-RCB	461-VCC-0161:CLOSE	Failed	RCP COOLER CCW OUTLET CNMT. ISOL. VALVE: CLOSE
3-000-RCB	451-VCV-0501:CLOSE	Required	VCT DISCHARGE ISOL. VALVE: CLOSE
3-000-RCB	451-VCV-0504:CLOSE	Required	VCT DISCHARGE ISOL. VALVE:CLOSE

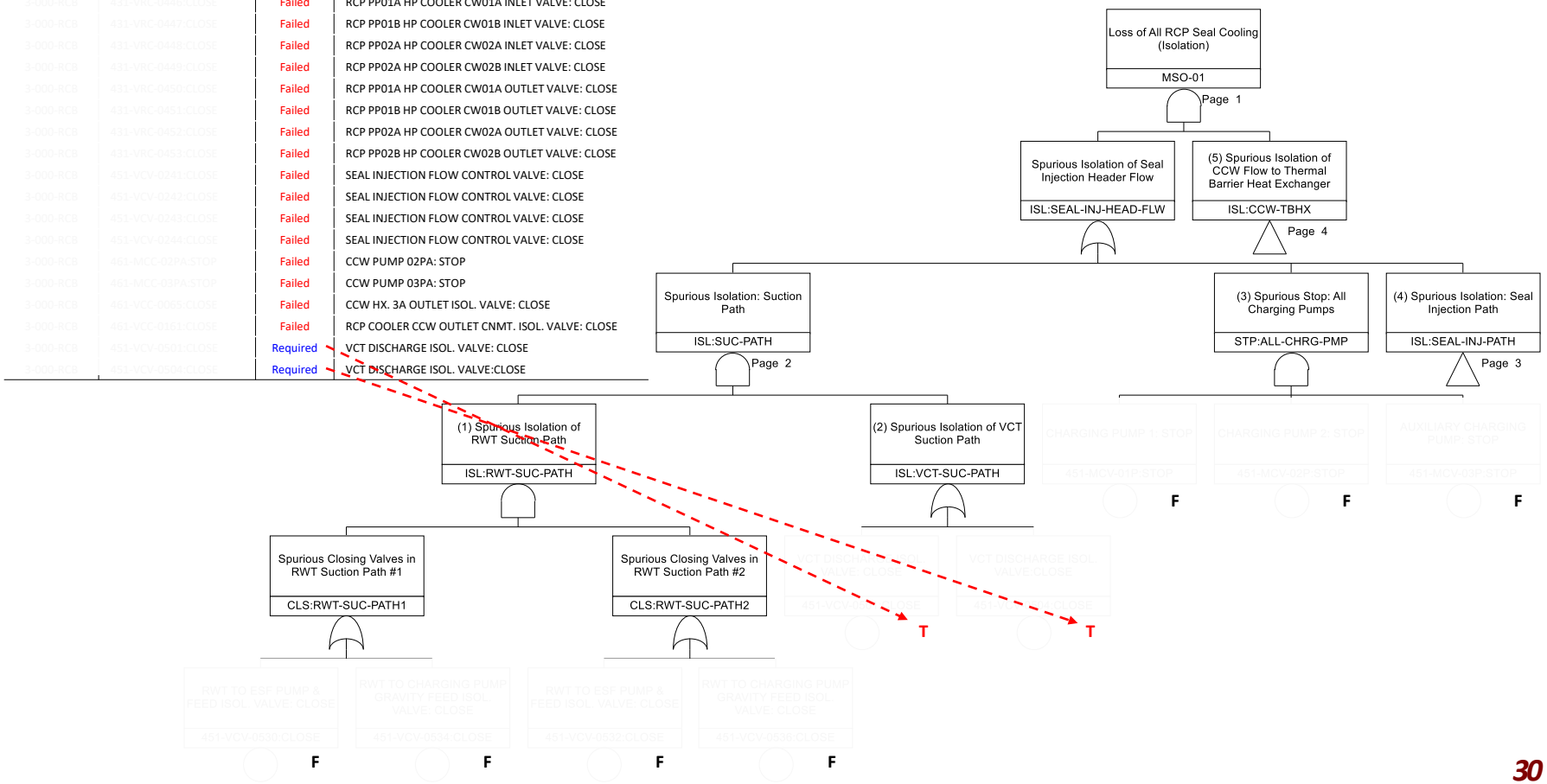
2 MSO Analysis Method using FTA

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.4 Generating Area Specific Fault Tree applied the Components/Cables

