Uncertainties in LP/SD PRA Modeling

NRC/EPRI Workshop on PRA Uncertainty
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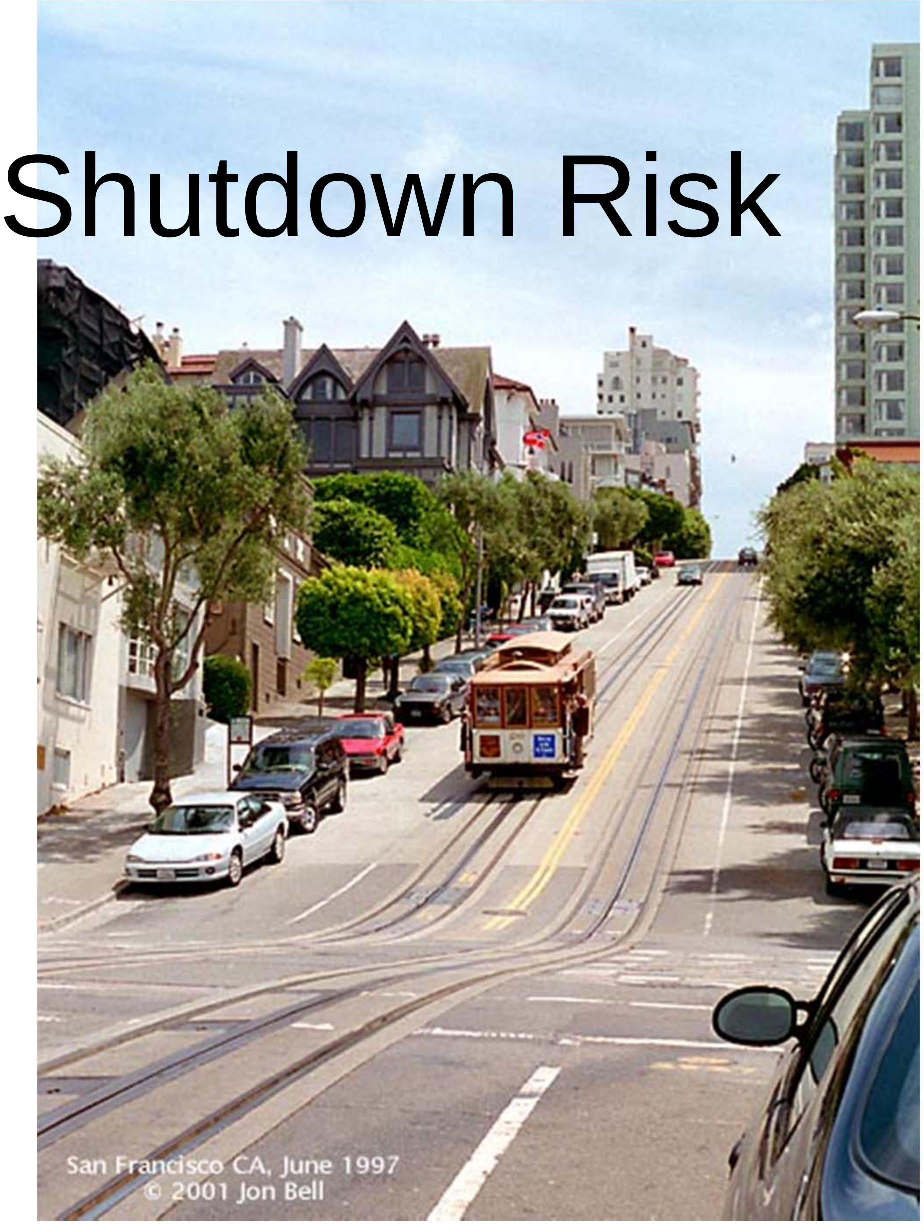
PICTURE of Shutdown Risk

- Car parked on San Francisco hill
- Source of shutdown risk is different – potential energy vs nuclear decay heat - but...
- Clearly there is “non-negligible” risk from this stationary car.
- Risk Management actions are required – parking brake, turning wheels into curb.



