Development of Standardized Probabilistic Risk Assessment Models for Shutdown Operations Integrated in SPAR Level 1 Model

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Discussion Topics

- SPAR PRA Models
- Shutdown PRA Model History
- Methodology
- Initiating Events
- SPAR Human Reliability Analysis
- SD Modeling Issues

SPAR PRA Models

- **SPAR : Simplified Plant Analysis Risk**
- **SAPHIRE Code: System Analysis Programs for Hands-on Integrated Reliability Evaluation**
- **Small Event Tree – Large Fault Tree**
- **Failure Data Module**
- **Human Reliability Calculator**
- **Common-Cause Failure Calculator**
- **Total 76 Level-1 Models**

Shutdown PRA Model History

NRC Study

First Low Power/Shutdown Studies - 1994

- **BWR: Grand Gulf Unit 1 (NUREG/CR-6144)**

  Five TS Operating Modes Divided into 7 POSs

  Only POS 5 (TS Mode 4 and 5 partial) Analyzed

- **PWR: Surry Unit 1 (NUREG/CR-6143)**

  Six Tech Spec (TS) Operating Modes Divided into 15 Plant Operating States (POS)

  Only Mid-Level Operating Mode Analyzed (POS 6; Mid-loop Operation)

History (Cont'd)

- **INL Developed Non-Integrated SD PRA Model with Level 1 (Stand Alone)**
- **Grand Gulf and Surry SD PRA Models Reproduced in IRRAS – Mid'90s**
- **Developed SD Template Models for BWR and PWR in ~2000**

  PWR – POSs 3 to 11 except POS 8 (Refueling)
- **Same Approach as NUREG Studies**
- **Matrix of four time windows versus POSs**
- **Shutdown Risk from Generic Shutdown**

Methodology

INL SD PRA Models - Current

- **Integrated within Level-1 SPAR models**
- **24 hrs After Reactor Trip**
- **Only RHR/SDC Cooling Tech Spec Modes**
  - **PWR: TS Modes 4, 5, and 6 Divided into 9 POSs**
  - **BWR: TS Modes 4 and 5 Divided into 6 POSs**
  - **Four Time Windows**
  - **Each POS Assigned to One of the Four Time Windows**
  - **Time Window Defines Time Available for Operator Response**

Methodology (Cont'd)

Plant operating state definitions and corresponding technical specification operating mode.

NUREG/ CR-6144 Plant Operating State	POS Description	Standard Technical Specification Mode (SPAR POS)	T. S. Mode Description
POS 1	Low power and reactor shutdown	1	Power Operation
POS 2	Cooldown with SGs from operating temperature to 345°F	3	Hot standby
POS 3	Cooldown with RHR from 345°F to 200°F)	4 (4E)[a]	Hot shutdown
POS 4	Cooldown with RHR (below ~200°F)	5 (5EF)	Cold shutdown
POS 5	Draining RCS to mid-loop	5 (5EF)	Cold shutdown
POS 6	Mid-loop operation	5 (5ER)	Cold shutdown
POS 7	Fill for refueling	5 (5ER)	Cold shutdown
POS 8	Refueling	6 (6)	Refueling
POS 9	Draining RCS to mid-loop after refueling	5 (5LR)	Cold shutdown
POS 10	Mid-loop operations after refueling	5 (5LR)	Cold shutdown
POS 11	Refilling RCS	5 (5LF)	Cold shutdown
POS 12	RCS heatup solid and draw bubble	5 (5LF)	Cold shutdown
POS 13	RCS heatup to 350°F	4 (4L)	Hot shutdown
POS 14	RCS heatup with SGs available (above 350°F)	2	Startup
POS 15	Startup and low power operations	1	Power operation

a. POS identifier in parenthesis is what is actually used in the LP/SD SPAR model. First character is T.S. mode (4, 5 or 6). Second character is time frame in relation to refueling (Early - before refueling; Late - after refueling). Third character is the status of the RCS inventory (Full RCS inventory, or Reduced RCS inventory).