Area Specific F.T. for MSO #m

Area ID	Basic Event Name	Condition	Basic Event Description
3-000-RCB	431-VRC-0446:CLOSE	Failed	RCP PP01A HP COOLER CW01A INLET VALVE: CLOSE
3-000-RCB	431-VRC-0447:CLOSE	Failed	RCP PP01B HP COOLER CW01B INLET VALVE: CLOSE
3-000-RCB	431-VRC-0448:CLOSE	Failed	RCP PP02A HP COOLER CW02A INLET VALVE: CLOSE
3-000-RCB	431-VRC-0449:CLOSE	Failed	RCP PP02A HP COOLER CW02B INLET VALVE: CLOSE
3-000-RCB	431-VRC-0450:CLOSE	Failed	RCP PP01A HP COOLER CW01A OUTLET VALVE: CLOSE
3-000-RCB	431-VRC-0451:CLOSE	Failed	RCP PP01B HP COOLER CW01B OUTLET VALVE: CLOSE
3-000-RCB	431-VRC-0452:CLOSE	Failed	RCP PP02A HP COOLER CW02A OUTLET VALVE: CLOSE
3-000-RCB	431-VRC-0453:CLOSE	Failed	RCP PP02B HP COOLER CW02B OUTLET VALVE: CLOSE
3-000-RCB	451-VCV-0241:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	451-VCV-0242:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	451-VCV-0243:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	451-VCV-0244:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	461-MCC-02PA:STOP	Failed	CCW PUMP 02PA: STOP
3-000-RCB	461-MCC-03PA:STOP	Failed	CCW PUMP 03PA: STOP
3-000-RCB	461-VCC-0065:CLOSE	Failed	CCW HX. 3A OUTLET ISOL. VALVE: CLOSE
3-000-RCB	461-VCC-0161:CLOSE	Failed	RCP COOLER CCW OUTLET CNMT. ISOL. VALVE: CLOSE
3-000-RCB	451-VCV-0501:CLOSE	Required	VCT DISCHARGE ISOL. VALVE: CLOSE
3-000-RCB	451-VCV-0504:CLOSE	Required	VCT DISCHARGE ISOL. VALVE:CLOSE



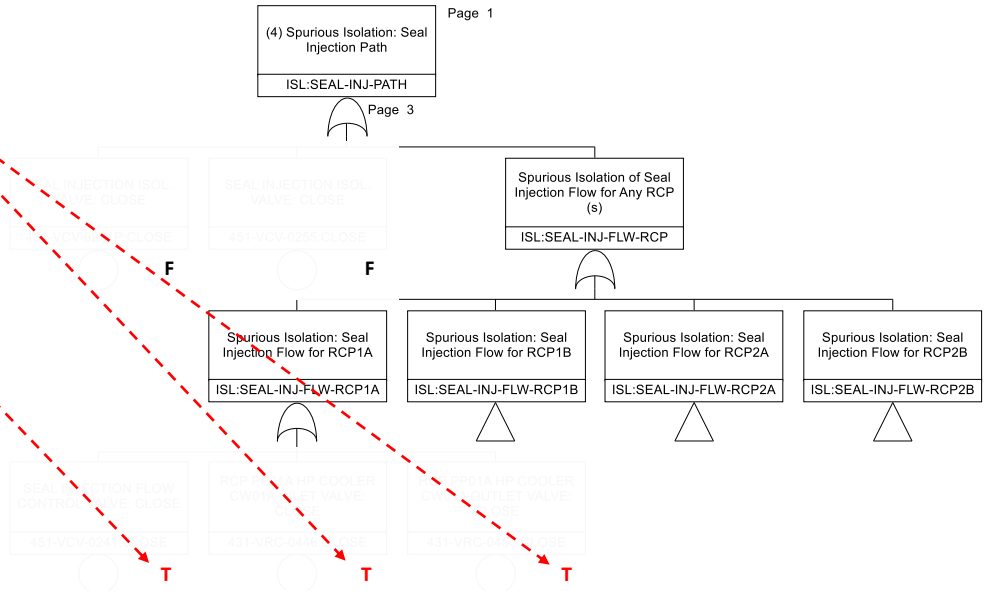
2 MSO Analysis Method using FTA

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.4 Generating Area Specific Fault Tree applied the Components/Cables

