



Idaho National Laboratory

Module M

SHUTDOWN RISK

Shutdown Risk

- **Purpose:** To understand why shutdown modes of operation are thought to be of concern from a risk perspective, and to become familiar with approaches to analyzing shutdown risk.
- **Objectives:**
 - Describe how shutdown modes can be risk-significant
 - Describe why PRA must treat separate modes of operation during shutdown
 - Discuss the risk importance of systems available to maintain plant safety functions and the effect of maintenance outages on shutdown risk
- **References:**
 - NUREG-1449 - Review of shutdown events
 - NUREG/CR-6143 and NUREG/CR-6144 - Analysis of low-power shutdown risks at Grand Gulf and Surry, respectively
 - NUREG/CR-6616 - Risk comparison of scheduling preventive maintenance at shutdown versus at power operation for PWRs
 - SPAR LPSD models
 - Draft ANSI/ANS Std. for LPSD PRA

Shutdown Risk

- **Shutdown (S/D) and low power encompasses operation when the reactor is subcritical or in transition between subcriticality and power operations up to ~15% of rated power**
- **S/D risk studies examine events that could occur during low power or shutdown operations**
- **In early risk studies, risk from full-power operation was assumed to be dominant because during shutdown:**
 - **Reactor is subcritical**
 - **Decay heat is decreasing with time**
 - **Longer time is available to respond to accidents**

LPSD Operational Events Established the Significance of LPSD Risk

- **Precursor events implied that potential generic vulnerabilities existed:**
 - **April 87 Diablo Canyon event resulting in loss of RHR while in hot mid-loop operation (and numerous similar events at other plants)**
 - **March 90 Vogtle plant loss of all AC power while shutdown**
 - **Numerous precursors to interfacing system LOCA during shutdown or startup**
 - **Led to GSI-105**
 - **Two generic letters were subsequently issued relating to low-power and shutdown operations:**
 - **GL 87-12 -- Loss of RHR while the RCS is partially filled**
 - **GL 88-17 -- Loss of Decay Heat Removal**

Other Factors Also Contribute to LPSD Risk

- **Some systems may not be available since Tech. Specs. allow more equipment to be inoperable during LPSD than at power**
- **LPSD initiating events (by definition) impact the operable train of decay heat removal systems**
 - **IE for LPSD is a loss of shutdown cooling**
- **Human errors are more likely because of the increase in activity during shutdown**
 - **Unusual equipment line-ups also make mistakes more likely**
 - **Less procedural control during LPSD**
 - **Plant instruments and indications may not be available or accurate**

NRC Staff's Evaluation of LPSD Risk

- **Vogtle (1990) SBO investigation motivated broader look at LP/SD risk (NUREG-1449)**
 - **Study published in Sept 1993 documented significant technical findings including:**
 - **Outage planning is crucial to safety during LPSD**
 - **Significant maintenance activities increase potential for fires during shutdown**
 - **PWRs are more likely to experience events than BWRs; dominant contributor to PWRs is loss of RHR during operations with reduced inventory (midloop operation)**
 - **Extended loss of RHR in PWRs can lead to LOCAs caused by failure of temporary pressure boundaries in RCS or rupture of RHR system piping**

LPSD Risk Focuses on Non-Power Operations

- **Typical full-power PRA's examine plant risks associated with steady-state power operation (i.e., Mode 1)**
 - **Component unavailability and unreliability estimates based on Mode-1 Technical Specifications**
- **LPSD PRA considers all other operating modes**
 - **More complicated since plant can be in different states and configurations**
 - **Decay heat is a function of time after reactor shutdown (affects time available for recovery)**

PWR Operating Modes (Westinghouse Standard Tech. Specs.)

Mode	Title	K_{eff}	Thermal Power ^a	Ave. Coolant Temp. (°F)
1	Power Ops	≥ 0.99	$> 5\%$	NA
2	Startup	≥ 0.99	$\leq 5\%$	NA
3	Hot Standby	< 0.99	NA	≥ 350
4	Hot Shutdown ^b	< 0.99	NA	$350 > T > 200$
5	Cold Shutdown ^b	< 0.99	NA	≤ 200
6	Refueling ^c	NA	NA	NA

- a. Excluding decay heat
- b. All reactor head bolts fully tensioned
- c. One or more reactor head bolts less than fully tensioned

BWR Operating Modes (BWR/4 Standard Tech. Specs.)

Mode	Title	Reactor Mode Switch Position	Ave. Coolant Temp. (°F)
1	Power Ops	Run	NA
2	Startup	Refuel ^a or Startup/Hot-Standby	NA
3	Hot Shutdown ^a	Shutdown	> 200
4	Cold Shutdown ^a	Shutdown	≤ 200
5	Refueling ^b	Shutdown or Refuel	NA

a. All reactor head bolts fully tensioned

b. One or more reactor head bolts less than fully tensioned

LPSD PRA Structured Around Plant Operating State

- **PRA models (event trees and fault trees) developed for each plant operating state (POS) and each initiating event**
 - **Some PRAs imbed the POS in the IE identifier**
 - **LOSP-POS1, LOSP-POS2, LOSP-POS3, etc.**
 - **Data can be POS-dependent as well**
 - **Test or maintenance unavailability changes as Tech Specs change according to operating mode**

Plant Operating States (PWR)