Methodology (Cont'd)

Plant Operating State (POS) Defined Based on Availability of Components and Heat Generation Rate

Example: POS M4EFIO

Modes 4 (M4), 5 (M5), and 6 (M6)

- **Time Frame: Early (E), Refueling (X), Late (L)**
- **RCS Inventory: Full (F), Reduced (R), Cavity Flooded (X)**
- **RCS Pressure Boundary: Vented (V), Intact (I)**
- **Steam Generator Status: Blocked (B), Open (O)**

Methodology (Cont'd)

Time Window Definitions

Condition	TW 1	TW 2	TW 3	TW 4
POS		M4EFIO		
	M5ERIO	M5EFIO	M4LFIO	M6XCVB
	M5ERVB	M5LRIO	M5LFIO	
		M5LRVB		
Average Time to Boil-off (RHR is unavailable)	15 mins	30 mins	90 mins	> 3 hrs

Methodology (Cont'd)

Modeling Assumptions:

- **Success Criteria**
- **Time Spent in Various POS (Plant Configuration)**
- **Test and Maintenance**
- **Human Error Probabilities**
- **Definition of Core Damage**

INITIATING EVENTS

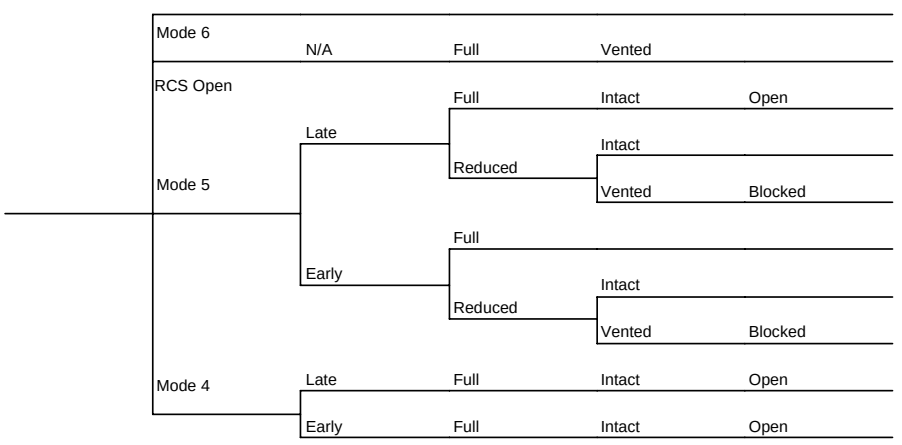
SD: Plant Operating States

POS-M4EFIO: Mode 4, Early, RCS Full, Intact, SG Available

- **IESD-ISOL : RHR Isolation**
- **IESD-LOI: Loss of Inventory**
- **IESD-LOAC: Loss of Vital AC Bus**
- **IESD-LOOP: Loss of Off-Site Power**
- **IESD-OD : Over Drain – Only Demand Based IE**
- **IESD-LORHR : Loss of RHR Cooling**

Event Trees

Plant Shutdown (Mode 4, 5 or 6)	Plant is in Mode	Mode Time Frame	RCS Inventory Status	RCS Integrity Status	RCS Loop Status	#	PLANT_STATE	Frequency
SD	MODE	MXE	MXXR	MXXXV	MXXXXB			



#	PLANT_STATE	Frequency
1	@	
2	POS-M6XCVO	4.500E-001
3	POS-M5LFIO	3.060E-001
4	@POS-M5LRIO	
5	@POS-M5LRVB	
6	POS-M5EFIO	2.040E-001
7	@POS-M5ERIO	
8	@POS-M5ERVO	
9	POS-M4LFIO	1.480E-002
10	POS-M4EFIO	2.520E-002

SD - Plant Operating State 2008/03/03

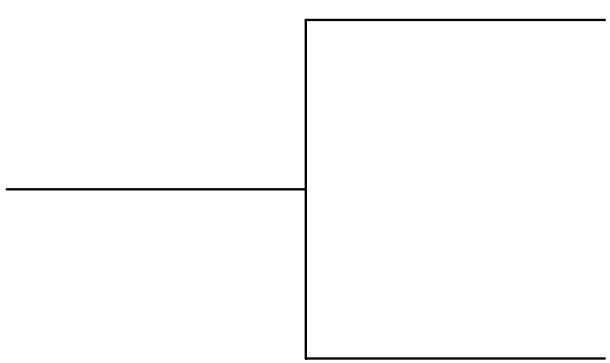
Event Trees (continued)

Mode 4 Early, RCS Full & Intact, Loops Open	LP/SD Initiating Event			
POS-M4EFIO	IE	#		END-STATE
		1		@
	IESD-LORHR	2	T	IESD-LORHR
	IESD-ISOL	3	T	IESD-ISOL
	IESD-LOOP	4	T	IESD-LOOP
	IESD-LOAC	5	T	IESD-LOAC
	IESD-LOI	6	T	IESD-LOI
	IESD-LOLC	7	T	@IESD-LOLC
	IESD-OD	8		@IESD-OD