› Area Specific F.T. for MSO #m

Area ID	Basic Event Name	Condition	Basic Event Description
3-000-RCB	431-VRC-0446:CLOSE	Failed	RCP PP01A HP COOLER CW01A INLET VALVE: CLOSE
3-000-RCB	431-VRC-0447:CLOSE	Failed	RCP PP01B HP COOLER CW01B INLET VALVE: CLOSE
3-000-RCB	431-VRC-0448:CLOSE	Failed	RCP PP02A HP COOLER CW02A INLET VALVE: CLOSE
3-000-RCB	431-VRC-0449:CLOSE	Failed	RCP PP02A HP COOLER CW02B INLET VALVE: CLOSE
3-000-RCB	431-VRC-0450:CLOSE	Failed	RCP PP01A HP COOLER CW01A OUTLET VALVE: CLOSE
3-000-RCB	431-VRC-0451:CLOSE	Failed	RCP PP01B HP COOLER CW01B OUTLET VALVE: CLOSE
3-000-RCB	431-VRC-0452:CLOSE	Failed	RCP PP02A HP COOLER CW02A OUTLET VALVE: CLOSE
3-000-RCB	431-VRC-0453:CLOSE	Failed	RCP PP02B HP COOLER CW02B OUTLET VALVE: CLOSE
3-000-RCB	451-VCV-0241:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	451-VCV-0242:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	451-VCV-0243:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	451-VCV-0244:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	461-MCC-02PA:STOP	Failed	CCW PUMP 02PA: STOP
3-000-RCB	461-MCC-03PA:STOP	Failed	CCW PUMP 03PA: STOP
3-000-RCB	461-VCC-0065:CLOSE	Failed	CCW HX. 3A OUTLET ISOL. VALVE: CLOSE
3-000-RCB	461-VCV-0161:CLOSE	Failed	RCP COOLER CCW OUTLET CNMT. ISOL. VALVE: CLOSE
3-000-RCB	451-VCV-0501:CLOSE	Required	VCT DISCHARGE ISOL. VALVE: CLOSE
3-000-RCB	451-VCV-0504:CLOSE	Required	VCT DISCHARGE ISOL. VALVE:CLOSE



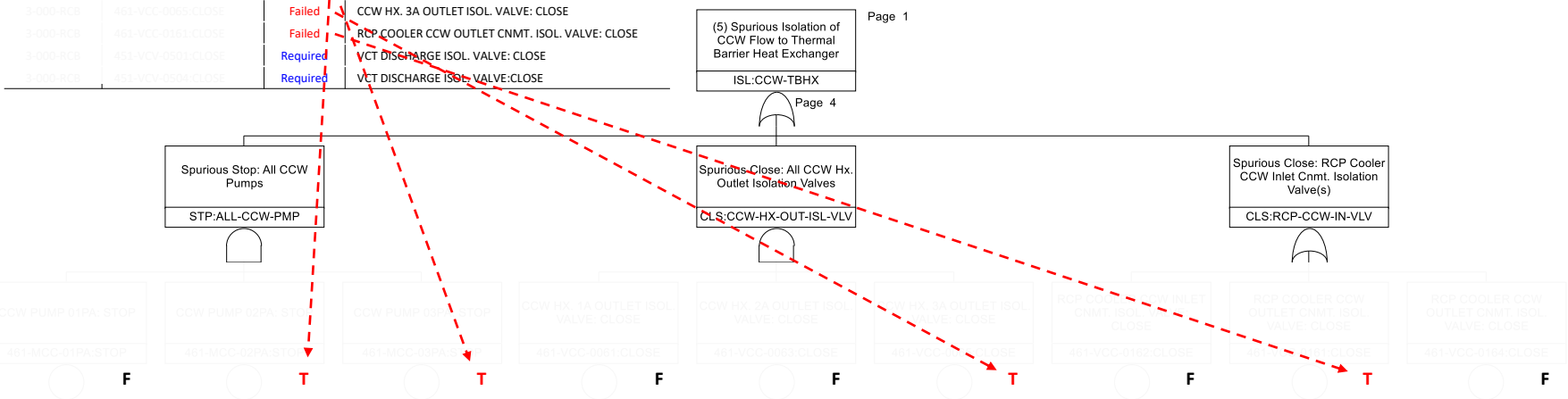
2 MSO Analysis Method using FTA

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.4 Generating Area Specific Fault Tree applied the Components/Cables

