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Insights from Low Power and Shutdown Human Reliability Analysis

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Introduction

- Low-power and shutdown (LPSD) includes a number of distinct and significantly different plant configurations**.**
- Variant plant configurations and heavy work tasks make the LPSD conditions as relatively dynamic situations
- The operational experience and research studies showed that human activities play a much larger role in low power and shutdown than during full power operations
  - ***Shutdown and Low-Power Operation at Commercial Nuclear Power Plants in the United States*”, NUREG-1449, 1993**

Introduction

- *"An analysis of operational experience during low power and shutdown and a plan for addressing human reliability assessment issues*", NUREG/CR-6093, 1994, by BNL and SNL.
  - Errors of commission (EOCs) were the dominant mode of human errors and important in all temporal phases of a PRA (pre-accident, initiating event and post-accident).
  - Dependent human actions were found to impact the progression of LPSD events
  - Human performance during LPSD is frequently influenced by the **synergistic effects** of multiple PSFs.
  - A large number of multiple concurrent tasks are possible during LPSD.

A LPSD HRA Example

- **Most nuclear power plants on operation in China have finished full power level 1 internal PSA/HRA, and some are extending PSA analysis to LPSD condition.**

- **Some HRA results from Daya Bay LPSD PSA/HRA study:**
  - **9 groups of or 74 initiating events in DBSD. The total core damage frequency for DBSD comes out to be 5.02E-6/ry**
  - **Totally there are 171 Type C HFEs modelled in the plant LPSD PSA model.**
  - **SPAR-H method is used for HFE quantification.**
  - **PSA results show that HFEs have a big contribution to the plant LPSD CDF value, e.g., HFEs are included in 43 MCSs among the top 50 MCS list of the LPSD PSA model, accounting 58.6% of total CDF.**

10 HFEs with the highest FV Importance Values

HFE	Description	HEP	FV Importance
HE-BY1FH1	In POSF, fail to provide water supply to RCP as IRRA2 procedure	2.20E-03	1.28E-01
HE-BS1CH1	Fail to initiate safety water injection	2.10E-03	7.83E-02
HE-SW2BH1	In POSB, fail to restore main feed water in the second loop	3.50E-03	7.74E-02
HE-SW2BH2	In POSB, fail to feed-bleed as U1 procedure	5.00E-01	7.64E-02
HE-BY1EH0	In POSE, local operators fail to isolate the leak	1.00E-02	6.75E-02
EAS-CS-H1	Fail to initiate containment spray system	5.00E-03	5.60E-02
HE-BY1DH0	In POSD, local operators fail to isolate the leak	1.00E-02	5.35E-02
HE-RR1DH2	In POSD, fail to cool primary loop as IRRA2 procedure	5.20E-02	4.02E-02
HE-RR1DH3	In POSD, fail to cool primary loop as SPIR procedure	1.46E-01	4.01E-02
RRI-SEC-POP-HE	Fail to open RRI/S EC pump & valves in train B	1.00E-01	3.75E-02

Human Performances in LPSD Conditions

- Most detection and nearly all actions are manual
- Big dependence exists among human actions, as well as operator-induced initiating events
- A large number of multiple concurrent tasks are possible during LPSD
- There are many chances for EOCs

PSFs in LPSD Conditions

- Synergistic effects of multiple PSFs: Several non-independent PSFs can be involved
- Human-machine Interfaces: Impacts of instrument failures and control system failures on operator performance can be very important
- Available time: Highly variable time frames for detection and action from minutes to days
- Plant configurations: Changing configurations (POS and maintenance) mean that operators are less secure in their situation model
- Procedures: Many seldom-used procedures are carried out; EOPs are less thoroughly tested and exercised
- Management factors, including workload and work disturbances, planning, coordination and cooperation problems
- Communications: Communications are very important for information sharing in different teams
- Personnel training and experience

LPSD HRA Requirements

- ANS LPSD PSA standard set forces requirements for Type A and C HRA in LPSD conditions.
  - HLR-HR-A ~ HLR-HR-D for Type A; HLR-HR-E ~ HLR-HR-H for Type C; and HLR-HR-I for documentations of the whole HRA.
  - Some of the detailed supporting requirements are revised to reflect the characteristics of human performances in LPSD conditions.
  - In general, ANS LPSD PSA standard provides guidance about what to do in HRA at a high level, but not how to do it.
  - There may be several approaches to meet the standards by making different assumptions and approximates and, hence, producing different results. This is particularly true of HRA, characterized by lack of consistency among practitioners on the treatment of human performance in the context of a PSA.

HRA Methods for LPSD Conditions

- An OECD study in 2005 showed that the majority of plant LPSD models utilized existing HRA methodologies that have been applied in full power PSAs, with some adjustments or changes in the methodologies

  - **THERP**
  - **SLIM**
  - **SHARP**
  - **HCR/ORE**
  - **ASEP**

HRA Methods for LPSD Conditions

- As for quantification, the selected HRA methods should:
  - **Be able to deal with human actions with different available times changing from minutes to hours and even days**
  - **Be able to account both the positive and negative influence of available time on the human performance**
  - **Be able to consistently account some important influence factors and their synergistic effects, like organizational factors, human system interface, communication, operator training, procedure quality, etc.**
  - **Be able to consider possible dependencies among multiple human actions, for all type A, B and C human actions**

EOCs in LPSD Condition

- The need to consider EOCs has long been recognized
  - Errors of commission (EOCs) were the dominant mode of human errors and important in all temporal phases of a PRA (pre-accident, initiating event and post-accident): NUREG/CR-6093, 1994
- Work in the area over the years has made advances in the ability to identify EOCs without the need to perform an exhaustive search
  - ATHEANA
  - CESA
- Explicit modeling of EOCs has generally been beyond current PSA practice and is not explicitly addressed in RG 1.200 or ASME Standard HRA requirements.
- In HRA good Practice, i.e. NUREG-1792, it is recommended that future HRA/PSAs should attempt to identify and model not only errors of omission (EOOs) as is typically done, but also potentially important EOCs.

Conclusions

- Human actions play a significant role in SPSD mode and thus highlight the importance of LPSD HRA in plant risk assessment and management.
- Though there are some related PSA standards and NRC HRA good practices that can be used as good references for LPSD HRA, specific LPSD HRA good practices are requested.
- SPAR-H, which has comprehensive PSFs and good dependence considerations for multiple HFEs, was used in Dayabay LPSD HRA analysis and found to be an easy and consistent way to quantify HFEs in LPSD conditions.
- EOCs play a significant role in the LPSD conditions and available methods, like ATHEANA and CESA, have made it possible to identify and quantify EOCs in LPSD HRA.

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