POS-M4EFIO - Mode 4 Early - RCS Full & Intact - Loops Open 2007/11/08

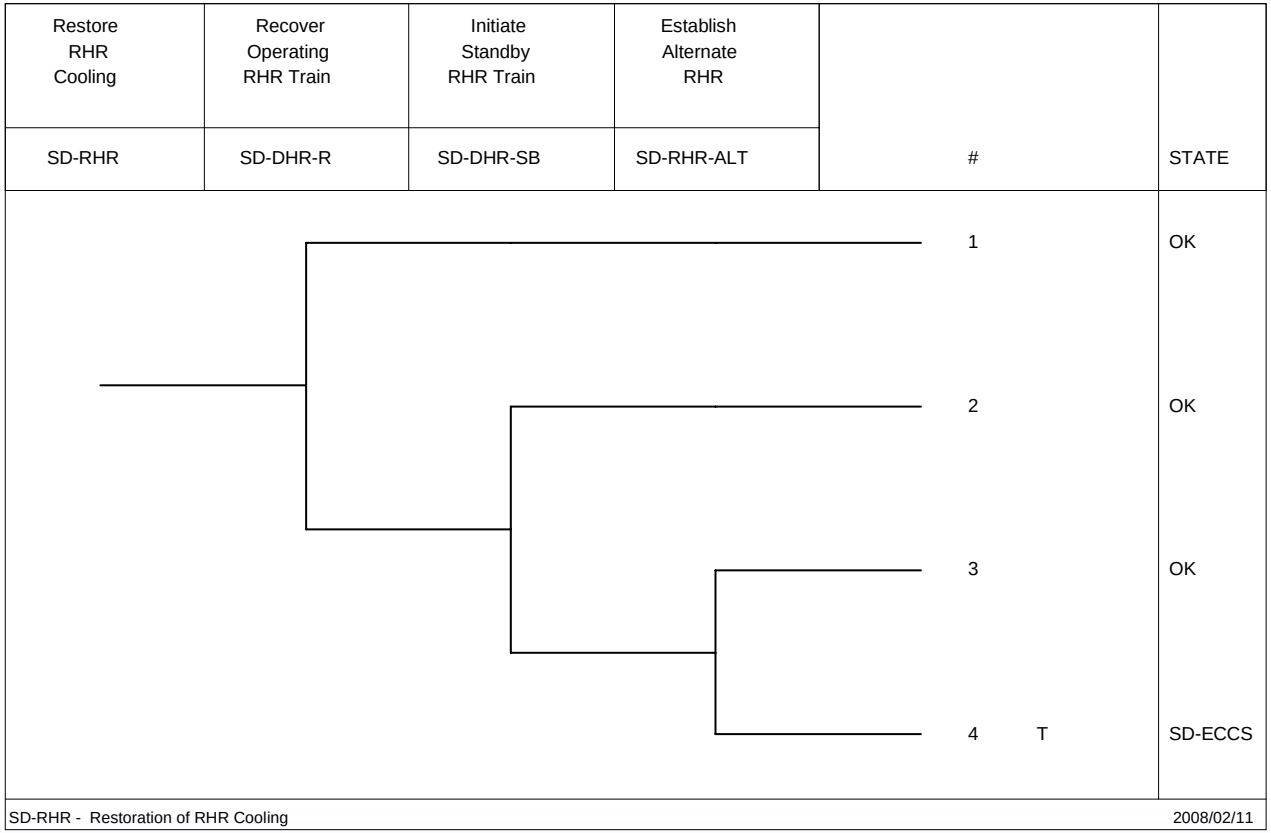
Event Trees (continued)

Loss of RHR Cooling Initiating Event	Operator Diagnoses Loss of RHR		
IESD-LORHR	SD-LORHR-D	#	STATE
		1 T	SD-RHR
		2 T	SD-ECCS



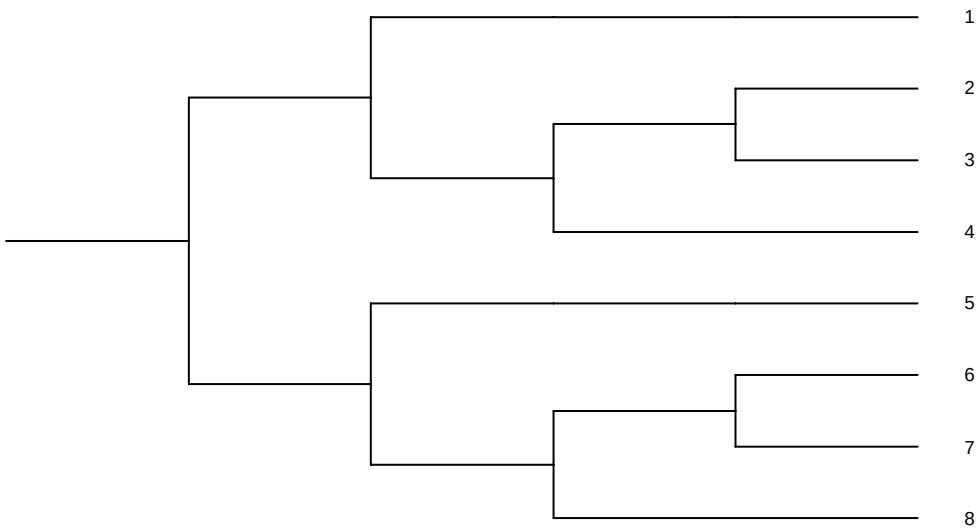
IESD-LORHR - Shutdown Loss of RHR Cooling 2007/11/05