› Area Specific F.T. for MSO #m

Area ID	Basic Event Name	Condition	Basic Event Description
3-000-RCB	431-VRC-0446:CLOSE	Failed	RCP PP01A HP COOLER CW01A INLET VALVE: CLOSE
3-000-RCB	431-VRC-0447:CLOSE	Failed	RCP PP01B HP COOLER CW01B INLET VALVE: CLOSE
3-000-RCB	431-VRC-0448:CLOSE	Failed	RCP PP02A HP COOLER CW02A INLET VALVE: CLOSE
3-000-RCB	431-VRC-0449:CLOSE	Failed	RCP PP02A HP COOLER CW02B INLET VALVE: CLOSE
3-000-RCB	431-VRC-0450:CLOSE	Failed	RCP PP01A HP COOLER CW01A OUTLET VALVE: CLOSE
3-000-RCB	431-VRC-0451:CLOSE	Failed	RCP PP01B HP COOLER CW01B OUTLET VALVE: CLOSE
3-000-RCB	431-VRC-0452:CLOSE	Failed	RCP PP02A HP COOLER CW02A OUTLET VALVE: CLOSE
3-000-RCB	431-VRC-0453:CLOSE	Failed	RCP PP02B HP COOLER CW02B OUTLET VALVE: CLOSE
3-000-RCB	451-VCV-0241:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	451-VCV-0242:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	451-VCV-0243:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	451-VCV-0244:CLOSE	Failed	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
3-000-RCB	461-MCC-02PA:STOP	Failed	CCW PUMP 02PA: STOP
3-000-RCB	461-MCC-03PA:STOP	Failed	CCW PUMP 03PA: STOP
3-000-RCB	461-VCC-0065:CLOSE	Failed	CCW HX. 3A OUTLET ISOL. VALVE: CLOSE
3-000-RCB	461-VCC-0161:CLOSE	Failed	RCP COOLER CCW OUTLET CNMT. ISOL. VALVE: CLOSE
3-000-RCB	451-VCV-0501:CLOSE	Required	VCT DISCHARGE ISOL. VALVE: CLOSE
3-000-RCB	451-VCV-0504:CLOSE	Required	VCT DISCHARGE ISOL. VALVE:CLOSE



2

MSO Analysis Method using FTA

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

2.5 Assessment for each Fire Area

❯ Expected MSO Analysis Results for Area

	MSO #1	MSO #2	MSO #3	MSO #4	MSO #5	MSO #6	MSO #7	•••	MSO #m
Fire Area #1	-	-	O	-	-	-	O		
Fire Area #2	-	O	-	-	O	-	-		
Fire Area #3	-	N/A	-	N/A	-	N/A	-		
Fire Area #4	-	-	O	-	O	-	-		
Fire Area #5	-	-	-	-	-	-	-		
• • •									
Fire Area #n									

※ 'N/A': No Cable related MSO, '-': MSO Not Occurred, 'O': MSO Occurred

3. Application Example

3 Application Example

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

▪ Assessment Result applying the Method

Fire Area	MSO #1	MSO #2	MSO #3	MSO #4
RCB	Occur	Occur	Occur	Occur
PAB General A	Occur	Occur	Occur	Occur
PAB General B	Occur	Occur	Occur	Occur
HPSI Pump Room A	OK	-	OK	OK
HPSI Pump Room B	OK	-	OK	OK
Battery Room A	OK	-	OK	OK
Battery Room B	OK	-	OK	OK
AFW Pump Room A	OK	Occur	Occur	OK
AFW Pump Room B	OK	OK	OK	OK
CC Pump Room A	OK	Occur	Occur	OK
CC Pump Room B	OK	OK	OK	OK
Cable Spreading A	Occur	Occur	Occur	Occur
Cable Spreading B	Occur	Occur	Occur	Occur
Remote Shutdown A	OK	Occur	Occur	OK
Remote Shutdown B	OK	OK	OK	OK
Elec. Equip. Room A	Occur	Occur	Occur	Occur
Elec. Equip. Room B	Occur	Occur	Occur	Occur
Computer Room	OK	Occur	Occur	OK
Control Room	Occur	Occur	Occur	Occur
SAB General Area	Occur	Occur	Occur	Occur

(Total 282 Areas, ~1000 Cases Analyzed)

3 Application Example

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

▪ Assessment Result applying the Method (cont.)

