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	≤ 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 then 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 then 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**

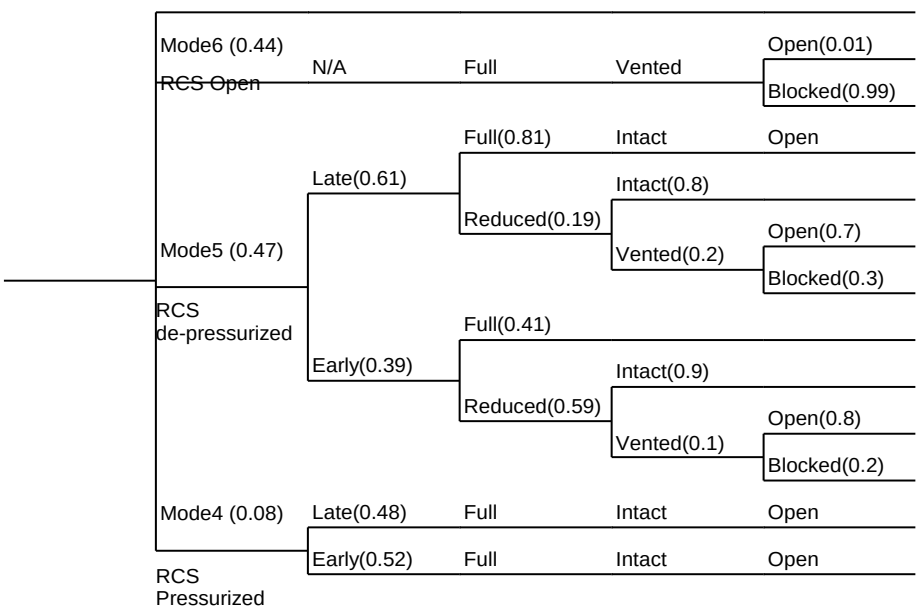
Subsequent PRA Studies

- **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	#	PLANT_STATE	6144-POS
SD	MODE	MXE	MXXR	MXXXV	MXXXXB			



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-M5ERVO	POS-6/7	
T11=> 9	POS-M5ERVB	POS-6/7	
T12=> 6	POS-M4LFIO	POS-13	
T13=> 5	POS-M4EFIO	POS-3	

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