Event Trees (continued)



Event Trees (continued)

Inventory Control	Accumulator Injection	Secondary Cooling	Feed and Bleed	Long-term Recovery		
SD-ECCS	SD-ACC	SD-SEC	SD-FAB	SD-LT-REC	#	STATE
					1	OK
					2	OK
					3	SD-CD
					4	SD-CD
					5	OK
					6	OK
					7	SD-CD
					8	SD-CD



SD-ECCS - ECCS Inventory Control 2007/11/05

SPAR HUMAN RELIABLITY ANALYSIS

- **The SPAR HRA, or SPAR-H Method to Support NRC PRA Program**
  - **A Simplified HRA Approach for Engineers**
  - **Quantification of Human Reliability**
- **SPAR-H Quantification Worksheet**
  - **Diagnostic, Action, and Dependency Matrix**
- **Performance Shaping Factors (PSF)**
  - **Available Time, Stress, Complexity, Experience, Procedures, Ergonomics, Fitness, Work Process**

RESULTS

		Probability per Hour per Initiating Event						
POS	**POS Description**	**ISOL[1]**	**LOAC[2]**	**LOI[3]**	**LOLC[4]**	**LOOP[5]**	**LORHR[6]**	**OD[7]**
M4EFIO	Mode 4 Early RCS Full & Intact, Loops Open	7.3E-09	3.9E-08	1.4E-10	0.0E+00	1.3E-09	6.4E-09	NA
M4LFIO	Mode 4 Late RCS Full & Intact, Loops Open	7.3E-09	3.9E-08	1.4E-10	0.0E+00	1.3E-09	6.4E-09	NA
M5EFIO	Mode 5 Early RCS Full & Intact, Loops Open	7.3E-09	3.9E-08	1.4E-10	0.0E+00	1.3E-09	6.4E-09	NA
M5ERIO	Mode Early RCS Reduced & Intact, Loops Open	6.1E-05	3.0E-05	1.0E-05	9.7E-08	5.0E-06	5.3E-05	5.4E-06
M5ERVB	Mode Early RCS Reduced & Vented, Loops Blocked	5.1E-05	4.1E-05	8.3E-05	8.1E-08	4.7E-06	4.5E-05	4.5E-06
M5LFIO	Mode 5 Late RCS Full & Intact, Loops Open	7.3E-09	3.9E-08	1.4E-10	0.0E+00	1.3E-09	6.4E-09	NA
M5LRIO	Mode 5 Late RCS Reduced & Intact, Loops Open	7.3E-09	3.9E-08	4.4E-08	2.1E-10	1.3E-09	6.4E-09	1.1E-08
M5LRVB	Mode 5 Late RCS Reduced & Vented, Loops Blocked	3.2E-06	2.3E-05	4.4E-05	8.1E-08	7.9E-07	2.8E-06	4.5E-06
M6XCVB	Mode 6 RCS Full & Vented, Loops Blocked	1.5E-08	6.1E-07	1.6E-09	0.0E+00	1.4E-08	1.4E-08	NA

Notes:
1. Isolation of the primary means of shutdown cooling, typically RHR, from closure of a hotleg isolation valve.
2. Loss of alternating current power only to the running RHR train.
3. Loss of RCS inventory typically due to valve misalignment.
4. Loss of level control during reduced inventory (this is a short-term level decrease necessitating a shutdown of RHR without a loss of inventory).
5. Loss of offsite power.
6. Loss of the running RHR loop—not covered by the other initiators.
7. Overdrain—failure to terminate the drain down to mid-loop when desired level is reached (this is the only per demand initiator).

SD Modeling Issues

- **Initiating Event Data**
- **Equipment Availability/Test and Maintenance Data**
- **Systems/Components Recovery Data**
- **Time Available for Operator Action**
- **Operator Actions – *System Level*, Train Level, or Component Level**
- **Generic Shut Down Risk/Event Specific Risk**
- **Data on POS stay time**
- ***Risk per Shutdown-hr*/ Risk per Shutdown-yr**