› FTA Result for MSO #1 in RCB – Cut-Set List

Cut-Set No.	Estimated Fault Tree: FaultTree() ⇒ Cut-Set List-Up							the Object (Gate/Event) Info.	
(iCS)	x	y	z	Seq. No.	Up Obj.	Type	Logic	Obj. Name	Obj. Description
								Area ID: 3-000-RCB	(Reactor Containment Building)
1	0	0	0	**1**	-	Top	T	MSO-01	Loss of All RCP Seal Cooling (Isolation)
1	1	1	1	**79**	1	+	T	ISLSEAL-INJ-HEAD-FLW	Spurious Isolation of Seal Injection Header Flow
1	2	3	3	**82**	79	+	T	ISLSEAL-INJ-PATH	(4) Spurious Isolation: Seal Injection Path
1	3	3	8	**96**	82	+	T	ISLSEAL-INJ-FLW-RCP	purious Isolation of Seal Injection Flow for Any RCP(s
1	4	1	5	**87**	96	+	T	ISLSEAL-INJ-FLW-RCP1A	Spurious Isolation: Seal Injection Flow for RCP1A
1	5	1	5	**54**	87	B	T	451-VCV-0241-CLOSE	SEAL INJECTION FLOW CONTROL VALVE: CLOSE
2	0	0	0	**1**	-	Top	T	MSO-01	Loss of All RCP Seal Cooling (Isolation)
2	1	1	1	**79**	1	+	T	ISLSEAL-INJ-HEAD-FLW	Spurious Isolation of Seal Injection Header Flow
2	2	3	3	**82**	79	+	T	ISLSEAL-INJ-PATH	(4) Spurious Isolation: Seal Injection Path
2	3	3	8	**96**	82	+	T	ISLSEAL-INJ-FLW-RCP	purious Isolation of Seal Injection Flow for Any RCP(s
2	4	1	5	**87**	96	+	T	ISLSEAL-INJ-FLW-RCP1A	Spurious Isolation: Seal Injection Flow for RCP1A
2	5	2	6	**55**	87	B	T	431-VRC-0446-CLOSE	RCP PP01A HP COOLER CW01A INLET VALVE: CLOSE
3	0	0	0	**1**	-	Top	T	MSO-01	Loss of All RCP Seal Cooling (Isolation)
3	1	1	1	**79**	1	+	T	ISLSEAL-INJ-HEAD-FLW	Spurious Isolation of Seal Injection Header Flow
3	2	3	3	**82**	79	+	T	ISLSEAL-INJ-PATH	(4) Spurious Isolation: Seal Injection Path
3	3	3	8	**96**	82	+	T	ISLSEAL-INJ-FLW-RCP	purious Isolation of Seal Injection Flow for Any RCP(s
3	4	1	5	**87**	96	+	T	ISLSEAL-INJ-FLW-RCP1A	Spurious Isolation: Seal Injection Flow for RCP1A
3	5	3	7	**59**	87	B	T	431-VRC-0450-CLOSE	RCP PP01A HP COOLER CW01A OUTLET VALVE: CLOSE

3

Application Example

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

▪ Assessment Result applying the Method (cont.)

› FTA Result for MSO #1 in RCB – Summary

No. (iBE)	No. of B.E. in F.T.	No. of B.E. in Cut-Set	the B.E. Name	the B.E. Description	Cable No. related B.E. (= Function Code) #1	#2	#3	#4	•••
	(16 EA)	(13 EA)							
1	1	1	451-VCV-0241:CLOSE	SEAL INJECTION FLOW CONTROL VALVE: CLOSE	3451CCV60A	3451CCV60D	3451CCV60E		
2	1	1	431-VRC-0446:CLOSE	RCP PP01A HP COOLER CW01A INLET VALVE: CLOSE	3431CRC25B	3431CRC25D			
3	1	1	431-VRC-0450:CLOSE	RCP PP01A HP COOLER CW01A OUTLET VALVE: CLOSE	3431CRC29B	3431CRC29D			
4	1	1	451-VCV-0242:CLOSE	SEAL INJECTION FLOW CONTROL VALVE: CLOSE	3451CCV61A	3451CCV61D	3451CCV61E		
5	1	1	431-VRC-0447:CLOSE	RCP PP01B HP COOLER CW01B INLET VALVE: CLOSE	3431CRC26B	3431CRC26D			
6	1	1	431-VRC-0451:CLOSE	RCP PP01B HP COOLER CW01B OUTLET VALVE: CLOSE	3431CRC30B	3431CRC30D			
7	1	1	451-VCV-0243:CLOSE	SEAL INJECTION FLOW CONTROL VALVE: CLOSE	3451CCV62A	3451CCV62D	3451CCV62E		
8	1	1	431-VRC-0448:CLOSE	RCP PP02A HP COOLER CW02A INLET VALVE: CLOSE	3431CRC27B	3431CRC27D			
9	1	1	431-VRC-0452:CLOSE	RCP PP02A HP COOLER CW02A OUTLET VALVE: CLOSE	3431CRC31B	3431CRC31D			
10	1	1	451-VCV-0244:CLOSE	SEAL INJECTION FLOW CONTROL VALVE: CLOSE	3451CCV63A	3451CCV63D	3451CCV63E		
11	1	1	431-VRC-0449:CLOSE	RCP PP02A HP COOLER CW02B INLET VALVE: CLOSE	3431CRC28B	3431CRC28D			
12	1	1	431-VRC-0453:CLOSE	RCP PP02B HP COOLER CW02B OUTLET VALVE: CLOSE	3431CRC32B	3431CRC32D			
13	1	0	461-MCC-02PA:STOP	CCW PUMP 02PA: STOP					
14	1	0	461-MCC-03PA:STOP	CCW PUMP 03PA: STOP					
15	1	0	461-VCC-0065:CLOSE	CCW HX. 3A OUTLET ISOL. VALVE: CLOSE					
16	1	1	461-VCC-0161:CLOSE	RCP COOLER CCW OUTLET CNMT. ISOL. VALVE: CLOSE	3461CCC19B	3461CCC19E	3461CCC19H		