Outline

- Fundamental Sources of Uncertainty
- POS Structure
- Low Power & Hot Standby (Mode 1^-, 2, 3)
- Shutdown Model Structure (Mode 4, 5, 6)
- HRA at Shutdown
- Other Risk Issues

Fundamental Sources of Uncertainty for LP/SD PRAs

- Potentially <u>larger uncertainties</u> in LP/SD PRAs compared to Full-Power PRAs due to:
  - Less operating experience due to limited time in LP/SD states
  - Larger variability in plant configurations during shutdown states
  - Larger variability in plant configurations from plant to plant
  - Less design-basis analyses to support shutdown states
  - Less formal EOP-equivalent network at shutdown
  - No formalized guidance for developing LP/SD PRAs
- Generally <u>lower risks</u> in LP/SD PRAs compared to Full-Power PRAs due to:
  - Short duration POSs
  - Many POSs with large thermal margin
  - Outage risk management programs

Plant Operating States (POSs)

- POSs: building blocks of LP/SD PRA
  - A standard arrangement of the plant during which the plant conditions are relatively constant, <u>are modeled as constant</u>, and are distinct from other configurations in ways that impact risk.
  - A basic modeling device used for a phased-mission risk assessment that discretizes the plant conditions for specific phases of a LPSD evolution.
- POS structure is a <u>basic issue of uncertainty</u>
  - Discretization is biased conservatively – using the limiting values for plant conditions (e.g., decay heat, temperature, pressure)
  - More POSs allow for more accurate modeling of plant configurations
  - Fewer POSs force conservative assumptions within a POS
  - Analysis resources limit the number of POSs defined
  - The “right” number of POSs allows efficient modeling without overly conservative assumptions.

POS Structure (Example) 1|2

Plant Operating States [1, 2]		RCS Conditions [3]					Beginning of POS Boundary [4]
		Power	**T (°F)**	**P (psig)**	**Integrity**	**Level**	(for refueling outage)
1A1	Full Power Operation (>70% power)	100%	557	2235	Intact	PZR	Power above 70%
1BA	Mode 1 Shutdown, Auto Control (70-20% power)	70%	557	2235	Intact	PZR	~70% power, shut down heater drain pump
2BM	Mode 2 Shutdown, Manual Control (20-0% power)	20%	557	2235	Intact	PZR	~20% power, manual feedwater control
3C1	Cooldown & Depressurize to 1000 psig	0%	557	2235	Intact	PZR	Rx trip breaker open
3C2	Cooldown & depressurize to 350 psig / 350°F	0%	450	1000	Intact	PZR	Isolate accumulators at 1000 psig
4D1	Cooldown to 200°F	0%	350	350	Intact	PZR	Start RHR train for decay heat removal, with RCS at 350 psig and 350°F
5D2	Cooldown to 170°F	0%	200	350	Intact	PZR	Enter Mode 5 at 200°F
5D3	Solid PZR Operation	0%	170	350	Intact	Solid	Take PZR solid
5E0 [5]	Draindown to Flange for Head Removal	0%	100	0	Intact	Flange	Begin draindown to Flange
5E1 [6]	Draindown to Flange (for Early ML)	0%	100	0	Safety off	Flange	Begin draindown to Flange
5E2 [6]	Draindown to Midloop (Early ML)	0%	100	0	Safety off	Midloop	Begin draining to Midloop
5E3 [6]	Level at Midloop (Early ML)	0%	100	0	Safety off	Midloop	Level at Midloop
5E4 [6, 7]	Flood up to Flange for Head Removal (following Early ML)	0%	100	0	Safety off	Flange	Start to flood up to Flange
6F0 [5]	Head Removal	0%	100	0	Head off	Flange	Level at Flange and head fully detensioned
6F1	Head Removal (following Early ML)	0%	100	0	Head off	Flange	Level at Flange and head fully detensioned
6F2[8]	Cavity Flooded, Internals In	0%	100	0	Head off	Cavity	Cavity flooded
6F3	Refueling Cavity Full, Internals Out	0%	100	0	Head off	Cavity	Internals removed