NUREG/CR-6144 POS	POS Description	Standard Technical Specification Mode (SPAR POS)	Technical Specification Mode Description
POS 1	Low power and reactor shutdown	1	Power operation
POS 2	Cooldown with SGs from operating temp to 345 F	3	Hot standby
POS 3	Cooldown with RHR from 345 F to 200 F	4 (4E)	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	6 (6)	Refueling
POS 8	Refueling	6 (6)	Refueling
POS 9	Draining RCS to mid-loop after refueling	6 (6)	Refueling
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

PRAs Analyze LPSD Operating Modes

- **Typically include only time spent using shutdown cooling (SDC) systems, not normal power conversion system (PCS)**
 - **Difficult to analyze all possible operating modes and configurations**
 - **Time spent at low power and using PCS is short (few hours per year) compared to normal at-power operation (months per year) and SDC operation (weeks per year)**
 - **Also, low power ops using PCS still has all systems nominally available (at-power Tech Specs apply)**
 - **Therefore, risk associated with these transition states is assumed to be small compared to at-power and SD.**

Subsequent LPSD PRA Studies

- **LPSD risks not studied as extensively as those for power operation**
- **However, several LPSD PRAs have been completed**
 - **Both for PWRs and BWRs (e.g., Zion, Seabrook, Surry, Grand Gulf)**
 - **Significant findings include:**
 - **CDF estimates for certain shutdown modes of operation are comparable to estimates for full-power operation**

Subsequent PRA Studies

- **Most significant issues identified from a LPSD risk perspective are:**
 - **Mid-loop operation (PWRs) of particular concern**
 - **Operator errors, especially**
 - failure to determine proper actions to restore shutdown cooling
 - procedural deficiencies
 - **Loss of RHR shutdown cooling, especially**
 - operator induced
 - suction valve trips
 - cavitation due to overdraining of the RCS
 - **Loss of offsite power**

SPAR Program Developing Limited Number of LPSD Models

- **10 LPSD SPAR models available**
- **Models organized using 15 POSs based on plant configuration evolutions and 4 time windows (time after reactor shutdown, i.e., different decay heat levels)**
- **Initiating events include:**
 - **Loss of RHR**
 - **Loss of RHR given primary reactor coolant is at reduced inventory level**
 - **Loss of offsite power**
 - **Loss of primary reactor coolant Inventory**

Plant Shutdown (Mode 4, 5 or 6)	Plant is in Mode	Mode Time Frame	RCS Inventory Status	RCS Integrity Status	RCS Loop Status			
SD	MODE	MXE	MXXR	MXXXV	MXXXXB	#	PLANT_STATE	6144-POS
<div> <div>Mode6 (0.44)</div> <div>N/A</div> <div>Full</div> <div>Vented</div> <div>Open(0.01)</div> </div> <div> <div>RCS Open</div> <div>Blocked(0.99)</div> </div> <div> <div>Late(0.61)</div> <div>Full(0.81)</div> <div>Intact</div> <div>Open</div> </div> <div> <div>Mode5 (0.47)</div> <div>Reduced(0.19)</div> <div>Intact(0.8)</div> <div>Vented(0.2)</div> <div>Open(0.7)</div> <div>Blocked(0.3)</div> </div> <div> <div>RCS de-pressurized</div> <div>Early(0.39)</div> <div>Full(0.41)</div> <div>Intact(0.9)</div> <div>Vented(0.1)</div> <div>Open(0.8)</div> <div>Blocked(0.2)</div> </div> <div> <div>Mode4 (0.08)</div> <div>Late(0.48)</div> <div>Full</div> <div>Intact</div> <div>Open</div> </div> <div> <div>RCS Pressurized</div> <div>Early(0.52)</div> <div>Full</div> <div>Intact</div> <div>Open</div> </div>						1	@	
						T2=> 16	POS-M6XFVO	POS-8
						T3=> 15	POS-M6XFVB	POS-8
						T4=> 11	POS-M5LFIO	POS-11/12
						T5=> 12	POS-M5LRIO	POS-9/10
						T6=> 14	POS-M5LRVO	POS-9/10
						T7=> 13	POS-M5LRVB	POS-9/10
						T8=> 7	POS-M5EFIO	POS-4/5
						T9=> 8	POS-M5ERIO	POS-6/7
						T10=> 10	POS-M5ERVVO	POS-6/7
						T11=> 9	POS-M5ERVVB	POS-6/7
						T12=> 6	POS-M4LFIO	POS-13
						T13=> 5	POS-M4EFIO	POS-3

SD - Plant Operating State given it is in mode 4 5 or 6

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Page 17

Few LPSD PRAs Have Been Developed

- Perception continues that LPSD operations pose less risk than full-power
- LPSD PRA developed reputation of being very expensive and complicated process
 - NUREG/CR-6143, "Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Grand Gulf, Unit 1," July 1995
 - NUREG/CR-6144, "Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Surry, Unit 1," October 1995
- Most utilities have opted to manage LPSD risk using simpler configuration management approach
 - Vital safety functions defined - systems/trains needed to perform vital safety function maintained in-service

How Utilities are Addressing LPSD Risk

- **Some utilities have performed limited PRA studies of selected modes of operation**
- **Most utilities have adopted non-PRA approach**
 - Approach based on guidance in NUMARC 91-06
 - Approach based on maintaining barriers during shutdown
 - EPRI sponsored development of ORAM (Outage Risk Assessment and Management) software to implement this approach