4. Conclusion & Future Work

4 Conclusion & Future Work

❖ MSO Analysis Method Using FTA

- Selecting Plant Specific MSO Scenario
- Preparing Fault Tree for the MSO Scenarios (no. of m)
- Identifying Fire Affected Cables for each Area (no. of n)
- Generating Area Specific F.T. applied the Cables
- Logical Operation of the Area Specific F.T.
- Assessment for each Fire Area (m x n times)

❖ SSA Reflecting MSO Analysis Result

- Generating Area Specific FT for SSA reflecting MSO Analysis Result

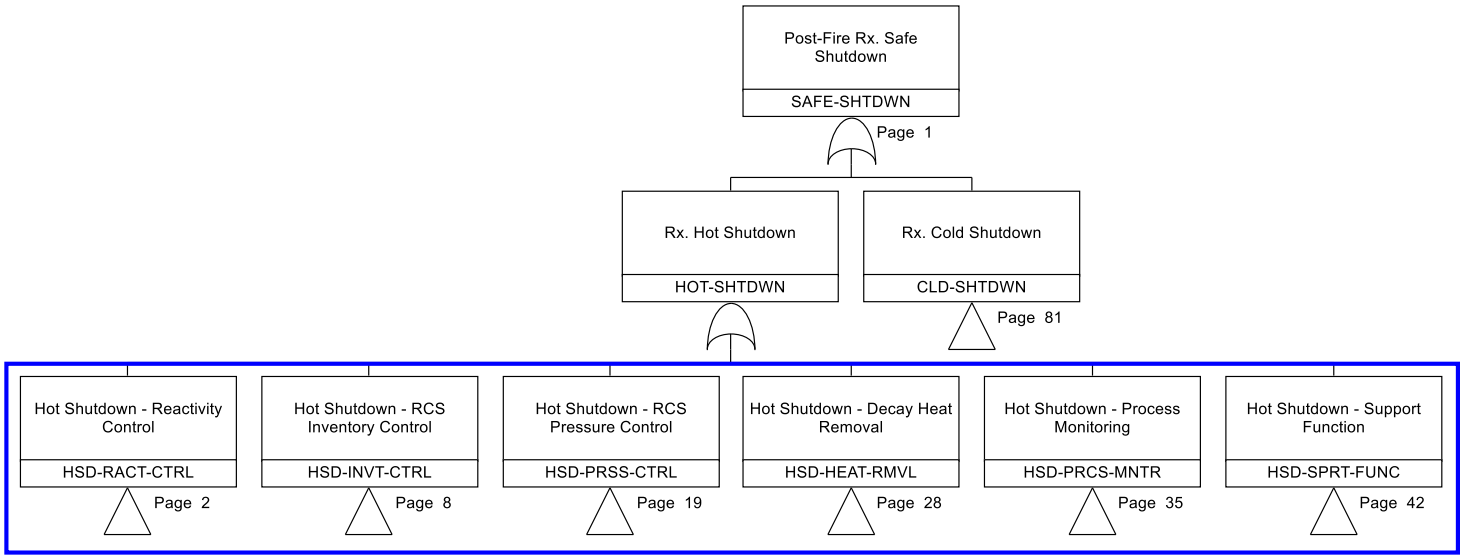
❖ Test on FHA/SSA Project

4 Conclusion & Future Work