POS Structure (Example) 2|2

Plant Operating States [1, 2]		RCS Conditions [3]					Beginning of POS Boundary [4]
		Power	**T (°F)**	**P (psig)**	**Integrity**	**Level**	(for refueling outage)
7G1	Spent Fuel Pool	0%	100	0	SFP open	Pool	Fuel offloaded to SFP.
6H3	Refueling Cavity Full, Internals Out	0%	100	0	Head off	Cavity	Re-enter Mode 6
6H2 [8]	Refueling Cavity Full, Internals In	0%	100	0	Head off	Cavity	Internals installed
6H1	Draindown to Flange to Install Head (following Early ML)	0%	100	0	Head off / Safety off	Flange	Start of cavity drain
6H0 [5]	Draindown to Flange to Install Head	0%	100	0	Head off	Flange	Start of cavity drain
5I3 [9]	Draindown to Midloop (Late ML)	0%	100	0	Safety off	Midloop	Start of draining to Midloop
5I2 [9]	Level at Midloop for Nozzle Dam Removal (Late ML)	0%	100	0	Safety off	Midloop	Level at Midloop
5I1	Level at Midloop for Evacuation (Late ML)	0%	100	vac.	Intact	Midloop	Nozzle dams removed & Safety valve on
5J2 [7]	Refill RCS to Pressurizer Level (following Late ML)	0%	100	vac.	Intact	Flange	Start of flood up to PZR
5J1	Draw PZR Bubble	0%	100	350	Intact	PZR	Start of PZR bubble formation
5K2	Prepare for Mode 4	0%	195	350	Intact	PZR	PZR drained to normal level, starting heatup
4K1	Heatup to 350°F	0%	350	350	Intact	PZR	Enter Mode 4, RCS temp > 200°F
3L2	Heatup to 400°F	0%	400	1000	Intact	PZR	Enter Mode 3, RCS temp > 350°F
3L1	Heatup to 557°F	0%	557	2235	Intact	PZR	RCS pressure > 1000 psig
2MM	Restart to 20% Power, Manual Control	20%	557	2235	Intact	PZR	Increase power above 0%
1MA	Power Increase to 70%, Auto Control	70%	557	2235	Intact	PZR	Increase power above 20%, auto feedwater control
1A1	Full Power Operation (>70% power)	100%	557	2235	Intact	PZR	> 70% power

Low Power (LP) & Hot Standby (HSB)

- LP & HSB POSs (Mode 1^-, 2, 3)
  - ☐ Risk model looks much more like Full-Power POS (Mode 1^+) that Shutdown POSs (Mode 4, 5, 6)
- LP & HSB vs Full-Power:
  - ☐ Same set of accident sequences
  - ☐ Similar initiators (with a few changes)
  - ☐ Same set of systems
  - ☐ Same EOP network
  - ☐ Same plant controls for TSs, etc
  - ☐ Similar uncertainty issues for Full-Power (except…)

LP & HSB Uncertainty Issues

- Uncertainty issues - distinct from Full-Power
  - Boundary between Low Power & Full Power
  - Variability in plant operation at LP & HSB
    - Transitions in plant configuration – reduction in number of FW/HD pumps, change from auto to manual SG control, etc.
    - Additional testing with potential for equipment challenges, plant transients – e.g., PORV test
    - Reactor trip frequency at LP - increased rate & variability
  - Reactivity issues
    - Shutdown – xenon cycle
    - Restart after refuel – high boric acid concentration

Reactor Trip Events vs Power Level

Power Level	Number of Trips	Percent
0	15	1.6%
1-10	58	6.4%
11-20	52	5.7%
21-30	41	4.5%
31-40	19	2.1%
41-50	28	3.1%
51-60	24	2.6%
61-70	18	2.0%
71-80	31	3.4%
81-90	43	4.7%
91-100	581	63.8%
TOTAL:	910	100.0%

DATA:
Number of reactor trips in US PWRs from 1987 and 1997, excluding first year operation.

