Is Green Good Enough? Managing Shutdown Risk in Generation III+ Nuclear Power Plants

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Purpose

- The purpose of this paper is to share the experiences and thoughts gained while developing a qualitative shutdown model for Generation III+ nuclear power plants like the AP1000®[1].

Background

- Generation II US nuclear power plants manage shutdown risk with guidance provided by NUMARC 91-06
- NUMARC 91-06 focuses on five Key Safety Functions (KSF)
  - Decay Heat Removal
  - Inventory Control
  - Power Availability
  - Reactivity Control
  - Containment Closure

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Use of 4 Color System For Risk Management

- 4 Color System based on the concept of “N”. “N” is defined as one set of SSC (Including Supports) or a safety method is available to support the defense of the KSF.

Color	SSCs	Metric	Status
GREEN	N+2	Acceptable Margin	Green represents a high level of DID and the lowest (minimal) risk level of the four color system.
YELLOW	N+1	Reduced Margin	Yellow represents a reduced but adequate level DID and a slightly elevated (but still low) risk level.
ORANGE	N	Minimal Margin	Orange represents reduced DID level and an elevated (moderate) risk level with little or no redundancy remaining.
RED	None	Unacceptable Margin	Red represents an unacceptable level of DID, characterized by the loss of all mitigating equipment for one or more KSFs.

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Generation III+ Design and Operation

- Generation III+ plants include Passive and Active safety systems where previous generations relied on Active alone.
- Passive systems rely on fail-safe components, gravity, convection and have limited power requirements
- Passive safety systems reduce the dependency on operator actions, AC powered components and supports.
- Non-Safety Active components support normal operations and provide Defense-In-Depth during accidents.

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Generation III+ Design and Operation

- Low power and shutdown operations are divided into three procedure groups
  - General Operating Procedures (GOPs)
    - Used for normal shutdown and startup
  - Emergency Operating Procedures (EOPs)
    - Divided into two sets of EOPs based on mode applicability.
      - Modes 1-4
      - Modes 5-6
    - Provide guidance for responding to challenges to critical safety functions (loss of inventory, loss of normal decay heat removal, high containment radiation, etc.)
  - Abnormal Operating Procedures (AOPs)
    - Applicable in all modes.
    - Used to respond to conditions outside of GOPs and EOPs

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Generation III+ Safety and Non-Safety Systems

- While the plants are designed to utilize Passive safety systems for accident mitigation, the GOPs direct the operators to use the Non-Safety Active systems.
- Passive safety systems are only called upon to respond during transients or emergency situations in which the Non-Safety systems are unavailable.
- Passive and Active systems can both be used to support each of the KSFs (with exception for Containment Closure)
- Each Safety and Non-Safety system consists of at least two redundant trains and three in some cases.
- Additionally, KSFs can be maintained by diverse groups of SSCs and/or methods.

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Generation III+ Safety and Non-Safety Systems

- Summing all of the safety and Non-Safety systems often results in six or more system trains or methods that can be used to maintain each KSF (Remember N+2 is Green).
- Using current industry practice would allow multiple system trains (four or more) can be out of service without reducing the KSF to less than Green.
- While having an abundance of redundancy results in a lower absolute risk. The issue is that it offers the ability to remove multiple Non-Safety systems from service at a time.
- With the Non-Safety systems out of service the Passive safety systems would be required to actuate in response to an accident

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Issues With Passive Safety System Actuation

- While the Passive safety systems are designed to mitigate design basis accidents their actuation may require an extensive and costly clean-up effort.
- Passive safety system actuation could result in RCS inventory being released within the containment and/or result in a steam environment within containment.
- Therefore, from an economic perspective it would be preferable to manage the Non-Safety systems in a way that reduces the likelihood of challenging the Passive safety systems.

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Expanding Beyond NUMARC 91-06

- One potential strategy for managing the Non-Safety systems and the plant economic risk is to create a new “Investment Protection” KSF.
- This strategy simulates the Passive safety systems being unavailable and forces the plant to manage shutdown risk with the Non-Safety system alone.
- This strategy results in a level of Non-Safety system margin that would reduce the likelihood of reaching a plant configuration requiring Passive safety system actuation.

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Additional Considerations

- Factoring in support systems can be challenging. While support systems might be logically divided into two trains; each train could support cooling of the components within both trains.
- Containment modeling in a Defense-In-Depth tool. NUMARC 91-06 defines containment closure for the purpose of preventing releases, however, for passive systems it could also serve the long term heat removal function.

Conclusion

- Managing shutdown risk with Safety and Non-Safety systems may result in KSFs always being Green with multiple systems/trains out of service.
- Generation III+ nuclear power plants have more diversity and redundancy to mitigate fuel damage events than the current generation of plants in service.
- There will be a need to factor additional considerations beyond the existing conventions.
- Shutdown risk management will have to evolve with the Generation III+ nuclear power plants.

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Questions?