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

❖ SSA Reflecting MSO Analysis Result

› Generating Plant Specific F.T. for SSA reflecting MSO



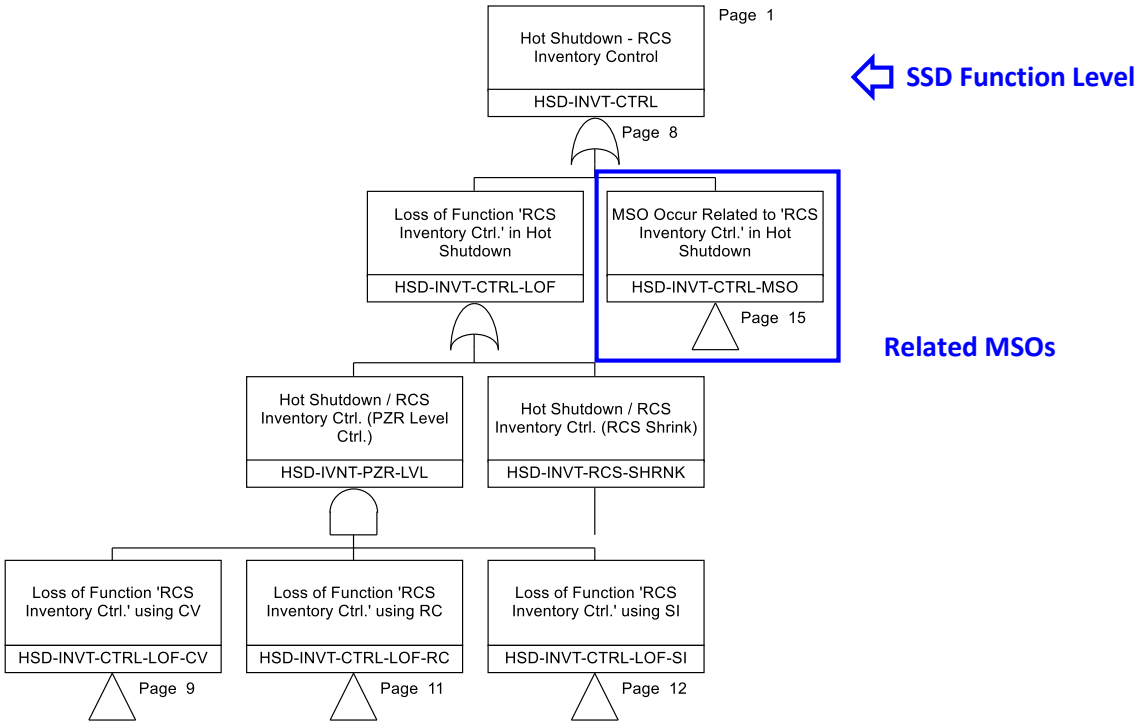
Safe-Shutdown Function

4 Conclusion & Future Work

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

❖ SSA Reflecting MSO Analysis Result

› Generating Plant Specific F.T. for SSA reflecting MSO

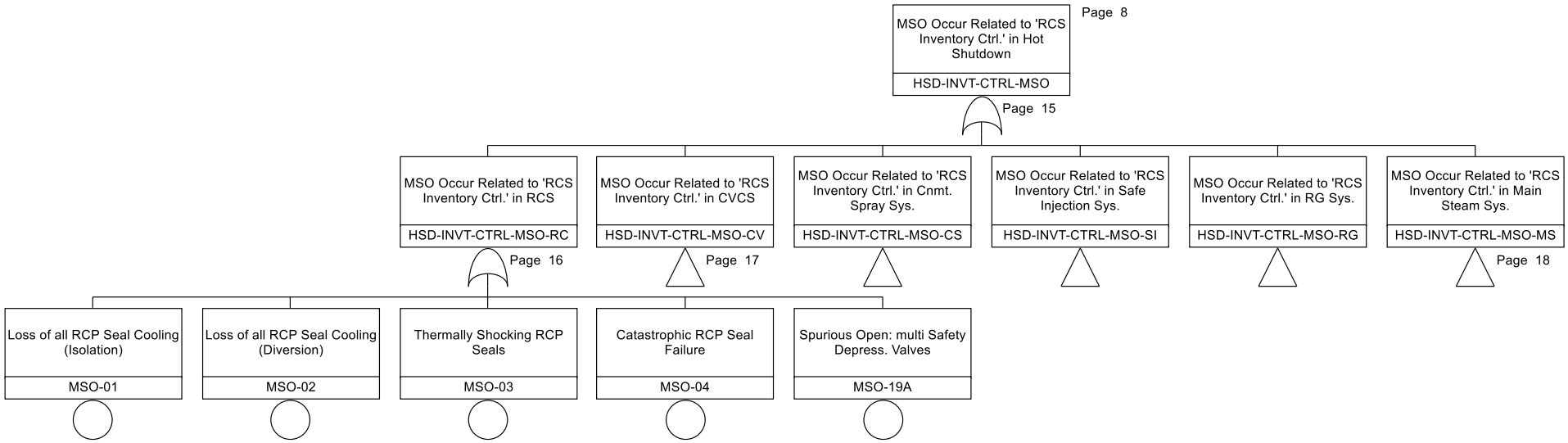


4 Conclusion & Future Work

A Method for Analyzing Multiple Spurious Operations in Nuclear Power Plant Using Fault Tree Analysis