Estimated fraction of total power operation (0 to 100%) time at low power (below 70%) = 0.02, but 28% of trips.

CONCLUSION:
Reactor trip rate at LP >> trip rate at FP.

Shutdown Model Structure

- Shutdown (S/D) Model (Mode 4, 5, 6)
  - Decay heat removal via RHR shutdown cooling

- MODEL UNCERTAINTY ISSUES:
  1. Boundary between S/D model & Spent Fuel Pool model
     - Options: fuel in core, fuel in containment in transit from core to SFP, fuel in SPF in transit, fuel in SFP temporarily, fuel in SFP for long term, fuel transferred to dry cask storage
  2. Average vs outage-specific PRA
     - Modeling choice based on applications
     - Different issues of uncertainty
  3. Outage types - refueling outage vs other plant shutdowns
     - Needed to address all of LP/SD risk
     - Different issues of uncertainty

Average vs Outage-Specific S/D PRA

- Average S/D PRA
  - Direct comparison with F/P
  - Allows calculation of “all” the risk from core
  - Requires definition of set of “average” outages, not difficult for refueling outages
  - Requires modeling of average plant conditions, with increased uncertainty due to the number of possible activities
- Outage-Specific S/D PRA
  - Directly applicable to outage risk management
  - Allows more accurate modeling of plant conditions
  - Difficult to peer review

Outage Types

- Refueling Outage
  - Standard outage templates
  - Little uncertainty regarding sequence of POSs
  - Little uncertainty regarding frequency & duration of outage
- Other Plant Shutdowns
  - Uncertainty regarding the type of outage
    - Unusual forced outage – e.g., shutdown to fix SG leak requires early midloop evolution
    - Emergent condition outage – e.g., failure causing a reactor trip may require a plant outage with less planning than other outages
  - Little uncertainty regarding sequence of POSs (given the type of shutdown is known)
  - Larger uncertainty regarding frequency & duration of outage

Changes in Outage Processes

- Changes in outage processes introduce new sources of uncertainty
  - New evolutions that do not have extensive industry experience
  - Future changes that cannot be anticipated now that modify outage structure
- Example (1): Primary side SG inspections
  - Changed from “2 every RF” to “4 every other RF,” eliminating ML operation in half of RF outages.
- Example (2): Nitrogen injection
  - Improves process of draining SG tubes to get to ML
  - Introduces a source of nitrogen to RCS

HRA for S/D PRA

- No EOP-equivalent network in Mode 4 - 6
  - PWR EOPs apply only down to Mode 3 / 4
  - Diagnosis is more important
  - Larger variability in crew responses expected
- POSs with low thermal margin
  - HRA methods used for Full-Power PRA should apply
- POSs with large thermal margin
  - Long term recovery analysis is important
  - EOC may become important – low probability, high consequence failures (e.g., human induced loss of inventory)

Other S/D Issues

- LERF
  - Isolability of containment (time required, environmental conditions, support systems)
  - Source term decay, LERF → zero some x days after shutdown – what figure of merit for containment?
- Internal Flood
  - More human induced events / more recovery
  - Latent error IEs - restoration of systems to service without intact boundary
  - Potential for flood barriers to be removed, impact of details cannot be captured easily in Average S/D model
- Fire (draft NUREG/CR-7114)
  - More human induced events / more transient combustibles / more recovery
  - Potential for fire barriers to be removed or configuration to change (e.g., cabinet doors open), impact of details cannot be captured easily in Average S/D model
- Seismic
  - Minor differences from Full Power (??)

Conclusion

- Uncertainties in LP/SD PRAs are dominated by <u>model structure issues</u>.
- These uncertainties could be reduced with <u>enhanced guidance</u> …
    - ☐ built on detailed knowledge of how plant shutdowns are planned & performed,
    - ☐ informed by review of outage operating experience.