❖ SSA Reflecting MSO Analysis Result

› Generating Plant Specific F.T. for SSA reflecting MSO



MSOs Related 'RCS Inventory Ctrl.' for Rx. Hot Shutdown

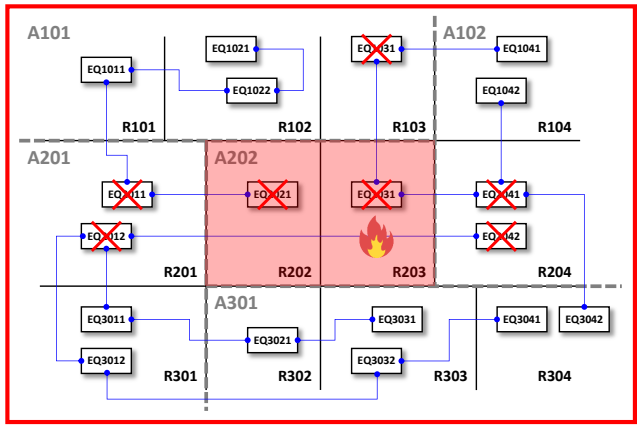
4 Conclusion & Future Work

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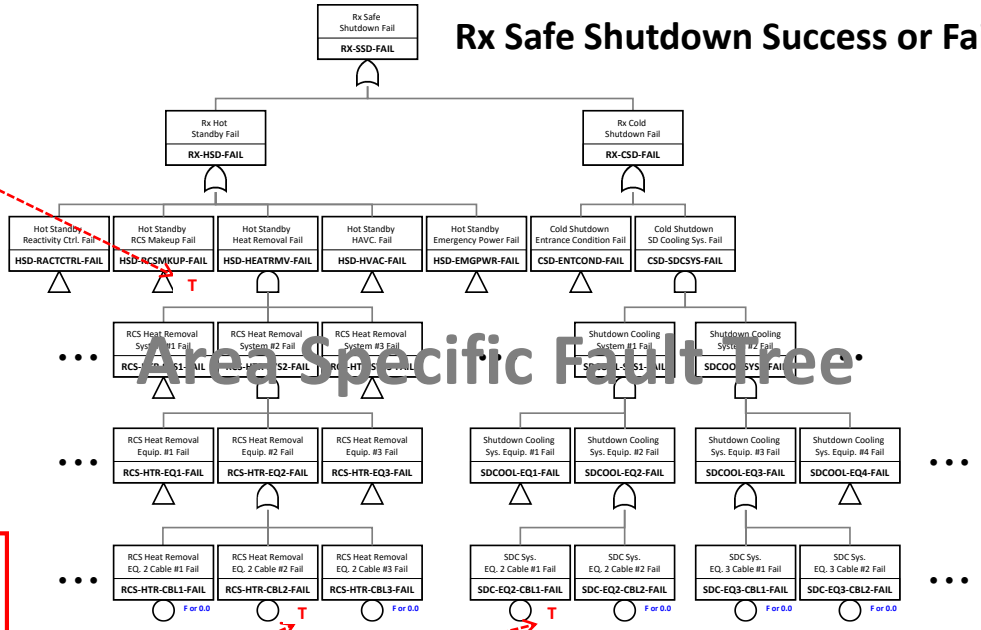
❖ SSA Reflecting MSO Analysis Result

	MSO #1	MSO #2	MSO #3	MSO #4	MSO #5	MSO #6	MSO #7	•••	MSO #m
Fire Area #1	-	-	O	-	-	-	O		
Fire Area #2	-	O	-	-	O	-	-		
Fire Area #3	-	N/A	-	N/A	-	N/A	-		
Fire Area #4	-	-	O	-	O	-	-		
Fire Area #5	-	-	-	-	-	-	-		
⋮									
Fire Area #n									

MSO Analysis Result



Fire Affected Cables in Area



Rx Safe Shutdown Success or Fail?

Area Specific Fault Tree

Q & A

THANK YOU

This Study is a result of project "**Development of a computer program to support the fire protection safety issues and regulatory activities**" (**R&D Project No. RS-2022-KN067510**) supported by Korea Foundation of Nuclear Safety (KOFONS) grant funded by Korean Government (Nuclear Safety and Security Commission).

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